Altair PBS Professional 2021.1.2

Administrator's Guide

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Administrator's Guide (AG)

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Contents

About PBS Documentation

The PBS Professional guides and release notes apply to the *commercial* releases of PBS Professional.

Document Conventions

`Abbreviation`

The shortest acceptable abbreviation of a command or subcommand is underlined

Attribute

Attributes, parameters, objects, variable names, resources, types

`Command`

Commands such as `qmgr` and `scp`

Definition

Terms being defined

`File name`

File and path names

`Input`

Command-line instructions

Method

Method or member of a class

`Output`

Output, example code, or file contents

Syntax

Syntax, template, synopsis

`Utility`

Name of utility, such as a program

Value

Keywords, instances, states, values, labels

Notation

Optional Arguments

Optional arguments are enclosed in square brackets. For example, in the `qstat` man page, the `-E` option is shown this way:

qstat [-E]

To use this option, you would type:

```
qstat -E
```

Variable Arguments

Variable arguments (where you fill in the variable with the actual value) such as a job ID or vnode name are enclosed in angle brackets. Here's an example from the `pbsnodes` man page:

pbsnodes -v <vnode>

To use this command on a vnode named "my_vnode", you'd type:

```
pbsnodes -v my_vnode
```

Optional Variables

Optional variables are enclosed in angle brackets inside square brackets. In this example from the `qstat` man page, the job ID is optional:

qstat [<job ID>]

To query the job named "1234@my_server", you would type this:

```
qstat 1234@my_server
```

Literal Terms

Literal terms appear exactly as they should be used. For example, to get the version for a command, you type the command, then "--version". Here's the syntax:

qstat --version

And here's how you would use it:

```
qstat --version
```

Multiple Alternative Choices

When there are multiple options and you should choose one, the options are enclosed in curly braces. For example, if you can use either "-n" or "--name":

```
{-n | --name}
```

List of PBS Professional Documentation

The PBS Professional guides and release notes apply to the *commercial* releases of PBS Professional.

PBS Professional Release Notes

Supported platforms, what's new and/or unexpected in this release, deprecations and interface changes, open and closed bugs, late-breaking information. For administrators and job submitters.

PBS Professional Big Book

All your favorite PBS guides in one place: *Installation & Upgrade, Administrator's, Hooks, Reference, User's*, *Programmer's, Cloud, Budget,* and *Simulate* guides in a single book.

PBS Professional Installation & Upgrade Guide

How to install and upgrade PBS Professional. For the administrator.

PBS Professional Administrator's Guide

How to configure and manage PBS Professional. For the PBS administrator.

PBS Professional Hooks Guide

How to write and use hooks for PBS Professional. For the PBS administrator.

PBS Professional Reference Guide

Covers PBS reference material: the PBS commands, resource, attributes, configuration files, etc.

PBS Professional User's Guide

How to submit, monitor, track, delete, and manipulate jobs. For the job submitter.

PBS Professional Programmer's Guide

Discusses the PBS application programming interface (API). For integrators.

PBS Professional Manual Pages

PBS commands, resources, attributes, APIs.

PBS Professional Licensing Guide

How to configure licensing for PBS Professional. For the PBS administrator.

PBS Professional Cloud Guide

How to configure and use the PBS Professional Cloud feature.

PBS Professional Budgets Guide

How to configure Budgest and use it to track and manage resource usage by PBS jobs.

PBS Professional Simulate Guide

How to configure and use the PBS Professional Simulate feature.

Where to Keep the Documentation

To make cross-references work, put all of the PBS guides in the same directory.

Ordering Software and Licenses

To purchase software packages or additional software licenses, contact your Altair sales representative at pbssales@altair.com.

1
New Features

This chapter briefly lists new features by release, with the most recent listed first.

For deprecations, please see the *Release Notes.*

The *Release Notes* included with this release of PBS Professional list all new features in this version of PBS Professional, and any warnings or caveats. Be sure to review the *Release Notes*, as they may contain information that was not available when this book was written.

1.1 Changes in Previous Releases

New Option to Specify that User's Home Directory is Shared (2021.1.1)

The administrator can specify that the user's home directory is shared in order to prevent sister MoMs from prematurely removing job files. See Chapter 14, "Staging and Execution Directories for Job", on page 525/

New Postpaid Mode for Budgets (2021.1.1)

You can use Budgets in postpaid or prepaid mode. See Chapter 1, "Understanding and Managing Resource Usage", on page 1 of the *PBS Professional Budgets Guide*.

Support for NVIDIA MIG (2021.1.1)

PBS supports NVIDIA MIGs. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

Improvements to Cgroups Hook (2021.1.1)

The cgroups hook has improvements to help manage swap and device discovery, and better default values for configuration file parameters mem_fences, reserve_amount in memory subsystem, vnode_hidden_mb. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

Better License Management for Cloud (2021.1.1)

PBS Cloud checks for application license availability; see the *PBS Cloud Guide*.

Offline Install Procedure for Cloud (2021.1.1)

You can install PBS Cloud on an offline host. See the *PBS Cloud Guide*.

New Options for Altering Reservations (2021.1)

You can change a reservation's select specification, and the administrator can override the scheduler to change the start time, end time, and duration of a reservation. See "pbs_ralter" on page 87 of the PBS Professional Reference Guide.

Integration with NEC SX-Aurora TSUBASA (2021.1)

PBS provides topologically aware job resource requests and scheduling. For configuration information, see Chapter 13, "Support for NEC SX-Aurora TSUBASA", on page 503. For job submission instructions, see "Submitting Jobs to NEC SX-Aurora TSUBASA", on page 199 of the PBS Professional User's Guide.

Integration with Container Access Control (2021.1)

PBS allows you to whitelist container registries, and supports logging into private container registries. You can also manage mount paths for greater security. See Chapter 18, "Configuring PBS for Containers", on page 623.

Managing Shared Job Directory Behavior (2021.1)

You can prevent sister MoMs from prematurely removing shared job directories and files during node release. See section 14.13.1, “Staging and Execution Directories for Job”, on page 525.

Limiting Number of Subjobs Running at One Time (2021.1)

Job submitters can limit the number of simultaneously running subjobs for an array job; see "Limiting Number of Simultaneously Running Subjobs", on page 152 of the PBS Professional User’s Guide.

New Cgroups Hook (2020.1)

PBS has an expanded cgroups hook with many new capabilities. This hook replaces the cpuset MoM. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

Cloud Bursting Feature (2020.1)

PBS now has its own cloud bursting feature. See the PBS Cloud Guide.

Budget Allocation Feature (2020.1)

PBS now has its own budget allocation feature. See the PBS Budgets Guide.

Workload Simulation Feature (2020.1)

PBS now has its own workload simulation feature. See the PBS Simulate Guide.

Timeout for Dynamic Server Resource Scripts (2020.1)

By default, PBS allows a dynamic server resource script 30 seconds to run. You can configure the timeout; see section 5.14.3.1, “Creating Server Dynamic Resource Scripts”, on page 268.

Specifying Hosts or Vnodes to Keep when Releasing Unneeded Vnodes (2020.1)

You can specify how many hosts or which vnodes to keep when releasing unneeded vnodes. See “pbs_release_nodes” on page 93 of the PBS Professional Reference Guide.

Using Undo Live Recorder to Capture Daemon Execution Recordings (2020.1) (Removed 2021.1.2)

You can use Undo Live Recorder to capture execution history for analysis by Altair support. See section 21.1.4, “Finding PBS Version Information”, on page 671.

PBS Reconfirms Degraded Reservations (2020.1)

If reservation vnodes become unavailable, PBS looks for replacements. See section 9.4.2, “Finding Replacement Vnodes for Degraded and In-conflict Reservations”, on page 435.

New Default for TPP Message Processing (2020.1)

The default for the number of TPP messages the server can process per thread iteration is now 64. See “rpp_max_pkt_check” on page 297 of the PBS Professional Reference Guide.

Automatic Deletion of Idle Reservations (2020.1)

PBS can automatically delete idle reservations. See "Introduction to Creating and Using Advance and Standing Reservations", on page 136 of the PBS Professional User’s Guide.

Flexible Job-specific Reservations (2020.1)

You can create flexible job-specific reservations for queued or running jobs. See "Job-specific Reservations", on page 140 of the PBS Professional User’s Guide.

Altering Reservation Duration, Authorized Groups, Authorized Users (2020.1)

You can alter the duration of a reservation; see “pbs_ralter” on page 87 of the PBS Professional Reference Guide.

Accounting Record for Job Suspend and Resume (2020.1)

PBS records job suspension and resumption in the accounting log. See Chapter 19, "Accounting", on page 635.

Managing Number of Scheduler Threads (2020.1)

You can set the maximum number of threads used by each scheduler. See section 4.5.7.3, “Setting Number of Scheduler Threads”, on page 100.

Configurable Authentication Methods (2020.1)

You can use various authentication methods with PBS; see section 8.4, “Authentication for Daemons & Users”, on page 380.

Using TLS for Encryption (2020.1)

You can use TLS encryption with PBS. See section 8.5, “Encrypting PBS Communication”, on page 389.

Mixed Operation on Linux and Windows (2020.1)

You can use both Linux and Windows execution and client hosts in the same PBS complex. See Chapter 20, "Mixed Linux-Windows Operation", on page 667.

Run Jobs on First Available Resources (Beta 2020.1)

You can submit a set of jobs that would all accomplish the same thing, but that specify different resources. PBS runs only the first that can run. See "Running Your Job on First Available Resources (2020.1 Beta)", on page 108 of the PBS Professional User’s Guide.

New pbs_login Command (2020.1)

PBS includes a new command for user authentication called `pbs_login`. See “pbs_login” on page 70 in the PBS Professional Installation & Upgrade Guide.

One way to sort jobs for preemption (2020.1)

Jobs are chosen for preemption only by which have been running the shortest time. See section 4.9.33, “Using Preemption”, on page 182.

New Threading Option for Schedulers (2020.1)

You can specify the number of threads each scheduler runs. See “pbs_sched” on page 106 of the PBS Professional Reference Guide.

License Server for Node and Socket Licenses (2020.1)

PBS uses a license server to license hosts in the complex. See the *PBS Works Licensing Guide*.

Specifying Additional Arguments for Container Engines (2020.1)

Job submitters can specify additional container engine arguments such as secondary groups and shared memory; see "Specifying Additional Arguments to Container Engine", on page 132 of the PBS Professional User’s Guide.

Update to SELinux Support

Support for SELinux is updated. See Chapter 17, "Configuring PBS for SELinux", on page 617.

Preemption via Deletion (19.4)

You can use deletion to preempt jobs. See section 4.9.33, “Using Preemption”, on page 182.

New Scheduler Attributes for Preemption (19.4)

The preempt_order, preempt_prio, preempt_queue_prio, and preempt_sort preemption settings are now scheduler attributes with the same names and formats. See “Scheduler Attributes” on page 300 of the PBS Professional Reference Guide.

All Groups Included in Group ACLs (19.4)

All of a user's groups are included in the list of groups in group ACLs. See section 8.3.4.5, “Contents of Group ACLs”, on page 366.

Changes to qstat Job Output (19.4)

Wide output lines can be displayed for any default or alternate `qstat` job output formats, and when output size is too large for a field, the last character is replaced with an asterisk. See "qstat" on page 198 of the PBS Professional Reference Guide.

Subjob Run Count Tracking (19.4)

PBS tracks the run_count attribute for subjobs, and holds job arrays whose subjobs hit the run count limit. See section 14.18, "Managing Number of Run Attempts", on page 535.

Faster Read of Custom Job Resources by Execution Hooks (19.4)

You can specify which custom resources are cached at MoMs so that execution hooks can read them faster. See section 5.14.2.3.x, "Allowing Execution Hooks to Read Custom Job Resources Faster", on page 263.

Applications Running in Containers Can Use Ports (19.4)

PBS can provide ports for applications running in containers. See "Configuring PBS for Containers".

Support for Singularity Containers (19.4)

You can run PBS jobs in Singularity containers. See "Configuring PBS for Containers".

New Post-suspend and Pre-resume Hooks (19.4)

PBS has two new hook events for just after suspending a job and just before resuming it. See "Event Types" on page 87 in the PBS Professional Hooks Guide.

Scheduler Logging Consistent with Other Daemons (19.4)

Schedulers use the same logging scheme as other daemons. See "Event Logging" on page 548 of the PBS Professional Reference Guide.

Option to Capture Only PBS Configuration Information with pbs_snapshot (19.4)

You can use the new `pbs_snapshot --basic` option to capture just PBS configuration information. See "pbs_snapshot" on page 113 of the PBS Professional Reference Guide.

Support for Cray Shasta Systems (19.4)

PBS is supported on Cray's Shasta systems. See section 11.1, "Support for Shasta", on page 473.

Expanded and New Accounting Records (19.4)

PBS writes a new "a" accounting record when a job is altered, and the "Q" record is expanded to include more information. See section 19.4, "Types of Accounting Log Records", on page 638.

IP Address Can Be Used for Vnode Name (19.4)

You can use the IP address as the vnode name. See "Vnode Name" on page 360 of the PBS Professional Reference Guide.

Developer Libraries and Headers in Developer Package (19.4)

The libraries and headers needed for development but not for running PBS have been moved to a developer package. See "Developer Headers and Libraries" on page 19 in the PBS Professional Programmer's Guide.

PBS Uses Python 3 (19.4)

As of 19.4.1, PBS uses Python 3.

New Basic Option to pbs_snapshot (19.4)

The `pbs_snapshot` command has a new `--basic` option. See "pbs_snapshot" on page 113 of the PBS Professional Reference Guide.

New Maintenance Reservation (19.4)

PBS provides a new type of reservations for performing maintenance. See section 4.9.37, "Reservations", on page 199.

Windows MoMs and Clients Run with Linux Server, Schedulers, Comms (19.4)

As of 19.4.1, PBS complexes that run Windows MoMs and Clients run with Linux server, schedulers, and comms.

Undo Live Recorder Debugger (19.4) (Removed 2021.1.2)

Undo's Live Recorder integration enhances our ability to pinpoint root causes of problematic behavior. (This capability is used under the direction of Altair support staff to speed troubleshooting.)

PBS Defaults to 24/7 Primetime (19.2)

You can use PBS without configuring primetime and/or holidays. See section 4.9.34, "Using Primetime and Holidays", on page 193

Microsecond Logging (19.2)

You can choose to have daemons log with microsecond resolution. See section 15.3.4.1, "Event Logfile Format", on page 551.

Limiting ncpus Count to Cores (19.2)

You can opt not to include hyperthreads when calculating the value for ncpus that MoM reports to the server. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

Change in Enabling Power Provisioning (19.2)

You enable power provisioning by enabling the PBS_power hook. See Chapter 6, "Managing Power Usage", on page 319.

Settable Maximum Job ID (19.2)

You can set the maximum value for job IDs, job array IDs, and reservation IDs, using the max_job_sequence_id server attribute.

Job Vnode Fault Tolerance (19.2)

You can allocate extra vnodes to jobs to allow jobs to successfully start and run despite vnode failures. See section 9.5, "Vnode Fault Tolerance for Job Start and Run", on page 436.

Hooks Support Reliable Job Startup and Run (19.2)

Hooks have been enhanced to allow you to provide jobs with extra vnodes in case of vnode failure. See section 9.5, "Vnode Fault Tolerance for Job Start and Run", on page 436.

New Reservation End Hook (19.2)

You can create hooks for the end of a reservation. See "resv_end: Event when Reservation Ends" on page 90 in the PBS Professional Hooks Guide.

Enhancements to pbs_snapshot (19.2)

You can run `pbs_snapshot` without root privilege, and the command captures JSON output. See "pbs_snapshot" on page 113 of the PBS Professional Reference Guide.

Tunable Job Release Wait Time for Cray (19.2)

You can set the amount of time that PBS waits between sending release requests to ALPS. See section 11.9.7, "Set ALPS Reservation Release Timeout on Cray XC", on page 482.

Managing Power Usage on Cray (18.2)

You can power nodes up and down, limit ramp rate, and use power profiles for jobs. See Chapter 6, "Managing Power Usage", on page 319.

On Cray, PBS Creates One Vnode per Compute Node (18.2)

Default behavior on the Cray has changed to create one vnode per compute node. See section 11.8, "Automatic Configuration for Cray XC", on page 477.

Suspend and Resume on Cray (18.2)

You can use suspend and resume on Cray. See section 11.16.5, “Suspending and Resuming Jobs on Cray XC”, on page 495

Installing PBS on Cray CLE 5.2 via RPM (18.2)

PBS is installed on Cray CLE 5.2 via RPM. See “Changes for Cray XC Installation” on page 142 in the PBS Professional Installation & Upgrade Guide.

Performance Enhancement for PBS on Cray via Improved MoM Reporting (18.2)

You can improve the performance of PBS on Cray by using the vnode_pool vnode attribute. This allows only one MoM to report inventory, and reduces communication traffic. See section 11.10, “Improving Server/MoM Inventory Performance for Cray XC”, on page 483.

Periodic Synchronization of Inventory on Cray (18.2)

PBS periodically makes sure that its inventory matches what ALPS reports. See section 11.11, “Synchronizing PBS with ALPS Inventory on Cray XC”, on page 485.

On Cray, Automatic Creation of One Vnode Per Compute Node (18.2)

PBS automatically creates one vnode for each compute node. See section 11.8, “Automatic Configuration for Cray XC”, on page 477.

Installing PBS on CLE 6 via IMPS (18.2)

See “Installing PBS on CLE 6 and 7” on page 142 in the PBS Professional Installation & Upgrade Guide.

Support for Xeon Phi (18.2)

PBS supports Xeon Phi. See Chapter 11, "Support for Xeon Phi on Cray XC", on page 485.

1.1.1 New Scheduling Features

Restricting Placement Set Creation to Resources with Values that Have Been Set (18.2)

See section 4.9.32, “Placement Sets”, on page 170.

Soft Walltimes for Jobs (18.2)

You can set a soft walltime for jobs, and PBS can estimate a job's soft walltime. See section 4.9.44, “Using Soft Walltime”, on page 221

Formula Uses Fairshare (18.2)

You can use fairshare in the job sorting formula. See section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151.

Manage Partitions with Multisceds (18.2)

You can schedule each partition separately. See section 4.2, “Scheduling Each Partition Separately”, on page 57.

Run Jobs in a Cloud (18.2)

PBS can burst jobs to a cloud. See the *PBS Professional Cloud Guide*.

1.1.2 New Hooks Features

The execjob_prologue Hook Runs on All Sister MoMs (18.2)

The execjob_prologue hook runs on all sister MoMs. See "execjob_prologue: Event Just Before Execution of Top-level Job Process" on page 97 in the PBS Professional Hooks Guide.

Python Version Changed to 2.7.1 (18.2)

PBS 18.2.1 uses Python 2.7.1. The use of Python 2.5.1 is deprecated.

Periodic Server Hook (18.2)

PBS has a periodic hook that runs at the server. See "periodic: Periodic Event at Server Host" on page 95 in the PBS Professional Hooks Guide.

Hook to Run Job Start Time Estimator (18.2)

PBS has a built-in hook named PBS_est that can run the job start time estimator. See section 4.9.15, "Estimating Job Start Time", on page 133.

Configurable Python Interpreter Restarts (18.2)

You can configure how often you want the Python interpreter to restart. See "Restarting the Python Interpreter" on page 23 in the PBS Professional Hooks Guide.

PBS Can Report Custom Resources Set in Hooks (18.2)

MoM can accumulate and report custom resources that are set in a hook. See "Setting Job Resources in Hooks" on page 49 in the PBS Professional Hooks Guide

1.1.3 Other New Features

Managing Job Resource Use with Cgroups (18.2)

You can use cgroups to manage the resources used by jobs. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

Running Jobs in Containers (18.2)

Job submitters can run each job in its own container. See Chapter 18, "Configuring PBS for Containers", on page 623 and "Running Your Job in a Container", on page 130 of the PBS Professional User's Guide.

Power Provisioning (18.2)

PBS can monitor and control job power usage. See Chapter 6, "Managing Power Usage", on page 319.

Collecting Diagnostic Information with pbs_snapshot Command (18.2)

See "pbs_snapshot" on page 113 of the PBS Professional Reference Guide.

New pbs_ralter Command (18.2)

You can change reservations using the `pbs_ralter` command. See "Modifying Reservations", on page 142 of the PBS Professional User's Guide.

Privileged Access to Server for MoMs (18.2)

You can give all MoMs privileged access to the server without having to explicitly add their hosts to the acl_hosts server attribute. See section 8.3.7.3, "Access to Server for MoMs", on page 372.

Releasing Unneeded Vnodes from Jobs (18.2)

You can release vnodes that were allocated to jobs when those vnodes are no longer needed. See "Releasing Unneeded Vnodes from Your Job", on page 128 of the PBS Professional User's Guide.

Running Subjobs Survive Server Restart (18.2)

Subjobs of an array job will continue to run during a restart of the server.

Writing Output and Error Files Directly to Final Destination (18.2)

You can have PBS write your standard output and error files directly to their final destination. See "Writing Files Directly to Final Destination", on page 45 of the PBS Professional User's Guide.

Deleting Output and Error Files (18.2)

You can have PBS delete your standard output and error files. See "Avoiding Creation of stdout and/or stderr", on page 43 of the PBS Professional User's Guide.

Output for qstat in JSON and DSV Formats; qstat Attribute Output on Single Line (18.2)

You can get output from `qstat` in JSON or DSV formats. You can also print out attribute information in one unbroken line. See "qstat" on page 198 in the PBS Professional Installation & Upgrade Guide.

Specifying Resources to Release on Suspension (18.2)

You can specify which resources you want released when jobs are suspended. See section 5.9.6.2, "Job Suspension and Resource Usage", on page 252.

Maintenance State for Powered-up Vnodes (18.2)

You can suspend a job and put all the vnodes belonging to a job into the *maintenance* state. See section 15.4.2, "Performing Maintenance on Powered-up Vnodes", on page 556.

Debuginfo RPM Package (18.2)

PBS is packaged with a debuginfo RPM package. See section 21.1.3, "Using the debuginfo RPM Package", on page 671.

Logging Hostname and Interfaces (18.2)

Each time a log file is opened, PBS logs the hostname and interface information. See section 15.3, "Event Logging", on page 548.

Subjobs Survive Server Restarts (18.2)

Subjobs keep running after you stop the server. See "Impact of Stop-Restart on Running Linux Jobs" on page 169 in the PBS Professional Installation & Upgrade Guide and "Impact of Stop-Restart on Running Windows Jobs" on page 174 in the PBS Professional Installation & Upgrade Guide.

You can see all attributes for subjobs; see "Viewing Status of a Job Array", on page 157 of the PBS Professional User's Guide.

Jobs Can Use Provisioning for Some Chunks (18.2)

Jobs can request an AOE for some chunks as long as all chunks use the same AOE. See Chapter 14, "Using Provisioning", on page 213.

Node Licenses (18.2)

You can license your hosts using node licenses. See the *PBS Works Licensing Guide*.

PBS Can Send Mail for Subjobs (18.2)

PBS can send mail for subjobs. See "Specifying Email Notification", on page 25 of the PBS Professional User's Guide.

Server Periodic Hook (14.2)

You can run a hook periodically at the server. See "periodic: Periodic Event at Server Host" on page 95 in the PBS Professional Hooks Guide.

Hook to Run Job Start Time Estimator (14.2)

PBS has a built-in hook named PBS_est that can run the job start time estimator. See section 4.9.15, "Estimating Job Start Time", on page 133.

PBS Can Report Custom Resources Set in Hooks (14.2)

MoM can accumulate and report custom resources that are set in a hook. See section 5.2.4.12, "Setting Job Resources in Hooks", on page 49.

Configurable Python Interpreter Restarts (14.2)

You can configure how often you want the Python interpreter to restart. See "Restarting the Python Interpreter" on page 23 in the PBS Professional Hooks Guide.

Python Version Changed to 2.7.1 (14.2)

PBS 14.2.1 uses Python 2.7.1. The use of Python 2.5.1 is deprecated.

Name for MoM to Use for Parent Vnode (14.2)

You can specify the name that MoM should use for her parent vnode and child vnodes. See section 3.3.2, "How to Choose Vnode Names", on page 40.

Grouping Jobs and Sorting by ID (14.2)

When getting job status, you can group jobs and sort them by ID. See "Grouping Jobs and Sorting by ID", on page 177 of the PBS Professional User's Guide.

Support for systemd (14.2)

PBS supports using sytemctl commands to start, stop, restart, and status PBS. See "Methods for Starting, Stopping, or Restarting PBS" on page 160 in the PBS Professional Installation & Upgrade Guide.

Support for Native Package Managers on Linux (14.2)

PBS supports use of RPM for installation and upgrading. See "Installation" on page 19 in the PBS Professional Installation & Upgrade Guide and "Upgrading" on page 65 in the PBS Professional Installation & Upgrade Guide.

Server Sets Job Comment on Run or Reject (14.2)

The server sets the job comment when the job is run or rejected. See section 14.7.3.1, "Comment Set When Running Job", on page 517.

Update to Accounting R Record (14.2)

PBS writes the R accounting record when MoM is restarted with `-p` or `-r`. See section , "R", on page 645.

Interactive GUI Jobs on Windows (13.1)

Users can run interactive GUI jobs on Windows. See "Submitting Interactive GUI Jobs on Windows", on page 125 of the PBS Professional User's Guide.

Administrators can choose a remote viewer for interactive GUI jobs. See section 14.20.1, "Configuring PBS for Remote Viewer on Windows", on page 535.

MUNGE Integration (13.1)

PBS can use MUNGE to create and validate credentials. See section 8.4.4, "Authentication via MUNGE", on page 381.

Controlling Backfill Depth at the Queue (13.1)

Administrators can choose the backfilling depth independently at each queue. See section 4.9.3, "Using Backfilling", on page 107.

Optional Scheduler Cycle Speedup (13.1)

You can optionally speed up the scheduling cycle. See section 4.9.40, "Scheduler Cycle Speedup", on page 211.

Preventing Some Jobs from Being Top Jobs (13.1)

You can prevent a job from being a top job by setting its topjob_ineligible attribute to True. See section 4.9.17.1, "Making Jobs Ineligible to be Top Jobs", on page 139.

Improved Mail on Windows (13.1)

Under Windows, you can specify an SMTP server. (As of 19.4.1, PBS does not use an SMTP server.)

New Hook Events (13.0)

PBS provides three new hook events:

- An execjob_launch hook runs just before MoM runs the user's program
- An execjob_attach hook runs when pbs_attach is called
- An exechost_startup hook runs when MoM starts up

See "When Hooks Run" on page 15 in the PBS Professional Hooks Guide, "execjob_launch: Event when Execution Host Receives Job" on page 98 in the PBS Professional Hooks Guide, "execjob_attach: Event when pbs_attach() runs" on page 100 in the PBS Professional Hooks Guide, and "exechost_startup: Event When Execution Host Starts Up" on page 106 in the PBS Professional Hooks Guide.

Configuration Files for Hooks (13.0)

You can use configuration files with hooks. See "Using Hook Configuration Files" on page 32 in the PBS Professional Hooks Guide.

Configuring Vnodes in Hooks (13.0)

You can use hooks to configure vnode attributes and resources. See "Setting and Unsetting Vnode Resources and Attributes" on page 48 in the PBS Professional Hooks Guide.

Adding Custom Resources in Hooks (13.0)

You can use hooks to add custom non-consumable host-level resources. See "Adding Custom Non-consumable Host-level Resources" on page 64 in the PBS Professional Hooks Guide.

Node Health Hook Features (13.0)

PBS has node health checking features for hooks. You can offline and clear vnodes, and restart the scheduling cycle. See "Offlining and Clearing Vnodes Using the fail_action Hook Attribute" on page 66 in the PBS Professional Hooks Guide and "Restarting Scheduler Cycle After Hook Failure" on page 63 in the PBS Professional Hooks Guide.

Hook Debugging Enhancements (13.0)

You can get hooks to produce debugging information, and then read that information in while debugging hooks. See "Debugging Hooks" on page 159 in the PBS Professional Hooks Guide.

Managing Built-in Hooks (13.0)

You can enable and disable built-in hooks. See "Managing Built-in Hooks" on page 155 in the PBS Professional Hooks Guide.

Scheduler Does not Trigger modifyjob Hooks (13.0)

The scheduler does not trigger modifyjob hooks. See the PBS Professional Hooks Guide.

Faster, Asynchronous Communication Between Daemons (13.0)

PBS has a communication daemon that provides faster, asynchronous communication between the server, scheduler, and MoM daemons. See “Communication” on page 45 in the PBS Professional Installation & Upgrade Guide.

Enhanced Throughput of Jobs (13.0)

By default, the scheduler runs asynchronously to speed up job start, and jobs that have been altered via `qalter`, server_dyn_res, or peering can run in the same scheduler cycle in which they were altered. See section 4.5.7.1, “Improving Throughput of Jobs”, on page 99.

Creating Custom Resources via qmgr (13.0)

You can create any custom resources using nothing but the `qmgr` command. See section 5.14.2.4, “Defining Custom Resources via qmgr”, on page 265.

Job Sorting Formula: Python Math Functions and Threshold (13.0)

You can use standard Python math functions in the job sorting formula. You can also set a threshold for job priority, below which jobs cannot run. See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

Fairshare: Formula and Decay Factor (13.0)

You can use a mathematical formula for fairshare, and you can set a custom decay factor. See section 4.9.19, "Using Fairshare", on page 140.

Preempted Jobs can be Top Jobs (13.0)

You can specify that preempted jobs should be classified as top jobs. See section 4.9.16, "Calculating Job Execution Priority", on page 136. You can use a new scheduler attribute called sched_preempt_enforce_resumption for this; see section 4.9.3, "Using Backfilling", on page 107.

Limiting Preemption Targets (13.0)

You can specify which jobs can be preempted by a given job. See section 4.9.33.4.i, "Setting Job Preemption Targets", on page 184.

Limiting Number of Jobs in Execution Queues (13.0)

You can speed up the scheduling cycle by limiting the number of jobs in execution queues. See section 4.5.7.2, "Limiting Number of Jobs Queued in Execution Queues", on page 100.

Improved Round-robin Behavior (13.0)

The round_robin scheduler parameter produces improved behavior. See section 4.9.38, "Round Robin Queue Selection", on page 206.

Limiting Resources Allocated to Queued Jobs (13.0)

You can set limits on the amounts of resources allocated to queued jobs specifically. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

Running qsub in the Foreground (13.0)

By default, the `qsub` command runs in the background. You can run it in the foreground using the `-f` option. See "qsub" on page 214 of the PBS Professional Reference Guide.

Windows Users can Use UNC Paths (13.0)

Windows users can use UNC paths for job submission and file staging. See "Set up Paths", on page 8 of the PBS Professional User's Guide and "Using UNC Paths", on page 35 of the PBS Professional User's Guide.

Automatic Installation and Upgrade of Database (13.0)

PBS automatically installs or upgrades its database. See "Automatic Upgrade of Database (13.0)" on page 66 in the PBS Professional Installation & Upgrade Guide.

Longer Job and Reservation Names (13.0)

You can use job and reservation names up to 236 characters in length. See "Formats" on page 355 of the PBS Professional Reference Guide.

Address Disambiguation for Multihomed Systems (13.0)

You can disambiguate addresses for contacting the server, sending mail, sending outgoing traffic, and delivering output and error files. See "PBS with Multihomed Systems" on page 60 in the PBS Professional Installation & Upgrade Guide.

Support for Hydra Process Manager in Intel MPI (13.0)

Intel MPI is integrated with PBS. See "Integrating Intel MPI 4.0.3 On Linux Using Environment Variables" on page 455.

Enhancements to pbsnodes Command (13.0)

You can now use the `pbsnodes` command to edit the comment attribute of a host, to write out host information, and to operate on specific vnodes. See "pbsnodes" on page 36.

Primary Group of Job Owner or Reservation Creator Automatically Added to Job group_list (13.0)

The job submitter's and reservation creator's primary group is automatically added to the job or reservation group_list attribute. See "qsub” on page 214 and "pbs_rsub” on page 97.

Intel MPI Integrated under Windows (13.0)

MPI is integrated with PBS under Windows (as well as Linux). See "Integrating Intel MPI 4.0.3 on Windows Using Wrapper Script” on page 456.

MPICH2 Integrated under Windows (13.0)

MPICH2 is integrated with PBS under Windows (as well as Linux). See "Integrating MPICH2 1.4.1p1 on Windows Using Wrapper Script” on page 456.

PBS pbsdsh Command Available under Windows (13.0)

The pbsdsh command is available under Windows. See "pbsdsh” on page 30.

PBS TM APIs Available under Windows (13.0)

The PBS TM APIs are available under Windows. See "TM Library” on page 93 of the PBS Professional Programmer's Guide.

PBS pbs_attach Command Available under Windows (13.0)

The pbs_attach command is available under Windows. See "pbs_attach” on page 56.

Xeon Phi Reported on Cray (13.0)

PBS automatically detects and reports a Xeon Phi in the ALPS inventory. See "Using Xeon Phi Vnodes on Cray XC", on page 193 of the PBS Professional User’s Guide.

Command Line Editing in qmgr (12.2)

The `qmgr` command provides a history and allows you to edit command lines. See “Reusing and Editing the qmgr Command Line” on page 151 of the PBS Professional Reference Guide.

Interactive Jobs Available under Windows (12.2)

Job submitters can run interactive jobs under Windows. See "Running Your Job Interactively", on page 121 of the PBS Professional User’s Guide.

Job Run Count is Writable (12.2)

Job submitters and administrators can set the value of a job's run count. See section 14.18, “Managing Number of Run Attempts”, on page 535 and "Controlling Number of Times Job is Re-run", on page 119 of the PBS Professional User’s Guide.

runjob Hook can Modify Job Attributes (12.2)

The runjob hook can modify a job's attributes and resources. See "Using Attributes and Resources in Hooks" on page 44 in the PBS Professional Hooks Guide.

Jobs can be Suspended under Windows (12.2)

You can suspend and resume a job under Windows.

Configuration of Directory for PBS Component Temporary Files (12.2)

You can configure the root directory where you want PBS components to put their temporary files. See section 15.8, “Temporary File Location for PBS Components”, on page 569.

Execution Event and Periodic Hooks (12.0)

You can write hooks that run at the execution host when the job reaches the execution host, when the job starts, ends, is killed, and is cleaned up. You can also write hooks that run periodically on all execution hosts. See the PBS Professional Hooks Guide.

Shrink-to-fit Jobs (12.0)

PBS allows users to specify a variable running time for jobs. Job submitters can specify a walltime range for jobs where attempting to run the job in a tight time slot can be useful. Administrators can convert non-shrink-to-fit jobs into shrink-to-fit jobs in order to maximize machine use. See "Adjusting Job Running Time", on page 110 of the PBS Professional User's Guide and section 4.9.42, "Using Shrink-to-fit Jobs", on page 213.

PBS Supports Socket Licensing (11.3)

PBS lets you use socket licenses to license hosts. See the *PBS Works Licensing Guide*.

Deleting Job History (11.3)

You can delete job histories. See section 14.15.9, "Deleting Moved Jobs and Job Histories", on page 534.

Managing Resource Usage by Project (11.2)

You can set resource usage limits for projects, at the server and queue. You can set limits for the amount of each resource being used, or for the number of jobs. Jobs have a new attribute called *project*. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

PBS Daemons Protected from OOM Killer (11.2)

PBS daemons are protected from being terminated by an OOM killer. See section 9.8, "OOM Killer Protection", on page 451.

PBS Supports X Forwarding for Interactive Jobs (11.2)

PBS allows users to receive X output from interactive jobs. See "Receiving X Output from Interactive Linux Jobs", on page 124 of the PBS Professional User's Guide, and section 15.2.1.1, "Contents of Environment File", on page 547.

Support for Accelerators on Cray (11.2)

PBS provides tight integration for accelerators on Cray. See Chapter 11, "Configuring PBS for Cray", on page 473.

Support for Interlagos on Cray (11.1)

No longer supported.

Improved Cray Integration (11.0)

PBS is more tightly integrated with Cray systems. You can use the PBS select and place language when submitting Cray jobs. See section , "Configuring PBS for Cray", on page 473.

Vnode Access for Hooks (11.0)

Hooks have access to vnode attributes and resources. See the PBS Professional Hooks Guide.

Enhanced Job Placement (11.0)

PBS allows job submitters to scatter chunks by vnode in addition to scattering by host. PBS also allows job submitters to reserve entire hosts via a job's placement request. See "Specifying Job Placement", on page 64 of the PBS Professional User's Guide.

Choice in PBS service account Name (11.0)

Under Windows, the PBS service account used to run PBS daemons can have any name. See "Creating PBS Service Account in Domained Environment" on page 40 in the PBS Professional Installation & Upgrade Guide.

Change of Licensing Method (11.0)

As of 11.0, PBS is licensed using a new Altair license server. See the *PBS Works Licensing Guide*.

Change in Data Management (11.0)

PBS uses a new data service. See section 15.5, "Managing the Data Service", on page 559.

Choice in Job Requeue Timeout (11.0)

You can choose how long the job requeue process should be allowed to run. See section 9.6.3, "Setting Job Requeue Timeout", on page 447.

Backfilling Around Top N Jobs (10.4)

PBS can backfill around the most deserving jobs. You can configure the number of jobs PBS backfills around. See section 4.9.3, "Using Backfilling", on page 107.

Estimating Job Start Times (10.4)

PBS can estimate when jobs will run, and which vnodes each job will use. See section 4.9.15, "Estimating Job Start Time", on page 133.

Unified Job Submission (10.4)

PBS allows users to submit jobs using the same scripts, whether the job is submitted on a Windows or Linux system. See "Python Job Scripts", on page 14 of the PBS Professional User's Guide.

Provisioning (10.2)

PBS provides automatic provisioning of an OS or application on vnodes that are configured to be provisioned. When a job requires an OS that is available but not running, or an application that is not installed, PBS provisions the vnode with that OS or application. See Chapter 7, "Provisioning", on page 329.

New Hook Type (10.2)

PBS has a new hook type which can be triggered when a job is to be run. See the PBS Professional Hooks Guide.

New Scheduler Attribute (10.2)

PBS allows the administrator to set the scheduler's cycle time using the new sched_cycle_length scheduler attribute. See the `pbs_sched_attributes(7B)` manual page.

Walltime as Checkpoint Interval Measure (10.2)

PBS allows a job to be checkpointed according to its walltime usage. See the `pbs_job_attributes(7B)` manual page.

Managing Resource Usage (10.1)

You can set separate limits for resource usage by individual users, individual groups, generic users, generic groups, and the total used. You can limit the amount of resources used, and the number of queued and running jobs. These limits can be defined separately for each queue and for the server. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290. These new limits are incompatible with the limit attributes existing before Version 10.1.

Managing Job History (10.1)

PBS Professional can provide job history information, including what the submission parameters were, whether the job started execution, whether execution succeeded, whether staging out of results succeeded, and which resources were used. PBS can keep job history for jobs which have finished execution, were deleted, or were moved to another server. See section 14.15, "Managing Job History", on page 531.

Reservation Fault Tolerance (10.1)

PBS attempts to reconfirm reservations for which associated vnodes have become unavailable. See section 9.4, "Reservation Fault Tolerance", on page 434.

Checkpoint Support via Epilogue (10.1)

Checkpointed jobs can be requeued if the epilogue exits with a special value. See section 9.3.7.3, "Requeueing via Epilogue", on page 431.

Hooks (10.0)

Hooks are custom executables that can be run at specific points in the execution of PBS. They accept, reject, or modify the upcoming action. This provides job filtering, patches or workarounds, and extends the capabilities of PBS, without the need to modify source code. See the PBS Professional Hooks Guide.

Versioned Installation (10.0)

PBS is now automatically installed in versioned directories. For most platforms, different versions of PBS can coexist, and upgrading is simplified. See Chapter 3, "Installation", on page 19 and Chapter 6, "Upgrading", on page 65 in the PBS Professional Installation and Upgrade Guide.

Resource Permissions for Custom Resources (9.2)

You can set permissions on custom resources so that they are either invisible to users or cannot be requested by users. This also means that users cannot modify a resource request for those resources via `qalter`. See section 5.14.2.3.vi, “Resource Permission Flags”, on page 262.

Extension to Job Sorting Formula (9.2)

The job sorting formula has been extended to include parentheses, exponentiation, division, and unary plus and minus. See section 4.9.3, “Using Backfilling”, on page 107.

Eligible Wait Time for Jobs (9.2)

A job that is waiting to run can be accruing "eligible time". Jobs can accrue eligible time when they are blocked due to a lack of resources. This eligible time can be used in the job sorting formula. Jobs have two new attributes, eligible_time and accrue_type, which indicates what kind of wait time the job is accruing. See section 4.9.13, “Eligible Wait Time for Jobs”, on page 128.

Job Staging and Execution Directories (9.2)

PBS now provides per-job staging and execution directories. Jobs have new attributes sandbox and jobdir, the MoM has a new option `$jobdir_root`, and there is a new environment variable called PBS_JOBDIR. If the job's sandbox attribute is set to *PRIVATE*, PBS creates a job-specific staging and execution directory. If the job's sandbox attribute is unset or is set to *HOME*, PBS uses the user's home directory for staging and execution, which is how previous versions of PBS behaved. If MoM's `$jobdir_root` is set to a specific directory, that is where PBS will create job-specific staging and execution directories. If MoM's `$jobdir_root` is unset or set to *PBS_USER_HOME*, PBS will create the job-specific staging and execution directory under the user's home directory. See section 14.13.1, “Staging and Execution Directories for Job”, on page 525.

Standing Reservations (9.2)

PBS now provides both advance and standing reservation of resources. A standing reservation is a reservation of resources for specific recurring periods of time. See section 4.9.37, “Reservations”, on page 199.

New Server Attribute for Job Sorting Formula (9.1)

The new server attribute "job_sort_formula" is used for sorting jobs according to a site-defined formula. See section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151.

Change to sched_config (9.1)

The default for job_sort_key of "cput" is commented out in the default `sched_config` file. It is left in as a usage example.

Change to Licensing (9.0)

PBS now depends on an Altair license server that will hand out licenses to be assigned to PBS jobs. See the *PBS Works Licensing Guide*. PBS Professional versions 8.0 and below will continue to be licensed using the proprietary licensing scheme.

Installing With Altair Licensing (9.0)

If you will use floating licenses, we recommend that you install and configure the Altair license server before installing and configuring PBS. PBS starts up faster. See “Overview of Installation” on page 19 in the PBS Professional Installation & Upgrade Guide.

Unset Host-level Resources Have Zero Value (9.0)

An unset numerical resource at the host level behaves as if its value is zero, but at the server or queue level it behaves as if it were infinite. An unset string or string array resource cannot be matched by a job's resource request. An unset boolean resource behaves as if it is set to "*False*". See section 4.9.28.7, “Matching Unset Resources”, on page 163.

Better Management of Resources Allocated to Jobs (9.0)

The resources allocated to a job from vnodes will not be released until certain allocated resources have been freed by all MoMs running the job. The end of job accounting record will not be written until all of the resources have been freed. The "end" entry in the job end ('E') record will include the time to stage out files, delete files, and free the resources. This will not change the recorded "walltime" for the job.

1.2 Commercial-only Features

PBS is dual-licensed. Altair releases a commercial version and an open-source version. The core of the product is the same, but the commercial version contains additional features available only in the commercial (licensed) version of PBS. For example:

- Estimated start times for non-top jobs via `pbs_est`
- Container integration
- PBS licensing

1.3 Backward Compatibility

1.3.1 New and Old Resource Usage Limits Incompatible

The new resource usage limits are incompatible with the old resource usage limits. See section 5.15.1.15, “Old Limit Attributes: Server and Queue Resource Usage Limit Attributes Existing Before Version 10.1”, on page 305, section 5.15.1.13.v, “Do Not Mix Old And New Limits”, on page 304, and section 5.15.1.14.i, “Error When Setting Limit Attributes”, on page 304.

1.3.2 Job Dependencies Affected By Job History

Enabling job history changes the behavior of dependent jobs. If a job j1 depends on a finished job j2 for which PBS is maintaining history, PBS releases j1's dependency, and takes appropriate action. If job j1 depends on a finished job j3 that has been purged from job history, j1 is rejected just as in previous versions of PBS where the job was no longer in the system.

1.3.3 PBS path information no longer saved in AUTOEXEC.BAT

Any value for PATH saved in AUTOEXEC.BAT may be lost after installation of PBS. If there is any path information that needs to be saved, AUTOEXEC.BAT must be edited by hand after the installation of PBS. PBS path information is no longer saved in AUTOEXEC.BAT.

1.3.4 OS-level Checkpointing Not Supported

PBS does not directly support OS-level checkpointing. PBS supports checkpointing using site-supplied methods. See section 9.3, "Checkpoint and Restart", on page 420.

1.3.5 Scheduler Parameters Changed to Scheduler Attributes (19.4.1)

The preempt_order, preempt_prio, preempt_queue_prio, and preempt_sort preemption settings were scheduler parameters in `$PBS_HOME/sched_priv/sched_config` in older versions of PBS. They are now scheduler attributes with the same names and formats. You cannot use the old parameters. Make sure that you use `qmgr` to set the attributes as desired. See "Scheduler Attributes" on page 300 of the PBS Professional Reference Guide.

2 Configuring the Server and Queues

This chapter describes how to configure the server and any queues.

2.1 The Server

2.1.1 Configuring the Server

You configure the server by setting server attributes via the `qmgr` command:

```
   Qmgr: set server <attribute> = <value>
```

For a description of the server attributes, see “Server Attributes” on page 283 of the PBS Professional Reference Guide.

For a description of the `qmgr` command, see “qmgr” on page 150 of the PBS Professional Reference Guide.

2.1.2 Default Server Configuration

The default configuration from the binary installation sets the default server settings. An example server configuration is shown below:

```
qmgr
Qmgr: print server
#
# Create queues and set their attributes.
# Create and define queue workq
#
create queue workq
set queue workq queue_type = Execution
set queue workq enabled = True
set queue workq started = True
#
# Set server attributes.
#
set server default_queue = workq
set server log_events = 511
set server mail_from = adm
set server query_other_jobs = True
set server resources_default.ncpus = 1
set server resv_enable = True
set server node_fail_requeue = 310
set server max_array_size = 10000
set server default_chunk.ncpus=1
```

2.1.3 The PBS Node File

The server creates a file of the nodes managed by PBS. This node file is written only by the server. On startup each MoM sends a time-stamped list of her known vnodes to the server. The server updates its information based on that message. If the time stamp on the vnode list is newer than what the server recorded before in the node file, the server will create any vnodes which were not already defined. If the time stamp in the MoM's message is not newer, then the server will not create any missing vnodes and will log an error for any vnodes reported by MoM but not already known.

Whenever new vnodes are created, the server sends a message to each MoM with the list of MoMs and each vnode managed by the MoMs. The server will only delete vnodes when they are explicitly deleted via `qmgr`.

This is different from the node file created for each job. See "The Job Node File", on page 77 of the PBS Professional User's Guide.

2.1.4 Server Configuration Attributes

See "Server Attributes" on page 283 of the PBS Professional Reference Guide for a table of server attributes.

2.1.5 Recording Server Configuration

If you wish to record the configuration of a PBS server for re-use later, you may use the `print` subcommand of `qmgr(8B)`. For example,

```
qmgr -c "print server" > /tmp/server.out
qmgr -c "print node @default" > /tmp/nodes.out
```

will record in the file `/tmp/server.out` the `qmgr` subcommands required to recreate the current configuration including the queues. The second file generated above will contain the vnodes and all the vnode properties. The commands could be read back into `qmgr` via standard input:

```
qmgr < /tmp/server.out
qmgr < /tmp/nodes.out
```

2.1.6 Support for Globus

Globus can still send jobs to PBS, but PBS no longer supports sending jobs to Globus. The Globus MoM is no longer available.

2.1.7 Configuring the Server for Licensing

The PBS server must be configured for licensing. You must set the location where PBS will look for the license server(s), by setting the server attribute pbs_license_info, then force the server to re-query for licenses by setting the server's scheduling attribute to *True*. The other server licensing attributes have defaults, but you may wish to set them as well. See the *PBS Works Licensing Guide*.

You may also wish to have redundant license servers. See the *Altair License Management System Installation and Operations Guide*, available at `www.pbsworks.com`.

2.2 How PBS Uses Mail

PBS sends mail to the administrator for administration-related issues, and to job submitters for job-related issues. See "Specifying Email Notification", on page 25 of the PBS Professional User's Guide for information about mail PBS sends to job submitters.

PBS sends mail to the administrator under the following circumstances:

- When failover occurs, PBS sends an email is sent to and from the account defined in the server's mail_from attribute.
- When the database is stopped unexpectedly. For example:
  ```
  "Panic shutdown of Server on database error.  Please check PBS_HOME file system for no space
      condition."
  ```
- When your license is expiring, PBS sends mail once a day.

2.2.1 Configuring Server Mail Address

You can configure the account that is used as the address to both send and receive administrative mail. These are the same account. For example, when failover occurs, an email is sent to and from the account defined in the server's mail_from attribute, saying that failover has occurred.

Use the `qmgr` command to set the mail_from server attribute to an address that is monitored regularly:

```
Qmgr: s server mail_from=<address>
```

You cannot configure which mail server PBS uses. PBS uses the default mail server. On Linux, this is `/usr/lib/sendmail`.

2.2.2 Specifying Mail Delivery Domain

You can use the PBS_MAIL_HOST_NAME parameter in `pbs.conf` on the server host to direct mail to a domain in which the user can receive it. For example, if a job is submitted from a cluster node, it may not be possible for mail to be delivered there, especially if the job runs on a different cluster.

You can specify the destination domain for email that is sent by the server to the administrator or to job submitters or reservation creators by setting the PBS_MAIL_HOST_NAME parameter in `pbs.conf`.

2.2.2.1 Delivering Mail to Administrator

The default user name for administrative mail is "adm". The following table shows where PBS sends administrator mail:

Table 2-1: How PBS Sets Administrator Mail

Value of mail_from	Destination
<username>@<hostname>	*<username>@<hostname>*
user	*user* *(Destination depends on mail server configuration)*
unset	*adm* *(Destination depends on mail server configuration)*

2.2.2.2 Delivering Mail to Job Submitter or Reservation Creator

The Mail_Users attribute is a list of one or more user names. For each entry in the list, PBS handles the entry according to the rules in the following table showing where PBS sends job or reservation mail:

Table 2-2: How PBS Sets Job or Reservation Mail

Value of Mail_Users	Value of PBS_MAIL_HOST_NAME	
	Set	Unset
<user-name>@<hostname>	Linux: *<username>@<hostname>*	*<username>@<hostname>*
user	*user@PBS_MAIL_HOST_NAME*	*user@<server FQDN from Job_Owner attribute of job>*
unset	*<job owner>@ PBS_MAIL_HOST_NAME*	*Linux: <job owner>@ <server FQDN from Job_Owner attribute of job>*

2.2.3 Attributes, Parameters Etc. Affecting Mail

PBS_MAIL_HOST_NAME

Parameter in `pbs.conf`. Optional. Used in addressing mail regarding jobs and reservations that is sent to users specified in a job or reservation's Mail_Users attribute. See section 2.2.2, “Specifying Mail Delivery Domain”, on page 22.

Should be a fully qualified domain name. Cannot contain a colon (":").

mail_from

Server attribute. Mail is sent from and to this account when failover occurs.

Mail_Users

Job and reservation attribute. List of users to whom mail about job or reservation is sent.

Mail_Points

Job and reservation attribute. List of events where PBS sends mail to users who are the job or reservation owner, or are listed in the Mail_Users job or reservation attribute.

PBS_O_MAIL

Value of MAIL environment variable, taken from job submitter's environment.

2.3 Queues

When a job is submitted to PBS and accepted, it is placed in a queue. Despite the fact that the name implies first-in, first-out ordering of jobs, this is not the case. Job submission order does not determine job execution order. See Chapter 4, "Scheduling", on page 55.

You can create different queues for different purposes: queues for certain kinds of jobs, queues for specific groups, queues for specific vnodes, etc. You can tell PBS how to automatically route jobs into each queue. PBS has a default execution queue named *workq*, where jobs are placed when no queue is requested; you can specify a different default queue. See section 2.3.14, “Specifying Default Queue”, on page 34.

2.3.1 Kinds of Queues

2.3.1.1 Execution and Routing Queues

There are two main types of PBS queues: *routing* and *execution*.

- A routing queue is used only to move jobs to other queues (destination queues). These destination queues can be routing or execution queues, and can be located at different PBS servers. For more information on creating and using routing queues, see section 2.3.6, “Routing Queues”, on page 27.
- An execution queue is used as the home for a waiting or running job. A job must reside in an execution queue to be eligible to run. The job remains in the execution queue during the time it is running. See section 2.3.5, “Execution Queues”, on page 25.

2.3.1.2 Available Kinds of Queues

PBS supplies the following kinds of execution and routing queues:

Table 2-3: Kinds of Queues

Kind of Queue		Description	Link
Routing queues		Used for moving jobs to another queue	See section 2.3.6, “Routing Queues”, on page 27
Execution queues	Reservation queues	Created for reservation. Do not operate on these directly; instead, operate on the reservation.	See section 2.3.5.2.iv, “Reservation Queues”, on page 26
	Dedicated time queues	Holds jobs that run only during dedicated time.	See section 2.3.5.2.i, “Dedicated Time Queues”, on page 26
	Primetime queues	Holds jobs that run only during primetime.	See section 2.3.5.2.ii, “Primetime and Non-Primetime Queues”, on page 26
	Non-primetime queues	Holds jobs that run only during non-primetime.	See section 2.3.5.2.ii, “Primetime and Non-Primetime Queues”, on page 26
	Anytime queues	Queue with no dedicated time or primetime restrictions	See section 2.3.5.2.iii, “Anytime Queues”, on page 26
	Express queues	High-priority queue; priority is set to the level signifying that it is an express queue	See section 2.3.5.3.i, “Express Queues”, on page 26
	Anti-express queue	Low-priority queue designed for work that should run only when no other jobs need the resources	See section 4.9.1, “Anti-Express Queues”, on page 104

2.3.2 Basic Queue Use

The simplest form of PBS uses just one queue. The queue is an execution queue named *workq*. This queue is always created, enabled, and started for you during installation. After a basic installation, this queue is ready to hold jobs submitted by users.

2.3.3 Creating Queues

To create a queue, use the `qmgr` command to create it and set its queue_type attribute:

```
Qmgr: create queue <queue name>
Qmgr: set queue <queue_name> queue_type = <execution or route>
```

For example, to create an execution queue named *exec_queue*, set its type, start it, and enable it:

```
Qmgr: create queue exec_queue
Qmgr: set queue exec_queue queue_type = execution
Qmgr: set queue exec_queue enabled = True
Qmgr: set queue exec_queue started = True
```

Now we will create a routing queue, which will send jobs to our execution queue:

```
Qmgr: create queue routing_queue
Qmgr: set queue routing_queue queue_type = route
Qmgr: set queue routing_queue route_destinations = exec_queue
```

2.3.4 Enabling, Disabling, Starting, and Stopping Queues

When you *enable* a queue, you allow it to accept jobs, meaning that jobs can be enqueued in the queue. When you *disable* a queue, you disallow it from accepting jobs. Queues are disabled by default. You enable a queue by setting its enabled attribute to *True*:

```
Qmgr: set queue <queue name> enabled = True
```

When you *start* a queue, you allow the jobs in the queue to be executed. Jobs are selected to be run according to the scheduling policy. When you *stop* a queue, you disallow jobs in that queue from running, regardless of scheduling policy. Except for the default queue, queues are stopped by default. You start a queue by setting its started attribute to *True*:

```
Qmgr: set queue <queue name> started = True
```

2.3.5 Execution Queues

Execution queues are used to run jobs; jobs must be in an execution queue in order to run. PBS does not route from execution queues.

2.3.5.1 Where Execution Queues Get Their Jobs

By default, PBS allows jobs to be moved into execution queues via the `qmove` command, by hooks, from routing queues, and by being submitted to execution queues. You can specify that an execution queue should accept only those jobs that are routed from a routing queue by PBS, by setting the queue's from_route_only attribute to *True*:

```
Qmgr: set queue <queue name> from_route_only = True
```

2.3.5.2 Execution Queues for Specific Time Periods

PBS provides a mechanism that allows you to specify that the jobs in an execution queue can run only during specific time periods. PBS provides a different kind of execution queue for each kind of time period. The time periods you can specify are the following:

Reservations

You can create an advance, standing, job-specific, or maintenance reservation. See section 4.9.37, “Reservations”, on page 199.

Dedicated time

Dedicated time is a period of time with a defined beginning and end. You can define multiple dedicated times.

Primetime

Primetime is a recurring time period with a defined beginning and end. You can define primetime to be different for each day of the week.

Non-primetime

Non-primetime is a recurring time period with a defined beginning and end. Non-primetime begins when primetime ends, and vice versa.

Holidays

Holidays are dates defined in the `<sched_priv directory>/holidays` file. PBS provides an example file with everything commented out, and you define your own holidays and primetime. Holiday time is treated like non-primetime, meaning jobs in non-primetime queues run during holiday time.

Anytime queue

The term "anytime queue" means a queue that is not a primetime or a non-primetime queue.

2.3.5.2.i Dedicated Time Queues

The jobs in a dedicated time execution queue can run only during dedicated time. Dedicated time is defined in `<sched_priv directory>/dedicated_time`. See section 4.9.10, “Dedicated Time”, on page 127.

To specify that a queue is a dedicated time queue, you prefix the queue name with the dedicated time keyword. This keyword defaults to "*ded*", but can be defined in the dedicated_prefix scheduler parameter in `<sched_priv directory>/sched_config`. See “dedicated_prefix” on page 252 of the PBS Professional Reference Guide.

2.3.5.2.ii Primetime and Non-Primetime Queues

The jobs in a primetime queue run only during primetime, and the jobs in a non-primetime queue run only during non-primetime. Primetime and non-primetime are defined in `<sched_priv directory>/holidays`. See section 4.9.34, “Using Primetime and Holidays”, on page 193.

To specify that a queue is a primetime or non-primetime queue, you prefix the queue name with the primetime or non-primetime keyword. For primetime, this keyword defaults to "*p_*", and for non-primetime, the keyword defaults to "*np_*", but these can be defined in the primetime_prefix and nonprimetime_prefix scheduler parameters in `<sched_priv directory>/sched_config`. See “Scheduler Parameters” on page 251 of the PBS Professional Reference Guide.

2.3.5.2.iii Anytime Queues

An anytime queue is a queue whose jobs can run at any time. An anytime queue is simply a queue that is not a dedicated time, primetime, or non-primetime queue.

2.3.5.2.iv Reservation Queues

When the `pbs_rsub` command is used to create a reservation or to convert a job into a reservation job, PBS creates a reservation queue. Jobs in the queue run only during the reservation. Do not operate on these queues directly; instead, operate on the reservations. See section 4.9.37, “Reservations”, on page 199.

2.3.5.3 Prioritizing Execution Queues

You can set the priority of each execution queue as compared to the other queues in this complex by specifying a value for the priority queue attribute:

```
Qmgr: set queue <queue name> priority = <value>
```

A higher value for priority means the queue has greater priority. There is no limit to the priority that you can assign to a queue, however it must fit within integer size. See “Queue Attributes” on page 313 of the PBS Professional Reference Guide.

For how queue priority is used in scheduling, see section 4.9.36, “Queue Priority”, on page 198.

2.3.5.3.i Express Queues

A queue is an *express queue* if its priority is greater than or equal to the value that defines an express queue. This value is set in the preempt_queue_prio parameter in `<sched_priv directory>/sched_config`. The default value for preempt_queue_prio is *150*.

You do not need to set by_queue to *True* in order to use express queues.

For how express queues can be used, see section 4.9.18, “Express Queues”, on page 139.

2.3.6 Routing Queues

A routing queue is used only to route jobs to other queues; jobs cannot run from a routing queue.

A routing queue has the following properties:

- Can route to multiple destination queues
- For each job, tries destination queues in the order listed, starting at the top of the list.
- Can route to execution queues
- Can route to other routing queues
- Can route to queues in other complexes (at other servers)

Destinations can be specified in the following ways:

```
route_destinations = Q1
route_destinations = Q1@Server1
route_destinations = "Q1, Q2@Server1, Q3@Server2"
route_destinations += Q1
route_destinations += "Q4, Q5@Server3"
```

2.3.6.1 How Routing Works

Whenever a job is in a started routing queue, PBS immediately attempts to route the job to a destination queue. When PBS routes a job, it starts at the top of the destination list and tries each destination in the order listed. The job's destination is the first queue that accepts it. The result is one of the following:

- The job is routed to one of the destination queues.
- The attempt to route is permanently rejected by each destination queue, and the job is deleted.
- Every destination queue rejects the job, but at least one rejection is temporary. In this case, the destination is tried again later, after the amount of time specified in the routing queue's route_retry_time attribute.
- If the job exceeds the time set in the queue's route_lifetime attribute, the job is deleted.

If there are multiple routing queues containing jobs to be routed, the routing queues are processed in the order in which they are displayed in the output of a `qstat -Q` command.

Queue priority does not play a role in routing jobs.

2.3.6.2 Requirements for Routing Queues

- A routing queue's destination queues must be created before being specified in the routing queue's route_destinations attribute.
- A routing queue's route_destinations attribute must be specified before enabling and starting the routing queue.
- A routing queue must be enabled in order to route jobs.

2.3.6.3 Caveats and Advice for Routing Queues

- Avoid routing loops. If a job makes more than 20 routing hops, it is discarded, and PBS sends mail to the job owner if the job's Mail_Points attribute contains "a" for "abort". Avoid setting a routing queue's destination to be the routing queue itself.
- When routing to a complex that is using failover, it's a good idea to include the names of both primary and secondary servers in a routing destination:
  `route_destinations = "destQ@primary_server, destQ@secondary_server"`
- When routing a job between complexes, the job's owner must be able to submit a job to the destination complex.
- When routing to a destination in another complex, the source and destination complexes should use the same version of PBS. If not, you may need a submission hook to modify incoming jobs.
- It is recommended to list the destination queues in order of the most restrictive first, because the first queue which meets the job's requirements and is enabled will be its destination

2.3.6.4 Using Resources to Route Jobs Between Queues

You can use resources to direct jobs to the desired queues. The server will automatically route jobs that are in routing queues, based on job resource requests. The destination queue can be at the local server or at another server. If you have more than one PBS complex, you may want to route jobs between the complexes, depending on the resources available at each complex.

You can set up queues for specific kinds of jobs, for example jobs requesting very little memory, a lot of memory, or a particular application. You can then route jobs to the appropriate queues.

A routing queue tests destination queues in the order listed in the queue's route_destinations attribute. The job is placed in the first queue that meets the job's request and is enabled.

Please read all of the subsections for this section.

2.3.6.4.i How Queue and Server Limits Are Applied, Except Running Time

The following applies to to all resources except for min_walltime and max_walltime.

You can set a minimum and a maximum for each resource at each queue using the resources_min.<resource name> and resources_max.<resource name> queue attributes. Any time a job is considered for entry into a queue, the job's resource request is tested against resources_min.<resource name> and resources_max.<resource name> for that queue. The job's resource request must be greater than or equal to the value specified in resources_min.<resource name>, and less than or equal to the value specified in resources_max.<resource name>.

The job is tested only against existing resources_min.<resource name> and resources_max.<resource name> for the queue.

Only those resources that are specified in the job's resource request are tested, so if a job does not request a particular resource, and did not inherit a default for that resource, the minimum and maximum tests for that resource are not applied to the job.

If you want jobs requesting only a specific value for a resource to be allowed into a queue, set the queue's resources_min.<resource name> and resources_max.<resource name> to the same value. This resource can be numeric, string, string array, or Boolean.

If you limit queue access using a string array, a job must request one of the values in the string array to be allowed into the queue. For example, if you set resources_min.strarr and resources_max.strarr to "blue,red,black", jobs can request `–l strarr=blue`, `-l strarr=red,` or `–l strarr=black` to be allowed into the queue.

2.3.6.4.ii How Queue and Server Running Time Limits are Applied

For shrink-to-fit jobs, running time limits are applied to max_walltime and min_walltime, not walltime. To set a running time limit for shrink-to-fit jobs, you cannot use resources_max or resources_min for max_walltime or min_walltime. Instead, use resources_max.walltime and resources_min.walltime. See section 4.9.42.6, "Shrink-to-fit Jobs and Resource Limits", on page 215.

2.3.6.4.iii Resources Used for Routing and Admittance

You can route jobs using the following kinds of resources:

- Any server-level or queue-level (job-wide) built-in or custom resource, whether it is numeric, string, or Boolean, for example ncpus and software

  When routing jobs with min_walltime and/or max_walltime, PBS examines the values for resources_min.walltime and resources_max.walltime at the server or queue. See section 2.3.6.4.ii, "How Queue and Server Running Time Limits are Applied", on page 29.
- The following built-in chunk-level resources:

  accelerator_memory

  mem

  mpiprocs

  naccelerators

  ncpus

  nodect

  vmem
- Custom vnode-level (chunk-level) resources that are global and have the n, q, or f flags set
- Any resource in the job's Resource_List attribute; see section 5.9.2, "Resources Requested by Job", on page 247. For string or string array resources, see section 2.3.6.4.iv, "Using String, String Array, and Boolean Values for Routing and Admittance", on page 29.

When jobs are routed using a chunk-level resource, routing is based on the sum of that resource across all chunks.

2.3.6.4.iv Using String, String Array, and Boolean Values for Routing and Admittance

When using strings or string arrays for routing or admittance, you can use only job-wide (server-level or queue-level) string or string array resources. String or string array resources in chunks are ignored. The resources_min and resources_max attributes work as expected with numeric values. In addition, they can be used with string and Boolean values to force an exact match; this is done by setting both to the same value. For example, to limit jobs entering queue big to those that specify `arch=unicos8`, or that do not specify a value for arch:

```
Qmgr: set q App1Queue resources_max.software=App1
Qmgr: set q App1Queue resources_min.software=App1
```

2.3.6.4.v Examples of Routing Jobs

You can force all jobs into a routing queue, or you can allow users to request some queues but not others. If you set up the default queue be a routing queue, and make all execution queues accept jobs only from routing queues, all jobs are initially forced into a routing queue.

Alternatively, you can set up one routing queue and a couple of execution queues which accept jobs only from routing queues, but add other queues which can be requested. Or you could allow jobs to request the execution queues, by making the execution queues also accept jobs that aren't from routing queues.

Example 2-1: Jobs can request one execution queue named *WorkQ*. All jobs that do not request a specific queue are routed according to their walltime:

- Create a routing queue *RouteQ* and make it the default queue:

```
Qmgr: create queue RouteQ queue_type = route
Qmgr: set server default_queue = RouteQ
```

- Create two execution queues, *LongQ* and *ShortQ*. One is for long-running jobs, and one is for short-running jobs:

```
Qmgr: create queue LongQ queue_type = execution
Qmgr: create queue ShortQ queue_type = execution
```

- Set resources_min.walltime and resources_max.walltime on these queues:

```
Qmgr: set queue LongQ resources_min.walltime = 5:00:00
Qmgr: set queue ShortQ resources_max.walltime = 4:59:00
```

- For *LongQ* and *ShortQ*, disallow jobs that are not from a route queue:

```
Qmgr: set queue LongQ from_route_only = True
Qmgr: set queue ShortQ from_route_only = True
```

- Set the destinations for *RouteQ* to be *LongQ* and *ShortQ*:

```
Qmgr: set queue RouteQ route_destinations = "ShortQ, LongQ"
```

- Create a work queue that can be requested:

```
Qmgr: create queue WorkQ queue_type = execution
```

- Enable and start all queues:

```
Qmgr: active queue RouteQ,LongQ,ShortQ,WorkQ
Qmgr: set queue enabled = True
Qmgr: set queue started = True
```

- Set default for walltime at the server so that jobs that don't request it inherit the default, and land in *ShortQ*:

```
Qmgr: set server resources_default.walltime = 4:00:00
```

Example 2-2: Jobs are not allowed to request any queues. All jobs are routed to one of three queues based on the job's walltime request:

- Create a routing queue *RouteQ* and make it the default queue:

```
Qmgr: create queue RouteQ queue_type = route
Qmgr: set server default_queue = RouteQ
```

- Create three execution queues, *LongQ*, *MedQ*, and *ShortQ*. One is for long-running jobs, one is for medium jobs, and one is for short-running jobs:

```
Qmgr: create queue LongQ queue_type = execution
Qmgr: create queue MedQ queue_type = execution
Qmgr: create queue ShortQ queue_type = execution
```

- Set resources_min.walltime and resources_max.walltime on these queues:

```
Qmgr: set queue LongQ resources_min.walltime = 10:00:00
Qmgr: set queue MedQ resources_max.walltime = 9:59:00
Qmgr: set queue MedQ resources_min.walltime = 5:00:00
Qmgr: set queue ShortQ resources_max.walltime = 4:59:00
```

- For *LongQ, MedQ,* and *ShortQ*, disallow jobs that are not from a route queue:

```
Qmgr: set queue LongQ from_route_only = True
Qmgr: set queue MedQ from_route_only = True
Qmgr: set queue ShortQ from_route_only = True
```

- Set the destinations for *RouteQ* to be *LongQ*, *MedQ* and *ShortQ*:
```
Qmgr: set queue RouteQ route_destinations = "ShortQ, MedQ, LongQ"
```
- Enable and start all queues:
```
Qmgr: active queue RouteQ,LongQ,ShortQ,MedQ
Qmgr: set queue enabled = True
Qmgr: set queue started = True
```

2.3.6.4.vi Caveats for Queue Resource Limits

If a job is submitted without a request for a particular resource, and no defaults for that resource are set at the server or queue, and either the server or queue has resources_max.<resource name> set, the job inherits that maximum value. If the queue has resources_max.<resource name> set, the job inherits the queue value, and if not, the job inherits the server value.

2.3.6.5 Using Access Control to Route Jobs

You can route jobs based on job ownership by setting access control limits at destination queues. A queue's access control limits specify which users or groups are allowed to have jobs in that queue. Default behavior is to disallow an entity that is not listed, so you need only list allowed entities.

To set the list of allowed users at a queue:
```
Qmgr: set queue <queue name> acl_users = "User1@*.example.com, User2@*.example.com"
```
To enable user access control at a queue:
```
Qmgr: set queue <queue name> acl_user_enable = True
```
To set the list of allowed groups at a queue:
```
Qmgr: set queue <queue name> acl_groups = "Group1, Group2"
```
To enable group access control at a queue:
```
Qmgr: set queue <queue name> acl_group_enable = True
```
For a complete explanation of access control, see section 8.3, “Using Access Control Lists”, on page 364.

2.3.6.6 Allowing Routing of Held or Waiting Jobs

By default, PBS will not route jobs that are held. You can allow a routing queue to route held jobs by setting the queue's route_held_jobs attribute to *True*:
```
Qmgr: set queue <queue name> route_held_jobs = True
```
By default, PBS will not route jobs whose execution_time attribute has a value in the future. You can allow a routing queue to route jobs whose start time is in the future by setting the queue's route_waiting_jobs attribute to *True*:
```
Qmgr: set queue <queue name> route_waiting_jobs = True
```

2.3.6.7 Setting Routing Retry Time

The default time between routing retries is 30 seconds. To set the time between routing retries, set the value of the queue's route_retry_time attribute:
```
Qmgr: set queue <queue name> route_retry_time = <value>
```

2.3.6.8 Specifying Job Lifetime in Routing Queue

By default, PBS allows a job to exist in a routing queue for an infinite amount of time. To change this, set the queue's *route_lifetime* attribute:

```
Qmgr: set queue <queue name> route_lifetime = <value>
```

2.3.7 Queue Requirements

- Each queue must have a unique name. The name must be alphanumeric, and must begin with an alphabetic character
- A server may have multiple queues of either or both types, but the server must have at least one execution queue defined.

2.3.8 Queue Configuration Attributes

Queue configuration attributes fall into three groups:

- Those which apply to both types of queues
- Those which apply only to execution queues
- Those which apply only to routing queues

If an "execution queue only" attribute is set for a routing queue, or vice versa, it is ignored. However, as this situation might indicate the administrator made a mistake, the server will write a warning message on `stderr` about the conflict. The same message is written when the queue type is changed and there are attributes that do not apply to the new type.

See “Queue Attributes” on page 313 of the PBS Professional Reference Guide for a table of queue attributes.

2.3.9 Viewing Queue Status

To see the status of a queue, including values for attributes, use the `qstat` command:

```
qstat -Qf <queue name>
```

To see the status of all queues:

```
qstat -Qf
```

The status of the queue is reported in the *State* field. The field shows two letters. One is either *E* (enabled) or *D* (disabled.) The other is *R* (running, same as started) or *S* (stopped.) Attributes with non-default values are displayed. See “qstat” on page 198 of the PBS Professional Reference Guide.

The following queue attributes contain queue status information:

total_jobs
state_count
resources_assigned
hasnodes
enabled
started

2.3.10 Deleting Queues

Use the `qmgr` command to delete queues.

```
Qmgr: delete queue <queue name>
```

2.3.10.1 Caveats for Deleting Queues

- A queue that has queued or running jobs cannot be deleted.
- The vnode queue attribute is **deprecated**. A queue that is associated with a vnode via that vnode's queue attribute cannot be deleted. To remove the association, save the output of `pbsnodes -a` to a file and search for the queue. Unset the queue attribute for each associated vnode.

2.3.11 Defining Queue Resources

For each queue, you can define the resources you want to have available at that queue. To set the value for an existing resource, use the `qmgr` command:

```
Qmgr: set queue <queue name> resources_available.<resource name> = <value>
```

For example, to set the value of the Boolean resource RunsMyApp to *True* at *QueueA*:

```
Qmgr: set queue QueueA resources_available.RunsMyApp = True
```

For information on how to define a new resource at a queue, see section 5.14, “Custom Resources”, on page 257.

For information on defining default resources at a queue, see section 5.9.3.3, “Specifying Job-wide Default Resources at Queue”, on page 248 and section 5.9.3.2.ii, “Specifying Chunk Default Resources at Queue”, on page 248.

2.3.12 Setting Queue Resource Defaults

The jobs that are placed in a queue inherit the queue's defaults for any resources not specified by the job's resource request. You can specify each default resource for each queue. This is described in section 5.9.3, “Specifying Job Default Resources”, on page 247. Jobs inherit default resources according to the rules described in section 5.9.4, “Allocating Default Resources to Jobs”, on page 249.

2.3.13 How Default Server and Queue Resources Are Applied When Jobs Move

When a job is moved from one server to another, the following changes happen:

- Any default resources that were applied by the first server are removed
- Default resources from the new server are applied to the job

When a job is moved from one queue to another, the following changes happen:

- Any default resources that were applied by the first queue are removed
- Default resources from the new queue are applied to the job

For more details on how default resources are inherited when a job is moved, see section 5.9.4.3, "Moving Jobs Between Queues or Servers Changes Defaults", on page 250.

2.3.14 Specifying Default Queue

PBS has a default execution queue named *workq*, where jobs are placed when no queue is requested. You can specify which queue should be the default. To specify the queue which is to accept jobs when no queue is requested, set the server's default_queue attribute to the name of the queue:

```
Qmgr: set server default_queue = <queue name>
```

2.3.15 Associating Queues and Vnodes

You can set up vnodes so that they accept jobs only from specific queues. See section 4.9.2, "Associating Vnodes with Queues", on page 105.

2.3.16 Configuring Access to Queues

You can configure each queue so that only specific users or groups can submit jobs to the queue. See section 8.3, "Using Access Control Lists", on page 364.

2.3.17 Setting Limits on Usage at Queues

You can set limits on different kinds of usage at each queue:

- You can limit the size of a job array using the max_array_size queue attribute
- You can limit the number of jobs or the usage of each resource by each user or group, or overall. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290

2.3.18 Queues and Failover

For information on configuring routing queues and failover, see section 9.2.6.1, "Configuring Failover to Work with Routing Queues", on page 417.

2.3.19 Additional Queue Information

For a description of each queue attribute, see "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

For information on using queues for scheduling, see section 4.6, "Using Queues in Scheduling", on page 100.

3
Configuring MoMs and Vnodes

3.1 About MoMs

A MoM runs and manages the jobs on each execution host. The `pbs_mom` daemon starts jobs on the execution host, monitors and reports resource usage, enforces resource usage limits, manages job file transfer, and notifies the server when the job is finished. When the MoM starts a job, she creates a new session that is as identical to the user's login session as is possible. For example, under Linux, if the user's login shell is `csh`, then MoM creates a session in which `.login` and `.cshrc` are run. MoM returns the job's output to the user. The MoM performs any communication with job tasks and with other MoMs. The MoM on the first vnode on which a job is running manages communication with the MoMs on the remaining vnodes on which the job runs. The MoM on the first vnode is called the *primary execution host MoM*.

The MoM writes a log file in `PBS_HOME/mom_logs`. The MoM writes an error message in its log file when it encounters any error. The MoM also writes other miscellaneous information to its log file. If it cannot write to its log file, it writes to standard error.

You start a MoM via the `pbs_mom` command. The executable for `pbs_mom` is in `PBS_EXEC/sbin`, and can be run only by root. For Linux, see "MoMs: Starting, Stopping, Restarting" on page 166 in the PBS Professional Installation & Upgrade Guide, and for Windows, see "MoMs: Starting, Stopping, Restarting" on page 172 in the PBS Professional Installation & Upgrade Guide.

The MoM also runs any prologue scripts before the job runs, and runs any epilogue scripts after the job runs.

PBS supplies a hook that you can use to manage cgroups on each execution host, and via the hook, cpusets. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573. If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

3.1.1 Configuring MoMs

3.1.1.1 MoM Configuration File

During the installation process, PBS creates a Version 1 configuration file for each MoM. Each parameter in this file controls some aspect of MoM's behavior. To configure MoM's behavior, edit this file, and set each parameter as desired.

The default location for the Version 1 configuration file is on MoM's host, in `PBS_HOME/mom_priv/config`, or if `PBS_MOM_HOME` is defined, `PBS_MOM_HOME/mom_priv/config`. It can be in a different location; in that case, MoM must be started with the `-c` option. See "pbs_mom" on page 72 of the PBS Professional Reference Guide.

If you add or change anything via a Version 1 configuration file, you can HUP the MoM, but if you remove anything, you must restart the MoM so that the default value is re-applied.

The Version 1 configuration file must be secure. It must be owned by a user ID and group ID both less than 10 and must not be world-writable.

For a complete description of the syntax and contents of the Version 1 configuration file, see "MoM Parameters" on page 241 of the PBS Professional Reference Guide.

3.1.1.2 Editing Version 1 Files

Use your favorite text editor to edit Version 1 configuration files.

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

3.1.1.3 Caveats and Restrictions for Configuration Files

- The `pbs_mom -d` option changes where MoM looks for `PBS_HOME`, and using this option will change where MoM looks for all configuration files. If you use the `-d` option, MoM will look in the new location for all MoM and vnode configuration files. Instead, we recommend setting the location of `PBS_HOME` or `PBS_MOM_HOME` in `/etc/pbs.conf` on MoM's host.
- When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

3.1.1.4 When MoM Reads Configuration Files

MoM reads `pbs.conf` at startup, and her own configuration files at startup and reinitialization. On Linux, this is when `pbs_mom` receives a `SIGHUP` signal or is started or restarted, and on Windows, when MoM is started or restarted.

If you make changes to the hardware or a change occurs in the number of CPUs or amount of memory that is available to PBS, such as a non-PBS process releasing a cpuset, you should restart PBS, by typing the following:

```
<path-to-script>/pbs restart
```

The MoM daemon is normally started by the PBS start/stop script.

When MoM is started, it opens its Version 1 configuration file, `mom_priv/config`, in the path specified in `pbs.conf`, if the file exists. If it does not, MoM will continue anyway. The `config` file may be placed elsewhere or given a different name, by starting `pbs_mom` using the `-c` option with the new file and path specified. See “MoMs: Starting, Stopping, Restarting” on page 172 in the PBS Professional Installation & Upgrade Guide.

The files are processed in this order:

1. Version 1 configuration file
2. PBS reserved configuration files
3. Version 2 configuration files

Within each category, the files are processed in lexicographic order.

The contents of a file that is read later will override the contents of a file that is read earlier.

If there is an error in `mom_priv/config`, MoM will not start.

3.1.2 Configuring MoM Polling Cycle

3.1.2.1 Cgroups Hook Can Replace Polling

The cgroups hook (see Chapter 16, "Configuring and Using PBS with Cgroups", on page 573) can provide accurate accounting information and job resource usage management, so that MoM does not need to perform periodic job resource usage polling. If you use the cgroups hook to manage jobs at a host, MoM does not need to poll throughout the life of the job, and the server and the datastore experience less traffic.

Each time a MoM polls, the server rewrites all of the job's data to the datastore, causing traffic to the data store. If you have smaller jobs, MoM needs to poll often in order to get reasonably accurate information. If you have many of these jobs, this slows the server and reduces throughput.

Each job is always polled at the start and end, regardless of periodic polling. MoM polls at job end, before running the epilogue, when she detects that the last job task is done. If the job was spawned with `tm_spawn`, MoM can get an accurate value for cput. If the job was `tm_attached` and the cgroups hook is not running on the host, she cannot get an accurate value for cput, because a process other than MoM reaped the job. For example, if memory is reaped by something other than MoM, there is no way to get usage. However, if the cgroups hook is managing that job, the hook can get accurate usage.

If the cgroups hook manages the jobs at a host, MoM does not need to do any periodic job polling at that host.

3.1.2.2 Polling on Linux

MoM's polling cycle is determined by the values of $min_check_poll and $max_check_poll in the Version 1 configuration file. The interval between each poll starts at $min_check_poll and increases with each cycle until it reaches $max_check_poll, after which it remains the same. The amount by which the cycle increases is the following:

(max_check_poll - min_check_poll + 19) / 20

The default value for $max_check_poll is 120 seconds. The minimum is 1 second.

The default value for $min_check_poll is 10 seconds. The minimum is 1 second.

The start of a new job resets the polling for all of the jobs being managed by this MoM.

MoM polls for resource usage for cput, walltime, mem and ncpus.

3.1.2.2.i Linux Polling Caveats

Please note that polling intervals cannot be considered to be exact:

- The polling calculation simply provides a minimum amount of time between one poll and the next.
- The actual time between polls can vary. The actual time taken by MoM also depends on the other tasks MoM is performing, such as starting jobs, running a prologue or epilogue, etc.
- The timing of MoM's activities is not completely under her control, because she is a user process.
- The finest granularity for calculating polling is in seconds.

3.1.2.3 Polling on Windows

On Windows, MoM updates job usage at fixed intervals of 10 seconds. The $min_check_poll and $max_check_poll parameters are not used by MoM on Windows. MoM looks for any job that has exceeded a limit for walltime, mem, or cput, and terminates jobs that have exceeded the limit.

3.1.2.4 How Polling is Used

- Job-wide limits are enforced by MoM using polling. See section 5.15.2.4.i, "Job Memory Limit Enforcement on Linux", on page 309. MoM can enforce cpuaverage and cpuburst resource usage. See section 5.15.2.5.i, "Average CPU Usage Enforcement", on page 310 and section 5.15.2.5.ii, "CPU Burst Usage Enforcement", on page 311.
- MoM enforces the $restrict_user access restrictions on the polling cycle controlled by $min_check_poll and $max_check_poll. See section 15.4.7, "Restricting User Access to Execution Hosts", on page 558.
- Cycle harvesting has its own polling interval. See "$kbd_idle <idle wait> <min use> <poll interval>" on page 245 of the PBS Professional Reference Guide for information on $kbd_idle.

3.1.2.5 Polling for Multi-host Jobs

Polling cycles are different on the primary execution host MoM and sister MoMs.

- The primary execution host MoM polls immediately when a task is started and again after the minimum polling period, then continues polling at each maximum polling period
- Sister MoMs poll a full cycle after the first task is created there

3.1.2.6 Recommendations for Polling Interval

Consider the workload at the host, and the overall workload at the server, when you set polling intervals. MoM's polling period should depend on the length of the typical job, and the importance for your site of accurate accounting. If you have many small jobs, frequent polling can take up a lot of MoM's cycles, and cause heavy traffic for the datastore and the server.

You may want to set $min_check_poll and $max_check_poll to somewhat higher values than the defaults. For example, for a 1-hour job, you could poll at 10-minute intervals. We do not recommend a value for $max_check_poll of less than 30 seconds. We do not recommend setting $min_check_poll to less than 10 seconds.

3.1.3 Files and Directories Used by MoM

If PBS_MOM_HOME is present in the `pbs.conf` file, `pbs_mom` will use that directory for its "home" instead of `PBS_HOME`.

3.1.3.1 Linux Files and Directories Used by MoM

Under Linux, all files and directories that MoM uses must be owned by root. MoM uses the following files and directories:

Table 3-1: MoM Files and Directories Under Linux

File/Directory	Description	Permissions
`/etc/pbs.conf`	File	*0644*
`aux`	Directory	*0755*
`checkpoint`	Directory	*0700*
checkpoint script	File	*0755*
`mom_logs`	Directory	*0755*
`mom_priv`	Directory	*0751*
`mom_priv/jobs`	Directory	*0751*
`mom_priv/config`	File	*0644*
mom_priv/prologue	File	*0755*
mom_priv/epilogue	File	*0755*
`pbs_environment`	File	*0644*
`spool`	Directory	*1777 (drwxrwxrwt)*
`undelivered`	Directory	*1777 (drwxrwxrwt)*

Table 3-1: MoM Files and Directories Under Linux

File/Directory	Description	Permissions
Version 2 configuration files (optional)	Files	*0755*
PBS reserved configuration files	Files	----
Job temporary directory	Directory	*1777*

3.1.3.2 Linux Files and Directories Used by MoM

Under Windows, these directories must have at least Full Control permission for the local Administrators group. MoM uses the following files and directories:

Table 3-2: MoM Files and Directories Under Windows

File/Directory	Description	Ownership/Permission
`pbs.conf`	File	
`auxiliary`	Directory	At least Full Control permission for the local Administrators group and read-only access to Everyone
checkpoint	Directory	At least Full Control permission for the local Administrators group
checkpoint script	File	At least Full Control permission for the local Administrators group
`mom_logs`	Directory	At least Full Control permission for the local Administrators group and read-only access to Everyone
`mom_priv`	Directory	At least Full Control permission for the local Administrators group and read-only access to Everyone
`mom_priv/jobs`	Directory	At least Full Control permission for the local Administrators group and read-only access to Everyone
`mom_priv/config`	File	At least Full Control permission for the local Administrators group
`pbs_environment`	File	At least Full Control permission for the local Administrators group and read-only to Everyone
`spool`	Directory	Full access to Everyone
`undelivered`	Directory	Full access to Everyone
Job's temporary directory	Directory	Writable by Everyone

3.2 About Vnodes: Virtual Nodes

A virtual node, or *vnode*, is an abstract object representing a set of resources which form a usable part of a machine. This could be an entire host, a NUMA node, a nodeboard, or a blade. A single host can be represented by one vnode or multiple vnodes. PBS views hosts as being composed of one or more vnodes, and PBS can manage and schedule each vnode independently. One PBS MoM manages all of the vnodes for each host.

3.2.1 Parent Vnodes and Child Vnodes

Each machine is represented by at least one vnode. The main vnode is called the *parent vnode*. Vnodes that represent machine resources such as CPUs are called *child vnodes*.

For single-vnode machines, the parent vnode is also the child vnode, and this vnode represents all of the machine's resources, including its hardware.

For machines with more than one vnode, the parent vnode does not correspond to any actual hardware; instead, it is a collection of information that applies to the host but not the individual vnodes, such as dynamic host-level resources and shared resources. On multi-vnode machines, resources such as CPUs are represented in child vnodes.

3.3 Creating Vnodes

3.3.1 Overview of Creating Vnodes

1. For each machine, you create one parent vnode using `qmgr`. See "Creating the Parent Vnode" on page 42.

   For a single-vnode machine, vnode creation is done.

2. For a machine which will have more than one vnode, after you create the parent vnode, PBS handles creation of the child vnodes:
   - If you run the cgroups hook with vnode_per_numa_node set to *true*, the cgroups hook creates all the local child vnodes. We recommend using the cgroups hook for hosts where you need to fence jobs in or take advantage of the topology to keep job processes on nearby resources. See "Creating Child Vnodes via Cgroups Hook" on page 42.
   - If you are not using the cgroups hook to create child vnodes, you can have PBS create any child vnodes. You tell MoM which vnodes to create and how to set their attributes and resources by specifying them in a Version 2 configuration file. See "Creating Child Vnodes via Version 2 Configuration File" on page 42.

3. After all vnodes have been created, you can set vnode attributes and resources if necessary. See "Configuring Vnodes" on page 43.

3.3.1.1 Overview of Creating Vnodes on Cray XC

On the Cray XC, you create the parent vnode for each login node and MAMU node. After that, MoM creates any child vnodes.

3.3.2 How to Choose Vnode Names

MoM needs to know what name you will use for the parent vnode when she starts up. So if you decide to use a non-default name, define the name before starting MoM.

By default, the cgroups hook and MoM use the non-canonicalized hostname returned by `gethostname()` for the host as the vnode name. If you use the hostname, use the part before the first dot. You can use the `hostname()` command without any extra flags to get the hostname:

```
hostname<return>
```

For example, if this returns "myhost.mydomain", use "myhost".

You can choose the name for the parent vnode, such as an alias, or a name bound to another IP address on the host.

Except for Cray XC, you can use the IP address as the name of the parent vnode.

To use any parent vnode name that is not the default, you must specify the name by setting the PBS_MOM_NODE_NAME parameter in the host's `/etc/pbs.conf`. For example, if you use a name that has a dot in it and you don't set PBS_MOM_NODE_NAME, hooks will fail.

If you've already started MoM, then in order for MoM to be able to use the non-default name, you need to make the name available to her, then restart her. For example, to use the IP address:

1. Add `PBS_MOM_NODE_NAME=<IP address>` to `pbs.conf` on the execution host
2. Restart MoM

When PBS_MOM_NODE_NAME is defined, MoM performs a sanity check to ensure that the value is a resolvable host.

3.3.2.1 Names of Child Vnodes

If the cgroups hook creates child vnodes, it creates them with the same name as the parent vnode, with an index number. For example, on a machine with two NUMA nodes where each NUMA node is represented by a vnode, you'll have the parent vnode plus two child vnodes; if the parent vnode is named "myhost", they are named "myhost[0]" and "myhost[1]".

If you create child vnodes via a Version 2 configuration file, each vnode in your complex must have a unique name within the complex. We recommend using or at least including the name of the parent vnode, to ensure uniqueness and to make vnodes recognizable. Do not use square brackets for anything but the index.

3.3.2.2 Caveats for Vnode Names

- Do not change the name of the parent vnode after you create it
- If there is a dot in the name, you must set resources_available.host by hand; otherwise the part after the dot is stripped
- If you use an IP address as the name of a vnode, you must set it in PBS_MOM_NODE_NAME
- On Cray XC, you cannot use the IP address as the name of the vnode
- You cannot use a vnode attribute as the name of a vnode
- Vnode names are case-insensitive
- If you create a vnode with a different name from the short name returned by hostname, and you don't set it in PBS_MOM_NODE_NAME, the following happens:
  - MoM creates a vnode whose name is the short name returned by `hostname()`
  - The vnode you created is not recognized by MoM, and is marked stale

3.3.2.3 Errors and Logging for Vnode Names

- If PBS_MOM_NODE_NAME is unset and the call to `gethostname()` fails, or if PBS_MOM_NODE_NAME is set and the value does not conform to RFCs 952 and 1123, the following message is printed to the MoM log:
  ```
  Unable to obtain my host name
  ```
- Once the hostname is obtained, MoM ensures the hostname resolves properly. If the hostname fails to resolve, the following message is printed to the MoM log:
  ```
  Unable to resolve my host name
  ```

3.3.3 Creating the Parent Vnode

1. Make sure MoM can look up the name of the parent vnode when she starts. Follow the rules in section 3.3.2, "How to Choose Vnode Names", on page 40. Choose the name for the parent vnode:
   - If you will use the default, make sure that PBS_MOM_NODE_NAME is not set, or set it to the default. To get the default name, run this at MoM's host, and use the part before the dot:

     ```
     hostname<return>
     ```
   - If you will use a non-default name, set it in PBS_MOM_NODE_NAME in `/etc/pbs.conf` on the MoM host. For example, to use the IP address for the name of the vnode, add this to `/etc/pbs.conf` on the execution host:

     ```
     PBS_MOM_NODE_NAME=<IP address>
     ```
2. Start MoM using `systemd` or the PBS start/stop script:

   ```
   systemctl start pbs
   ```

   or

   ```
   <path to script>/pbs start
   ```

   For details on starting and stopping MoM, see "Methods for Starting, Stopping, or Restarting PBS" on page 160 in the PBS Professional Installation & Upgrade Guide.
3. Use the `qmgr` command to create the parent vnode:

   ```
   qmgr -c 'create node <vnode name> [<attribute>=<value>]'
   ```

   All comma-separated attribute-value strings must be enclosed in quotes:

   ```
   qmgr -c 'create node <vnode name> ["<attribute>=<value>, <attribute>=<value>"]'
   ```

   Attributes and their possible values are listed in "Vnode Attributes" on page 322 of the PBS Professional Reference Guide.

3.3.4 Creating Child Vnodes for Multi-vnode Machines

3.3.4.1 Creating Child Vnodes via Cgroups Hook

If you are running the cgroups hook with vnode_per_numa_node set to *true*, the hook creates the local child vnodes.

1. If you have not done so yet, create the parent vnode; see Chapter 3, "Creating the Parent Vnode", on page 42.
2. Configure and enable the cgroups hook. Follow all the instructions in Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.
3. Restart the MoM:

   ```
   <path to PBS start/stop script>/pbs restart
   ```

   or

   ```
   systemctl restart pbs
   ```

3.3.4.2 Creating Child Vnodes via Version 2 Configuration File

1. If you have not done so yet, create the parent vnode; see Chapter 3, "Creating the Parent Vnode", on page 42.
2. If you are not using the cgroups hook, you can create any child vnodes by defining the child vnodes you want in a Version 2 configuration file, so MoM creates the vnodes for you.

Note that in prior versions of PBS, a Version 2 configuration file was the preferred method for advanced GPU configuration (see "Advanced GPU Scheduling" on page 287). As of version 2020.1, the cgroups hook makes it much easier for job submitters to request exclusive use of GPUs. However, if you want to continue to use Version 2 configuration files for managing GPUs, you can do so.

See section 3.4.3.1, "Creating Version 2 Configuration Files", on page 45.

3. Restart the MoM:

```
<path to PBS start/stop script>/pbs restart
```

or

```
systemctl restart pbs
```

4. Check for stale vnodes. Make sure you spell "Stale" with a capital S:

```
qmgr -c 'print node @default' | grep "Stale"
```

3.3.5 Caveats for Creating Vnodes

When using `qmgr` to create vnodes, create only the parent vnode on each host. Do not use `qmgr` to create child vnodes on a multi-vnode host; MoM will not know about these, and cannot use them.

3.4 Configuring Vnodes

Each vnode has an associated set of attributes and resources, such as CPUs, memory, and partition. Vnode attributes are listed and described in "Vnode Attributes" on page 322 of the PBS Professional Reference Guide. Vnode resources can be built-in or custom (defined by you.) See Chapter 5, "Using PBS Resources", on page 231.

3.4.1 Methods for Configuring Vnodes

You may need to configure vnodes after you create them. You can use the following methods:

- Using exechost_startup hooks to set vnode attributes and resources

  This method is powerful and flexible. You can interrogate the host; for example, you can check whether a vnode exists before setting values for it. You can use this to set the sharing attribute and resources_available.host. If the cgroups hook creates your vnodes, make sure that the cgroups hook runs before the hook that configures the vnodes. Your exechost_startup hooks run when MoM is restarted. See "Setting and Unsetting Vnode Resources and Attributes" on page 48 in the PBS Professional Hooks Guide.

- Using Version 2 vnode configuration files, either to modify vnodes created by the cgroups hook, or to tell MoM to create the vnodes you specify. See section 3.4.3, "Version 2 Vnode Configuration Files", on page 44.

  Make sure that a Version 2 configuration file matches your available vnodes every time MoM is started. If your machine reboots with a missing blade, your earlier placement set information will not make sense because child vnode names will not match the available hardware. You can use a script to regenerate this file each time the machine starts, and run the script before MoM is restarted.

  You can use a Version 2 configuration file to set the sharing attribute and the value of resources_available.host (you cannot set these via `qmgr`).

  An advantage of using a Version 2 configuration file is that if you delete and re-create the parent vnode, you don't have to re-create this file. MoM automatically picks up everything in a Version 2 configuration file, whereas if you use `qmgr` you have to re-run all your configuration commands.

If you use the cgroups hook to create child vnodes, and you want to modify these child vnodes, make sure you create the Version 2 configuration file after the vnodes are created, and that you use the exact vnode names that the cgroups hook knows about, by checking the output of `pbsnodes -av`.

If you set a value using `qmgr`, this value overrides the existing value, and you cannot change the value using another method, such as a Version 2 configuration file. If you want to use a different method to set a value that has been set via `qmgr`, use `qmgr` to unset the value, then HUP the MoM.

Version 2 configuration files are read when MoM is restarted. See section 3.4.3, “Version 2 Vnode Configuration Files”, on page 44.

- Using the `qmgr` command to set vnode attribute and resource values

  You can easily use `qmgr` to set values across your complex. You cannot use this to set the sharing attribute or resources_available.host. If you delete and re-create a vnode, the effects of your configuration commands are lost. Changes take place immediately. See “qmgr” on page 150 of the PBS Professional Reference Guide.

- Using the `pbsnodes -o` or `pbsnodes -r` command to mark all vnodes on a host as offline or not offline

  You must use `qmgr` to change the state of a single vnode in a multi-vnode host. Changes take place immediately. See “pbsnodes” on page 36 of the PBS Professional Reference Guide.

3.4.2 Rules for Configuring Vnodes

- If you are using the cgroups hook to create child vnodes and manage subsystems, do not change attribute or resource values that are set by the cgroups hook.
- To set the sharing attribute or resources_available.host, you must use an exechost_startup hook or a Version 2 configuration file. You cannot use `qmgr`. See section 3.4.4, “Configuring the Vnode Sharing Attribute”, on page 48.
- Set the Mom attribute for the parent vnode only. You can set the initial value only via `qmgr -c 'create node <vnode name>'` to tell the server at what IP address MoM is located. The server will later update it based on the MoM's response. The server only queries for the canonicalized address of the MoM host, unless you let it know via the Mom attribute; if you have set PBS_LEAF_NAME in `/etc/pbs.conf` to something else, make sure you set the Mom attribute at vnode creation.

3.4.2.1 Rules for Configuring Vnodes on Cray XC

- On Cray XC, we recommend using an exechost_startup hook instead of a Version 2 configuration file; the inventory hook will detect any inconsistency and send a HUP to MoM.
- On Cray XC compute nodes, never change the sharing attribute.
- We do not recommend using Version 2 configuration files on Cray XC. A Version 2 configuration file on ALPS can interfere with the mechanism whereby ALPS updates PBS. For example, changes to node state will make vnodes stale. On Cray XC machines, compute nodes are not hosts; they are only vnodes, which means that they become *stale* and not *down* when ALPS marks them no longer available to PBS. Mentioning such stale nodes in Version 2 configuration files would interfere with this mechanism.

3.4.3 Version 2 Vnode Configuration Files

Version 2 configuration files contain settings for vnode attributes and resources. For example, to change the sharing vnode attribute or resources_available.host, you can use a Version 2 configuration file, or an exechost_startup hook, but not `qmgr`. You can use more than one Version 2 configuration file per host, but make sure they do not conflict.

PBS places Version 2 configuration files in an area that is private to each installed instance of PBS.

It's best to automate updates to Version 2 configuration files so that they are created at boot time to match available hardware, because a change in hardware may create a mismatch with an old Version 2 configuration file. This ensures that a Version 2 configuration file matches your available hardware every time MoM is started. If your machine reboots with a missing blade, your earlier placement set information will not make sense because child vnode names will be not match the available hardware. You can use a script to regenerate this file each time the machine starts, and run the script before MoM is restarted.

An advantage of using a Version 2 configuration file is that if you delete and re-create the parent vnode, you don't have to re-create this file. MoM automatically picks up everything in a Version 2 configuration file, whereas if you use `qmgr` you have to rerun all your configuration commands.

3.4.3.1 Creating Version 2 Configuration Files

Version 2 configuration files are created by PBS, through a process where you write a source file and then PBS copies it to the location where Version 2 files are used. Instead of editing one of these directly, you create an input file and give it as an argument to the `pbs_mom -s insert` option on the local host (`pbs_mom -N -s insert` on Windows), and PBS creates a new configuration file for you.

You use the `pbs_mom -s insert` command to create Version 2 configuration files. On Windows, use the `pbs_mom` command in standalone mode: `pbs_mom -N -s insert.`

First, you create an input file which is to be the contents of the configuration file. Then, you use the `pbs_mom -s insert` command, on the host you want to configure:

Linux:

pbs_mom -s insert <Version 2 configuration file> <input file name>

Windows:

pbs_mom -N -s insert <Version 2 configuration file> <input file name>

After you create the new Version 2 configuration file, restart the MoM.

3.4.3.1.i Syntax of Version 2 Configuration Files

In a Version 2 configuration file, you tell PBS that it's a Version 2 MoM configuration file by putting a special tag on the first line:

```
$configversion 2
```

The rest of the file describes vnodes, with one attribute specification per line.

The format of the remaining contents of the file is the following:

<vnode name> : <attribute name> = <attribute value>

where

<vnode name>

Sequence of characters not including a colon (":"). The vnode name must be unique in this PBS complex. Vnode names are case-insensitive. See "Vnode Name" on page 360 of the PBS Professional Reference Guide.

If you're modifying vnodes created by the cgroups hook, the *vnode name* must exactly match the output of `pbsnodes -av`.

<attribute name>

Name of the attribute being specified. See "Attribute Name" on page 355 of the PBS Professional Reference Guide.

<attribute value>

Value being specified. Sequence of characters not including an equal sign ("="). See "Resource Formats" on page 361 of the PBS Professional Reference Guide.

White space around the colon and equal sign is ignored.

In a Version 2 configuration file, do not use quotes around string array values. This is different from using the `qmgr` command; in the `qmgr` command line, you need to put quotes around the value.

Make sure that the first vnode entry is for the parent vnode. If you don't need to set anything, you can set the ntype attribute to "PBS" (the default).

Make sure that there is a newline at the end of the file. Under Windows, the Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

Make sure that entries do not conflict, whether within one file or multiple files.

Do not use Version 1 (MoM configuration file) syntax or contents in Version 2 files, and vice versa.

3.4.3.1.ii Example of Creating Version 2 Configuration File

Example 3-1: If your machine named "myhost" has 4 vnodes, where two are big (myhost[0] and myhost[1]), and two are small (myhost[2] and myhost[3]), and you want big jobs to have exclusive use of myhost[0] and myhost[1], and small jobs to share myhost[2] and myhost[3]:

a. Set sharing for big and small vnodes by creating a file "`set_sharing`" containing the following:

```
$configversion 2
myhost: ntype = PBS
myhost[0]: sharing = default_excl
myhost[0]: resources_available.nodetype=big
myhost[1]: sharing = default_excl
myhost[1]: resources_available.nodetype=big
myhost[2]: sharing = default_shared
myhost[2]: resources_available.nodetype=small
myhost[3]: sharing = default_shared
myhost[3]: resources_available.nodetype=small
```

b. Use the `pbs_mom -s insert <filename> <script>` option at myhost to create its configuration file:

Linux:

```
pbs_mom -s insert sharing_config set_sharing
```

Windows:

```
pbs_mom -N -s insert sharing_config set_sharing
```

PBS creates the new Version 2 configuration file called "sharing_config". Its contents will override previously-read sharing settings.

c. Restart the MoM after changing the configuration file:

Linux:

```
kill -INT <MoM PID>
PBS_EXEC/sbin/pbs_mom
```

or

```
systemctl restart pbs
```

or

```
<path to start/stop script>/pbs restart
```

Windows:

```
net stop pbs_mom
net start pbs_mom
```

Jobs can then request `nodetype = big` or `nodetype=small`, or you can use a hook to route jobs, etc.

3.4.3.2 Listing and Viewing Version 2 Configuration Files

You can list and view the Version 2 configuration files at each host.

To see the list of Version 2 configuration files:

Linux:

```
pbs_mom -s list
```

Windows:

```
pbs_mom -N -s list
```

To display the contents of a Version 2 configuration file:

Linux:

```
pbs_mom -s show <filename>
```

Windows:

```
pbs_mom -N -s show <filename>
```

See "pbs_mom" on page 72 of the PBS Professional Reference Guide.

3.4.3.3 Moving Version 2 Configuration Files

To move a set of Version 2 configuration files from one MoM host to another:

1. List the Version 2 files at the source instance:
   ```
   pbs_mom -s list
   ```
2. Save a copy of each file at the source instance:
   ```
   pbs_mom -s show <V2 filename> > <new input file>
   ```
3. Create the new Version 2 configuration files at the destination host. For each file:
   ```
   pbs_mom -s insert <Version 2 file> <new input file>
   ```

3.4.3.4 Removing Version 2 Configuration Files

You can remove a Version 2 configuration file:

Linux:

```
pbs_mom -s remove <filename>
```

Windows:

```
pbs_mom -N -s remove <filename>
```

See "pbs_mom" on page 72 of the PBS Professional Reference Guide.

3.4.3.5 Caveats for Version 2 Configuration Files

- If you are using the cgroups hook to create child vnodes at a host, and you use a Version 2 configuration file to modify those child vnodes:
  - Make sure that you use exactly the same vnode names in the Version 2 configuration file as those that the cgroups hook has created; check the output of `pbsnodes -av`.
  - Do not use a Version 2 configuration file to change hardware settings for that host.
- If you set a value using `qmgr`, this value overrides the existing value, and you cannot change the value using another method, such as a Version 2 configuration file. If you want to use a different method to set a value that has been set via `qmgr`, use `qmgr` to unset the value, then HUP the MoM.
- The `pbs_mom -d` option changes where MoM looks for `PBS_HOME`, and using this option will change where MoM looks for all configuration files. If you use the `-d` option, MoM will look in the new location for all MoM and vnode configuration files. Instead, we recommend setting the location of `PBS_HOME` or `PBS_MOM_HOME` in `/etc/pbs.conf` on MoM's host.
- When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

3.4.3.6 PBS Reserved Configuration Files

PBS reserved configuration files are created by PBS and are prefixed with "PBS". You cannot create or modify a configuration file whose name begins with "PBS". Do not move PBS reserved configuration files.

3.4.4 Configuring the Vnode Sharing Attribute

When PBS places a job, it can do so on hardware that is either already in use or has no jobs running on it. PBS can make the choice at the vnode level or at the host level. How this choice is made is controlled by a combination of the value of each vnode's sharing attribute and the placement requested by a job.

You can set each vnode's sharing attribute so that the vnode or host is always shared, is always exclusive, or so that it honors the job's placement request. If the vnode attribute is set to *force_shared* or *force_excl*, the value of a vnode's sharing attribute takes precedence over a job's placement request. If the vnode attribute is set to *default_*, the job request overrides the vnode attribute.

Each vnode can be allocated exclusively to one job (each job gets its own vnodes), or its resources can be shared among jobs (PBS puts as many jobs as possible on a vnode). If a vnode is allocated exclusively to a job, all of its resources are assigned to the job. The state of the vnode becomes *job-exclusive*. No other job can use the vnode.

Hosts can also be allocated exclusively to one job, or shared among jobs. If a host is to be allocated exclusively to one job, all of the host must be used: if any vnode from a host has its sharing attribute set to either *default_exclhost* or *force_exclhost*, all vnodes on that host must have the same value for the sharing attribute.

For a complete description of the sharing attribute, and a table showing the interaction between the value of the sharing attribute and the job's placement request, see "sharing" on page 326 of the PBS Professional Reference Guide.

3.4.4.1 Sharing on a Multi-vnode Machine

On a multi-vnode shared-memory machine, a scheduler will share memory from a chunk even if all the CPUs are used by other jobs. It will first try to put a chunk entirely on one vnode. If it can, it will run it there. If not, it will break the chunk up across any vnode it can get resources from, even for small amounts of unused memory.

To keep a job in a single vnode, use `-lplace=group=vnode`; if you want to restrict it to larger sets of vnodes, identify those sets using a custom string or string_array resource and use it in `-lplace=group=<resource>`. If you already have resources used in node_group_key you can usually use these.

3.4.4.2 Setting the sharing Vnode Attribute

To set the sharing attribute for a vnode, use either:

- An execshost_startup hook; see "Setting and Unsetting Vnode Resources and Attributes" on page 48 in the PBS Professional Hooks Guide
- A Version 2 configuration file; see section 3.4.4, "Configuring the Vnode Sharing Attribute", on page 48

3.4.4.3 Viewing Sharing Information

You can use the `qmgr` or `pbsnodes` commands to view sharing information. See "qmgr" on page 150 of the PBS Professional Reference Guide and "pbsnodes" on page 36 of the PBS Professional Reference Guide.

3.4.4.4 Sharing Caveats

- On the Cray XC, on *cray_compute* vnodes, the sharing attribute is set to *force_exclhost* by default. Do not change this setting, because ALPS does not support sharing a compute vnode with more than one job.
- The term "sharing" is also used to describe the case where MoM manages a resource that is shared among her vnodes, for example an application license shared by the vnodes of a multi-vnode machine.
- The term "sharing" is also used to mean oversubscribing CPUs, where more than one job is run on one CPU; the jobs are "sharing" a CPU. See section 9.6.5, "Managing Load Levels on Vnodes", on page 447
- If a host is to be allocated exclusively to one job, all of the host must be used: if any vnode from a host has its sharing attribute set to either *default_exclhost* or *force_exclhost*, all vnodes on that host must have the same value for the sharing attribute.
- For vnodes with sharing=*default_shared*, jobs can share a vnode, so that unused memory on partially-allocated vnodes is allocated to a job. The exec_vnode attribute will show this allocation.

3.4.5 Configuring Vnode Resources

Before configuring vnode (host-level) resources, consider how you will use them. When configuring static resources, it is best to configure global static resources. Even though they are global, they can be configured at the host level. Global resources can be operated on via the `qmgr` command and viewed via the `qstat` command. When configuring dynamic resources, if you need the script to run at the execution host, configure local dynamic resources. These resources cannot be operated on via the `qmgr` command or viewed via the `qstat` command. See section 5.4, "Categories of Resources", on page 235.

3.4.5.1 Configuring Global Static Vnode Resources

You can create global custom static host-level resources that can be reported by MoM and used for jobs. Follow the instructions in section 5.14.4.2, "Static Host-level Resources", on page 272.

You can set values for built-in and custom global static vnode resources; see section 3.4.5, "Configuring Vnode Resources", on page 49.

3.4.5.2 Configuring Local Dynamic Vnode Resources

You can create local custom dynamic host-level resources. The primary use of this feature is to add site-specific resources, such as software application licenses or scratch space. Follow the instructions in section 5.14.4.1, "Dynamic Host-level Resources", on page 271.

3.4.5.3 Rules for Configuring Vnode Resources

- In general, it is not advisable to set resources_available.ncpus or resources_available.mem to a value greater than PBS has detected on the machine. This is because you do not want MoM to try to allocate more resources than are available. However, if you have lots of I/O-bound jobs, you might get away with oversubscribing CPUs.
- In general, it is safe to set resources_available.ncpus or resources_available.mem to a value less than PBS has detected. If you are using a Version 2 configuration file, consider setting ncpus lower to set aside some of the resource for the operating system.
- For the parent vnode on a multi-vnode machine, set all values for resources_available.<resource name> to *zero* (*0*), unless the resource is being shared among child vnodes via indirection. Here is an example of the vnode definition for a parent vnode:

```
host03:  pnames = cbrick, router
host03:  sharing = ignore_excl
host03:  resources_available.ncpus = 0
host03:  resources_available.mem = 0
host03:  resources_available.vmem = 0
```

- When MoM creates a vnode, she automatically sets values for the following resources according to information from the host:

    resources_available.ncpus

    resources_available.arch

    resources_available.mem

- If you set the value of a resource via `qmgr`, that setting is carried forth across server restarts.
- If you add or change a value via a Version 2 configuration file, you can HUP the MoM. If you remove a value, you must restart MoM so that she uses the default. (Hint: to avoid restarting MoM, use the configuration file to set the default.)
- You can set values for the sharing attribute and resources_available.host only in an exechost_startup or exechost_periodic hook, or in a Version 2 configuration file. You cannot use `qmgr` to set these.
- Version 2 configuration files take effect before exechost_startup hooks.

3.4.6 Configuring Vnodes via the `qmgr` Command

You can use the `qmgr` command to set attribute and resource values for individual vnodes, for single-vnode and multi-vnode machines.

To set a vnode's attribute:

qmgr -c 'set node <vnode name> <attribute> = <value>'

We describe the `qmgr` command in "qmgr" on page 150 of the PBS Professional Reference Guide.

3.4.6.1 Caveats for Setting Values via qmgr Command

- When setting hardware resources, be careful about setting these to values that are higher than what MoM or the cgroups hook did. If you have lots of I/O-bound jobs, you might get away with oversubscribing CPUs.
- It is usually safe to set hardware resources to values lower than what MoM or the cgroups hook did.
- If you are not using the cgroups hook, consider setting ncpus to a slightly lower value than what MoM reports, to give some to the operating system.
- If you set a value using `qmgr`, this value overrides the existing value, and you cannot change the value using another method, such as a Version 2 configuration file. If you want to use a different method to set a value that has been set via `qmgr`, use `qmgr` to unset the value, then HUP the MoM.
- You cannot set the value of resources_available.host via the `qmgr` command.

3.4.7 Configuring Vnodes via the `pbsnodes` Command

You can use the `pbsnodes` command to set the state all of the vnodes on a host to be *offline* or not *offline*. To set the state attribute of one or more hosts to *offline*:

```
pbsnodes -o <hostname [hostname ...]>
```

To remove the *offline* setting from the state attribute of one or more hosts:

```
pbsnodes -r <hostname [hostname ...]>
```

See “pbsnodes” on page 36 of the PBS Professional Reference Guide.

3.4.7.1 Caveats for pbsnodes Command

For multi-vnode hosts, the `pbsnodes` command operates on all of the host's vnodes only. You cannot use it on individual vnodes where those vnodes are on multi-vnode machines. To operate on individual vnodes, use the `qmgr` command:

```
qmgr -c 'set node <vnode name> state = <new state>'
```

When you specify a hostname, the `pbsnodes` command looks for the value of a vnode's resources_available.host resource. If this is different from the PBS_MOM_NODE_NAME parameter, it may be helpful to use a Version 2 configuration file to set resources_available.host to match the PBS_MOM_NODE_NAME parameter (you cannot use `qmgr` for this).

Make sure that resources_available.host is unique for each host in your complex.

The `pbsnodes -o <target host>` command offlines everything with a matching resources_available.<target host>.

3.5 Deleting Vnodes

3.5.1 Deleting the Vnode on a Single-vnode Machine

Use the `qmgr` command to delete the vnode:

```
Qmgr: delete node <vnode name>
```

3.5.2 Deleting Vnodes on a Multi-vnode Machine

3.5.2.1 Deleting Vnodes When Not Using Version 2 Configuration File

4. Use the `qmgr` command to delete the vnodes:

   ```
   Qmgr: delete node <vnode name>
   ```

3.5.2.2 Deleting Vnodes When Using Version 2 Configuration File

To delete one or more vnodes on a multi-vnode machine where there is a Version 2 configuration file, you must first remove the configuration file. Then you can delete the vnodes. You may want to save the existing configuration file and edit it down to just the vnodes you want to preserve. On the local host:

1. To see the list of Version 2 configuration files:

   Linux:

   ```
   pbs_mom -s list
   ```

   Windows:

   ```
   pbs_mom -N -s list
   ```

2. To save the contents of a Version 2 configuration file in "tempconfig":

   Linux:

   ```
   pbs_mom -s show <filename> > tempconfig
   ```

   Windows:

   ```
   pbs_mom -N -s show <filename> > tempconfig
   ```

3. Edit `tempconfig` so that it describes only the vnodes you want to keep.
4. Use `pbs_mom -s remove` to remove the old Version 2 configuration file:

   On Linux:

   ```
   pbs_mom -s remove <filename>
   ```

   On Windows:

   ```
   pbs_mom -N -s remove <filename>
   ```

5. Use `pbs_mom –s insert` to create a new Version 2 configuration file describing the vnodes to be retained. If you created `tempconfig`, it is your input file:

   On Linux:

   ```
   pbs_mom -s insert <configuration file target> <input file>
   ```

   On Windows:

   ```
   pbs_mom -N -s insert <configuration file target> <input file>
   ```

6. Restart the MoM:

   ```
   <path to start/stop script>/pbs restart
   ```

or

```
systemctl restart pbs
```

7. Use the `qmgr` command to remove the vnodes no longer appearing in your configuration file:

```
Qmgr: delete node <vnode name>
```

8. Check for stale vnodes. Make sure you spell "Stale" with a capital S:

```
qmgr -c 'print node @default' | grep "Stale"
```

3.5.2.3 Deleting Vnodes on Cray XC

See section 11.16.8, “Deleting Vnodes on Cray XC”, on page 496.

4 Scheduling

The "Scheduling Policy Basics" section of this chapter describes what PBS can do, so that you can consider these capabilities when choosing how to schedule jobs. The "Choosing a Policy" section describes how PBS can meet the scheduling needs of various workloads. The "Scheduling Tools" section describes each scheduling tool offered by PBS.

4.1 Chapter Contents

4.2 Scheduling Each Partition Separately

You can leave your complex as a single default partition, or you can divide your complex into partitions, and run a separate scheduler for each partition. PBS automatically creates a default partition containing all queues and vnodes that are not explicitly labeled with a partition name. You can create named partitions, simply by labeling each queue and vnode with the desired partition. You can choose whether to assign each queue and vnode to a specific partition, or to have it remain as part of the default partition.

PBS has two kinds of schedulers:

- A default scheduler that handles the workload for the default partition (all queues and vnodes that have not been explicitly assigned to a named partition)

  The default scheduler runs its own scheduling policy.

  You cannot assign any non-default partitions to the default scheduler.

  The default scheduler runs only on the server host.
- A *multisched* that handles a named, non-default partition

  Each multisched runs its own scheduling policy, and can schedule jobs for one named partition.

  A multisched requires at least one queue and one vnode in its partition in order to be able to schedule jobs.

  Multischeds cannot share partitions.

  A multisched can run on any host.

A named partition is a collection of vnodes labeled with a partition name, along with one or more queues also labeled with the same partition name. A vnode can be in at most one partition. You can put some or all of your vnodes into partitions, where they will be scheduled by the multisched assigned to the partition. You can also leave vnodes out of named partitions; those vnodes will be scheduled by the default scheduler.

You can have as many named partitions and multischeds as you want. Each partition can have only one multisched. Each partition requires at least one execution queue.

Each multisched schedules only from the queue(s) in its partition, and only to the vnode(s) in its partition. Jobs do not span partitions.

You can define a unique policy for each scheduler.

4.2.1 Creating and Configuring a Multisched

4.2.1.1 Prerequisites for Creating a Multisched

You must be a PBS administrator or Manager to create a scheduler.

You must supply a name when you create a multisched. The maximum length for the name is 15 characters.

Before you start a multisched, you must create the `sched_priv` and `sched_log` directories for it.

- The default name for the `sched_priv` directory is `sched_priv_<multisched name>`, and the default location is on the server/scheduler host, directly under `PBS_HOME`, alongside the `sched_priv` of the default scheduler. You can set the name and location as desired, but we recommend keeping it in `PBS_HOME`. The `sched_priv` directory should have permissions 750, and should be accessible by the multisched. It should be owned by root. It cannot be shared with another multisched.
- Populate the `sched_priv` directory with the following:

  `sched_config`

  Required.

  `holidays`

  Required.

  `resource_group`

  Necessary for fairshare tree.

  `dedicated_time`

  Required.

  We provide default copies of these files in `PBS_EXEC/etc`.
- The default name and location for the multisched logging directory is `sched_logs_<multisched name>` (note the plural), on the server/scheduler host, directly under `PBS_HOME`, alongside the `sched_logs` of the default scheduler. You can set the name and location as desired, but we recommend keeping it in `PBS_HOME`. The `sched_log` directory should have permissions 755, and should be accessible by the multisched. It should be owned by root. It cannot be shared with another multisched.

4.2.1.2 Creating a Multisched

You use the `qmgr` command to create a scheduler:

qmgr -c "create sched <multisched name>"

For example:

```
qmgr -c "create sched multisched_1"
```

This creates a multisched with its attributes set to the defaults.

4.2.1.3 Configuring a Multisched

You must set the partition and sched_port multisched attributes:

qmgr -c "set sched <multisched name> partition = <partition name>"

qmgr -c "set sched <multisched name> sched_port = <port number>"

4.2.1.4 Enabling a Multisched

To enable a multisched, set its scheduling attribute to *True*:

```
qmgr -c "set sched <scheduler name> scheduling = 1"
```

4.2.2 Starting a Multisched

Do not start a multisched until:

- Its `sched_priv` directory is ready. See section 4.2.1.1, “Prerequisites for Creating a Multisched”, on page 57
- You have assigned it a partition. See section 4.2.1.3, “Configuring a Multisched”, on page 58

4.2.2.1 Starting a Multisched on Linux

Start a multisched by calling `pbs_sched` and specifying the name and port you already gave it:

pbs_sched -I <name of multisched> -S <same value as sched_port for this multisched>

For example:

```
pbs_sched -I multisched_1 -S 15050
```

When you start a multisched, you must specify its name.

4.2.3 Configuring Your Partitions for Multischeds

To schedule using partitions, compose each partition and start its multisched:

- Put each vnode into at most one partition, or leave it in the default partition; partitions cannot share vnodes. If putting the vnode into a named partition, set the value of the partition vnode attribute to the name of its partition:

  qmgr -c set node <vnode name> partition=<partition name>

  For example:

  ```
  qmgr -c set node <vnode1> partition=<part1>
  ```
- Assign at least one execution queue to each named partition: set the value of the partition queue attribute to the name of its partition:

  qmgr -c set queue <queue name> partition=<partition name>

  For example:

  ```
  qmgr -c set queue <queue1> partition=<part1>
  ```
- Create the desired multisched. See section 4.2.1, “Creating and Configuring a Multisched”, on page 57.
- Assign a multisched to each named partition: set the value of the partition multisched attribute to the name of its partition:

  qmgr -c "set sched <multisched name> partition=<partition name>"

  For example:

  ```
  qmgr -c "set sched multisched_1 partition=part1"
  ```
- Enable the multisched:

  qmgr -c 'set sched <multisched name> scheduling=1'
  For example:

  ```
  qmgr -c 'set sched multisched_1 scheduling=1'
  ```
- Start the multisched, and specify the port number:

  pbs_sched -I <name of multisched> -S <same value as sched_port for this multisched>

  For example:

  ```
  pbs_sched -I multisched_1 -S 15050
  ```

4.2.4 Using the Default Scheduler with Multischeds

PBS automatically creates the default scheduler; its name is "default". The `sched_priv` directory of the default scheduler is always `$PBS_HOME/sched_priv`. The default scheduler writes its logs in `$PBS_HOME/sched_logs`. If you do nothing, the default scheduler uses the default scheduling policy defined in the default `sched_config` file. Default behavior is described in section 4.4.7, “Default Scheduling Policy”, on page 88. You can set the desired policy for the default scheduler. The default scheduler schedules jobs using queues and vnodes in the default partition.

4.2.4.1 Configuring the Default Scheduler

When you use the `qmgr` command to configure the default scheduler, specify its name:

qmgr -c "set sched default <attribute> = <value>"

For example:

```
qmgr -c "set sched default job_sort_formula_threshold = <value>"
```

4.2.5 Multisched Caveats and Restrictions

- You cannot delete the default scheduler.
- You cannot change the name of the default scheduler.
- You cannot set sched_host, sched_priv, or sched_port for the default scheduler.
- If you create a new queue or vnode without assigning it to a specific partition, it is scheduled by the default scheduler.
- You cannot assign a new multisched to a partition that is already assigned to a multisched, or vice versa. To make the change, offline the vnodes, wait for jobs to finish running, then un-assign and re-assign the multisched or partition.
- You cannot change a queue to a routing queue when the queue has its partition attribute set.
- You cannot associate a vnode and a queue and assign them separate partitions.
- If there is more than one scheduler, job run limits for the entire complex set at the server are not supported. Queue limits are enforced.
- All schedulers in the complex have as a default value for backfill_depth the value that is set at the server. For each scheduler, this is overridden by the setting at a scheduler's queue.
- All schedulers in the complex use the same value for job_sort_formula, so all schedulers use the same formula.
- If the complex has more than one scheduler, you cannot use complex-wide fairshare. Each scheduler manages its own fairshare tree.

4.2.6 Attributes Used with Multischeds

partition

Scheduler attribute. Partition for which this scheduler is to run jobs. Cannot be set on default scheduler.

Format: *String*

Default: "*None*"

partition

Vnode attribute. Name of partition to which this vnode is assigned. A vnode can be assigned to at most one partition.

Settable by Manager and Operator, viewable by all.

Format: *String*

partition

Queue attribute. Name of partition to which this queue is assigned.

Cannot be set for routing queue.

An execution queue cannot be changed to a routing queue while this attribute is set.

Settable by Manager, administrator, viewable by all.

Format: *String*

sched_log

Scheduler attribute. Directory where this scheduler writes its logs. Permissions should be *755*. Must be owned by root. Cannot be shared with another scheduler. For default scheduler, directory is always `PBS_HOME/sched_log`.

Settable by Manager, administrator, viewable by all.

Default: `$PBS_HOME/sched_logs_<scheduler name>`

sched_port

Scheduler attribute. Port on which this scheduler listens. Cannot be set on default scheduler.

Settable by Manager, administrator, viewable by all.

Default: None

sched_host

Scheduler attribute. Hostname on which scheduler runs.

Cannot be set on default scheduler; value for default scheduler is server hostname.

Settable by Manager or administrator, viewable by all.

scheduling

Scheduler attribute. Enables scheduling of jobs. If you set the server's scheduling attribute, that value is assigned to the default scheduler's scheduling attribute, and vice versa.

Settable by Manager or administrator, viewable by all.

Default value for default scheduler: *True*

Default value for multisched: *False*

scheduler_iteration

Scheduler attribute. Time between scheduling iterations. If you set the server's scheduler_iteration attribute, that value is assigned to the default scheduler's scheduler_iteration attribute, and vice versa.

Settable by Manager, administrator, viewable by all.

Default: *600*

sched_priv

Scheduler attribute. Directory where this scheduler keeps fairshare `usage`, `resource_group`, `holidays`, and `sched_config`. Must be owned by root. For default scheduler, directory is always `PBS_HOME/sched_priv`.

Settable by Manager or administrator, viewable by all.

Default: `$PBS_HOME/sched_priv_<scheduler name>`

state

Scheduler attribute. State of this scheduler.

Set by server. Readable by all.

Valid values: one of *down, idle, scheduling*

down: scheduler is not running

idle: scheduler is running and is waiting for a scheduling cycle to be triggered

scheduling: scheduler is running and is in a scheduling cycle

Format: *String*

Default value for default scheduler: *idle*

Default value for multisched: *down*

comment

Scheduler attribute. Can be set by PBS or administrator. For certain scheduler errors, PBS sets the scheduler's comment attribute to specific error messages. You can use the comment field to notify another administrator of something, but PBS does overwrite the value of comment under certain circumstances.

Format: *String*

4.2.6.1 Behavior of Attributes Shared by Server and Scheduler

If you set the server's scheduling or scheduler_iteration attributes, the changes are applied to the default scheduler, and its corresponding scheduling or scheduler_iteration attributes are given the new setting(s). The reverse is also true.

4.2.7 Multisched Errors and Logging

4.2.7.1 Multisched Error Messages Appearing in Scheduler Comment

A scheduler's comment attribute can be set to specific error messages.

- Setting the sched_log attribute to an invalid value produces a scheduler comment. If the log directory is not accessible by the scheduler:
  ```
  Unable to change the sched_log directory
  ```
  In addition, the scheduling attribute is set to *False*.
- Attempting to set the sched_priv attribute to an invalid value:
  ```
  Unable to change the sched_priv directory
  ```
  In addition, the scheduling attribute is set to *False*.
- Setting sched_priv to a directory that fails validation checking produces a scheduler comment. If the sched_priv directory is not accessible by the scheduler, or the scheduler files are not found in the directory:
  ```
  PBS failed validation checks for sched_priv directory
  ```
  In addition, the scheduling attribute is set to *False*.

4.2.7.2 Multisched Error Messages Appearing in Scheduler Logs

- Attempting to start a multisched before assigning it a partition:
  `Scheduler does not contain a partition`
- When the partition has been removed from a multisched, the multisched is shut down.
  `Scheduler does not contain a partition`
- When the scheduler cannot get its attribute information from the server:
  `Unable to retrieve the scheduler attributes from server`

4.2.7.3 Multisched Error Messages Appearing in Server Logs

- Attempting to set sched_port, sched_priv, or sched_host for the default scheduler:
  `Operation is not permitted on default scheduler`
- Attempting to set the partition for the default scheduler:
  `Operation is not permitted on default scheduler`
  In addition, the error code is set to 15223.
- Attempting to assign a `sched_priv` to a multisched while that directory is already assigned to another multisched:
  `Another scheduler has same value for its sched_priv directory`

  In addition, the error code is set to 15216.
- Attempting to assign a `sched_log` to a multisched while that directory is already assigned to another multisched:
  `Another scheduler has same value for its sched_log directory`

  In addition, the error code is set to 15215.
- If the server is not able to reach a scheduler one of the following messages appears:
  ```
  Unable to reach scheduler associated with partition [<partition ID>]
  Unable to reach scheduler associated with job <job ID>
  ```

4.2.7.4 Multisched Errors Returned by qmgr Command

- Attempting to associate a vnode with a queue that has not been assigned to the same partition:
  ```
  qmgr obj=<vnode name> svr=<server name>: Partition <partition name> is not part of queue for node
  qmgr: Error (15220) returned from server
  ```
- Attempting to assign a partition to a vnode when that vnode is associated with a queue and the queue is not assigned to the same partition:
  ```
  qmgr obj=<vnode name> svr=<server name>: Queue <queue name> is not part of partition for node
  qmgr: Error (15219) returned from server
  ```
- When a queue is associated with one or more vnodes, and a partition is assigned to the queue and vnodes, attempting to change the queue's partition:
  ```
  qmgr obj=<queue name> svr=<server name>: Invalid partition in queue
  qmgr: Error (15221) returned from server
  ```
- Attempting to assign a partition to a multisched while that partition is already assigned to another multisched:
  ```
  Partition <partition name> is already associated with scheduler <scheduler name>.
  ```
- Attempting to set the partition attribute for a routing queue:
  ```
  qmgr obj=<queue name> svr=<server name>: Cannot assign a partition to route queue
  qmgr: Error (15217) returned from server
  ```
- Attempting to change an execution queue to a routing queue while the partition attribute is set:
  ```
  qmgr obj=<queue name> svr=<server name>: Cannot queue_type=route if partition is set
  qmgr: Error (15218) returned from server
  ```

4.2.8 Multisched Deprecations

Using `qmgr` on the default scheduler, without specifying it name, is deprecated. The old syntax is supported for backward compatibility.

Example of old syntax:

```
qmgr -c "set sched job_sort_formula_threshold = <value>"
```

Same with new syntax:

```
qmgr -c "set sched default job_sort_formula_threshold = <value>"
```

4.3 Scheduling Policy Basics

4.3.1 How Scheduling Can Be Used

You can use the scheduling tools provided by PBS to implement your chosen scheduling policy, so that your jobs run in the way you want.

Your policy can do the following:

- Prioritize jobs according to your specification
- Run jobs according to their relative importance
- Award specific amounts of resources such as CPU time to projects, users, and groups according to rules that you set
- Make sure that resources are not misused
- Optimize how jobs are placed on vnodes, so that jobs run as efficiently as possible
- Use special time slots for particular tasks
- Optimize throughput or turnaround time for jobs

4.3.2 What Is Scheduling Policy?

Scheduling policy determines when each job is run and on which resources. In other words, a scheduling policy describes a goal, or intended behavior. For convenience, we describe a scheduling policy as being a combination of sub-goals, for example a combination of how resources should be allocated and how efficiency should be maximized.

You implement a scheduling policy using the tools PBS provides. A scheduling tool is a feature that allows you control over some aspect of scheduling. For example, the job sorting formula is a tool that allows you to define how you want job execution priority to be computed. Some scheduling tools are supplied by the PBS scheduler(s), and some are supplied by other elements of PBS, such as the hooks, server, queues or resources.

You can group the resources in your complex into partitions, and you can run a separate scheduling policy on each partition.

4.3.3 Basic PBS Scheduling Behavior

The basic behavior of PBS is that it always places jobs where it finds the resources requested by the job. PBS will not place a job where that job would use more resources than PBS thinks are available. For example, if you have two jobs, each requesting 1 CPU, and you have one vnode with 1 CPU, PBS will run only one job at a time on the vnode. You do not have to configure PBS for this basic behavior.

PBS determines what hardware resources are available and configures them for you. However, you do have to inform PBS which custom resources and non-hardware resources are available and where, how much, and whether they are consumable or not. In addition, in order to ensure that jobs are sent to the appropriate vnodes for execution, you also need to make sure that they request the correct resources. You can do this either by having users submit their jobs with the right resource requests, using hooks that set job resources, or by configuring default resources for jobs to inherit.

4.3.4 Sub-goals

Your scheduling policy is the combination that you choose of one or more sub-goals. For example, you might need to meet two particular sub-goals: you might need to prioritize jobs a certain way, and you might need to use resources efficiently. You can choose among various outcomes for each sub-goal. For example, you can choose to prioritize jobs according to size, owner, owner's usage, time of submission, etc.

In the following sections, we describe the tools PBS offers for meeting each of the following sub-goals.

- Job prioritization and preemption; see section 4.3.5, “Job Prioritization and Preemption”, on page 66.
- Resource allocation & limits; see section 4.3.6, “Resource Allocation to Users, Projects & Groups”, on page 72.
- Time slot allocation; see section 4.3.7, “Time Slot Allocation”, on page 74.
- Job placement optimizations; see section 4.3.8, “Job Placement Optimization”, on page 75.
- Resource efficiency optimizations; see section 4.3.9, “Resource Efficiency Optimizations”, on page 78.
- Overrides; see section 4.3.10, “Overrides”, on page 80.

4.3.5 Job Prioritization and Preemption

Job prioritization is any technique you use to come up with a ranking of each job's relative importance. You can specify separate priority schemes for both execution and preemption.

4.3.5.1 Where PBS Uses Job Priority

PBS calculates job priority for two separate tasks: job execution and job preemption. Job execution priority is used with other factors to determine when to run each job. Job preemption priority is used to determine which queued jobs are allowed to preempt which running jobs in order to use their resources and run. These two tasks are independent, and it is important to make sure that you do not make them work at cross-purposes. For example, you do not want to have a class of jobs having high execution priority and low preemption priority; these jobs would run first, and then be preempted first.

Preemption comes into play when a scheduler examines the top job and determines that it cannot run now. If preemption is enabled, a scheduler checks to see whether the top job has sufficient preemption priority to be able to preempt any running jobs, and then if it does, whether preempting jobs would yield enough resources to run the top job. If both are true, a scheduler preempts running jobs and runs the top job.

If you take no action to configure how jobs should be prioritized, they are considered in submission order, one queue at a time. If you don't prioritize queues, the queues are examined in an undefined order.

4.3.5.2 Overview of Prioritizing Jobs

PBS provides several tools for setting job execution priority. There are queue-based tools for organizing jobs, moving them around, and specifying the order in which groups of jobs should be examined. There are tools for sorting jobs into the order you want. There is a meta-tool (strict ordering) that allows you to specify that the top job must go next, regardless of whether the resources it requires are available now.

A scheduler can use multiple sorting tools, in succession. You can combine your chosen sorting tools with queue-based tools to give a wide variety of behaviors. Most of the queue-based tools can be used together. A scheduler can treat all jobs as if they are in a single queue, considering them all with respect to each other, or it can examine all queues that have the same priority as a group, or it can examine jobs queue by queue, comparing each job only to other jobs in the same queue.

You can change how execution priority is calculated, depending on which time slot is occurring. You can divide time up into primetime, non-primetime, and dedicated time.

When a scheduler calculates job execution priority, it uses a built-in system of job classes. PBS runs special classes of jobs before it considers queue membership. These classes are for reservation, express, preempted, and starving jobs. Please see section 4.9.16, “Calculating Job Execution Priority”, on page 136. After these jobs are run, a scheduler follows the rules you specify for queue behavior. Within each queue, jobs are sorted according to the sorting tools you choose.

4.3.5.3 Using Queue-based Tools to Prioritize Jobs

4.3.5.3.i Using Queue Order to Affect Order of Consideration

When a scheduler examines queued jobs, it can consider all of the jobs in its partition as a whole, it can round-robin through groups of queues where the queues are grouped by priority, or it can examine jobs in only one queue at a time. These three systems are incompatible. Queues are always sorted by priority.

The by_queue scheduler parameter controls whether a scheduler runs all the jobs it can from the highest-priority queue before moving to the next, or treats all jobs as if they are in a single queue. By default, this parameter is set to *True*. When examining jobs one queue at a time, a scheduler runs all of the jobs it can from the highest-priority queue first, then moves to the next highest-priority queue and runs all the jobs it can from that queue, and so on. See section 4.9.4, "Examining Jobs Queue by Queue", on page 112.

The round_robin scheduler parameter controls whether or not a scheduler round-robins through queues. When a scheduler round-robins through queues, it groups the queues by priority, and round-robins first through the highest-priority group, then the next highest-priority group, and so on, running all of the jobs that it can from that group. So within each group, if there are multiple queues, a scheduler runs the top job from one queue, then the top job from the next queue, and so on, then goes back to the first queue, runs its new top job, goes to the next queue, runs its new top job, and so on until it has run all of the jobs it can from that group. All queues in a group must have exactly the same priority. The order in which queues within a group are examined is undefined. If all queues have different priorities, a scheduler starts with the highest-priority queue, runs all its jobs, moves to the next, runs its jobs, and so on until it has run all jobs from each queue. This parameter overrides by_queue. See section 4.9.38, "Round Robin Queue Selection", on page 206.

If you want queues to be considered in a specific order, you must assign a different priority to each queue. Queues are always sorted by priority. See section 4.9.47, "Sorting Queues into Priority Order", on page 225. Give the queue you want considered first the highest priority, then the next queue the next highest priority, and so on. If you want groups of queues to be considered together for round-robining, give all queues in each group one priority, and all queues in the next group a different priority. If the queues don't have priority assigned to them, the order in which they are considered is undefined. To set a queue's priority, use the `qmgr` command to assign a value to the priority queue attribute. See section 2.3.5.3, "Prioritizing Execution Queues", on page 26.

4.3.5.3.ii Using Express Queues in Job Priority Calculation

You can create express queues, and route jobs into them, if you want to give those jobs special priority.

An express queue is a queue whose priority is high enough to qualify as an express queue; the default for qualification is 150, but this can be set using the preempt_queue_prio scheduler attribute. For information on configuring express queues, see section 2.3.5.3.i, "Express Queues", on page 26.

When calculating execution priority, a PBS scheduler uses a built-in job class called "*Express*" which contains all jobs that have a preemption level greater than that of the normal_jobs level. By default, those jobs are jobs in express queues. See section 4.9.16, "Calculating Job Execution Priority", on page 136.

You can create preemption levels that include jobs in express queues. Jobs in higher preemption levels are allowed to preempt jobs in lower levels. See section 4.9.33, "Using Preemption", on page 182.

4.3.5.3.iii Routing Jobs into Queues

You can configure PBS to automatically put each job in the most appropriate queue. There are several approaches to this. See section 4.9.39, "Routing Jobs", on page 207.

4.3.5.3.iv Using Queue Priority when Computing Job Priority

You can configure a scheduler so that job priority is partly determined by the priority of the queue in which the job resides. See section 4.9.36, "Queue Priority", on page 198.

4.3.5.4 Using Job Sorting Tools to Prioritize Jobs

A scheduler can use multiple job sorting tools in succession to determine job execution priority. A scheduler groups all jobs waiting to run into classes, and then applies the sorting tools you choose to all jobs in each class.

- You can create a formula that a scheduler uses to sort jobs. A scheduler applies this formula to all jobs in its partition, using it to calculate a priority for each job. For example, you can specify in the formula that jobs requesting more CPUs have higher priority. If the formula is defined, it overrides fairshare and sorting jobs on keys. See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.
- You can use the fairshare algorithm to sort jobs. This algorithm allows you to set a resource usage goal for users or groups. Jobs are prioritized according to each entity's usage; jobs whose owners have used the smallest percentage of their allotment go first. For example, you can track how much CPU time is being used, and allot each group a percentage of the total. See section 4.9.19, "Using Fairshare", on page 140.
- You can sort jobs according to the same usage allotments you set up for fairshare. In this case, jobs whose owners are given the highest allotment go first. See section 4.9.14, "Sorting Jobs by Entity Shares (Was Strict Priority)", on page 133.
- You can sort jobs on one or more keys, for example, you can sort jobs first by the number of CPUs they request, then by the amount of memory they request. You can specify that either the high or the low end of the resulting sort has higher priority.

  You can create a custom resource, and use a hook to set a value for that resource for each job, and then sort on the resource.

  See section 4.9.45, "Sorting Jobs on a Key", on page 223.
- You can run jobs in the order in which they were submitted. See section 4.9.20, "FIFO Scheduling", on page 150.
- You can run jobs according to the priority requested for each job at submission time. This priority can be set via a hook. See section 4.9.46, "Sorting Jobs by Requested Priority", on page 225 and the PBS Professional Hooks Guide.

4.3.5.5 Prioritizing Jobs by Wait Time

You can use the amount of time a job has been waiting to run in the priority calculation. There are two ways to measure wait time:

- Eligible waiting time: how long a job has been waiting to run due to a shortage of resources, rather than because its owner isn't allowed to run jobs now. See section 4.9.13, "Eligible Wait Time for Jobs", on page 128
- Amount of time waiting in the queue

Both of these ways can be used when computing whether or not a job is starving. You can specify how long a job must be waiting to be considered starving. See section 4.9.48, "Starving Jobs", on page 225.

You can use a job's eligible waiting time in the job sorting formula. See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

When a job is considered to be starving, it is automatically assigned special execution priority, and placed in the Starving execution priority class; see section 4.9.16, "Calculating Job Execution Priority", on page 136. You can configure preemption levels that include starving jobs; see section 4.9.33, "Using Preemption", on page 182.

4.3.5.6 Calculating Preemption Priority

Execution priority and preemption priority are two separate systems of priority.

By default, if the top job cannot run now, and it has high preemption priority, a scheduler will use preemption to run the top job. A scheduler will preempt jobs with lower preemption priority so that it can use the resources to run the top job. The default definition of jobs with high preemption priority is jobs in express queues. You can configure many levels of preemption priority, specifying which levels can preempt which other levels. See section 4.9.33, “Using Preemption”, on page 182.

4.3.5.7 Making Preempted Jobs Top Jobs

You can specify that a scheduler should make preempted jobs be top jobs. See section 4.9.3.7, “Configuring Backfilling”, on page 109.

4.3.5.8 Preventing Jobs from Being Preempted

You may have jobs that should not be preempted, regardless of their priority. These can be jobs which cannot be effectively preempted, so that preempting them would waste resources. To prevent these jobs from being preempted, do one or both of the following:

- Set a value for the preempt_targets resource at all jobs that specify a value for a custom resource. For example, define a Boolean resource named Preemptable, and add "Resource_List.Preemptable=true" to preempt_targets for all jobs. Then set the value of Resource_List.Preemptable to *False* for the jobs you don't want preempted.

  For example, if we want JobA and JobB to be able to preempt Job1 and Job2, but not Job3:

  Define a Boolean resource named "Preemptable"

  For Job1 and Job2, set Resource_List.Preemptable to *True*:

  ```
  qsub ... -l Preemptable=True ...
  ```

  or

  ```
  qalter -l Preemptable=True Job1 Job2
  ```

  For Job3, set Resource_List.Preemptable to *False*:

  ```
  qalter -l Preemptable=False Job3
  ```

  For JobA and JobB, set Resource_List.preempt_targets to "*Preemptable=True*":

  ```
  qalter -l preempt_targets=Resource_List.Preemptable=True JobA JobB
  ```

- Route jobs you don't want preempted to one or more specific queues, and then use a hook to make sure that no jobs specify these queues in their preempt_targets.

4.3.5.9 Meta-priority: Running Jobs Exactly in Priority Order

By default, when scheduling jobs, PBS orders jobs according to execution priority, then considers each job, highest-priority first, and runs the next job that can run now. If a job cannot run now because the resources required are unavailable, the default behavior is to skip the job and move to the next in order of priority.

You can tell PBS to use a different behavior called *strict ordering*. This means that you tell PBS that it must not skip a job when choosing which job to run. If the top job cannot run, no job runs.

You can see that using strict ordering could lead to decreased throughput and idle resources. In order to prevent idle resources, you can tell PBS to run small filler jobs while it waits for the resources for the top job to become available. These small filler jobs do not change the start time of the top job. See section 4.9.49, “Using Strict Ordering”, on page 227 and section 4.9.3, “Using Backfilling”, on page 107.

4.3.5.10 Using Different Calculations for Different Time Periods

PBS allows you to divide time into two kinds, called *primetime* and *non-primetime*. All time is covered by one or the other of these two kinds of time. The times are arbitrary; you can set them up however you like. You can also choose not to define them, and instead to treat all time the same.

You can configure two separate, independent ways of calculating job priority for primetime and non-primetime. The same calculations are used during dedicated time; dedicated time is a time slot made up of primetime and/or non-primetime. Many scheduler parameters are prime options, meaning that they can be configured separately for primetime and non-primetime. For example, you can configure fairshare as your sorting tool during primetime, but sort jobs on a key during non-primetime.

If you use the formula, it is in force all of the time.

See section 4.9.34, “Using Primetime and Holidays”, on page 193.

4.3.5.11 When Priority Is Not Enough: Overrides

Sometimes, the tools available for setting job priority don't do everything you need. For example, it may be necessary to run a job right away, regardless of what else is running. Or you may need to put a job on hold. Or you might need to tweak the way the formula works for the next *N* jobs. See section 4.9.30, “Overrides”, on page 164.

4.3.5.12 Elements to Consider when Prioritizing Jobs

- Whether users, groups, or projects affect job priority: for techniques to use user, group, or project to affect job priority, see section 4.4.3, “Prioritizing Jobs by User, Project or Group”, on page 82.
- Reservation jobs: jobs in reservations cannot be preempted.
- Starving jobs: PBS has a built-in execution priority for starving jobs, but you can give starving jobs the highest execution priority by giving them the highest preemption priority and enabling preemption. See section 4.9.16, “Calculating Job Execution Priority”, on page 136 and section 4.9.33, “Using Preemption”, on page 182.
- Express jobs: PBS has a built-in execution priority for express jobs. You can set the preemption priority for express jobs; see section 4.9.33, “Using Preemption”, on page 182.
- Preempted jobs: PBS has a built-in execution priority for preempted jobs. See section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- Large or small jobs: you may want to give large and/or small jobs special treatment. See section 4.4.5, “Scheduling Jobs According to Size Etc.”, on page 84.
- User's priority request for job: the job submitter can specify a priority for the job at submission. You can sort jobs according to each job's specified priority. See section 4.9.46, “Sorting Jobs by Requested Priority”, on page 225.
- Whether the top job must be the next to run, regardless of whether it can run now; see section 4.9.49, “Using Strict Ordering”, on page 227.

4.3.5.13 List of Job Sorting Tools

4.3.5.13.i Queue-based Tools for Organizing Jobs

- Queue-by-queue: PBS runs all the jobs it can from the first queue before moving to the next queue. Queue order is determined by queue priority. See section 4.9.4, "Examining Jobs Queue by Queue", on page 112.
- Round-robin job selection: PBS can select jobs from queues with the same priority in a round-robin fashion. See section 4.9.38, "Round Robin Queue Selection", on page 206.
- Queue priority: Queues are always ordered according to their priority; jobs in higher-priority queues are examined before those in lower-priority queues. See section 2.3.5.3, "Prioritizing Execution Queues", on page 26.
- Sorting queues: PBS always sorts queues into priority order. See section 4.9.47, "Sorting Queues into Priority Order", on page 225.
- Express queues: Jobs in express queues are assigned increased priority. See section 2.3.5.3.i, "Express Queues", on page 26, and section 4.3.5.3.ii, "Using Express Queues in Job Priority Calculation", on page 67.
- Routing: You can set up a queue system so that jobs with certain characteristics are routed to specific queues. See section 4.9.39, "Routing Jobs", on page 207.

4.3.5.13.ii Job Sorting Tools

You can use multiple job sorting tools, one at a time in succession. You can use different sorting tools for primetime and non-primetime.

- Job sorting formula: You create a formula that PBS uses to calculate each job's priority. See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.
- Fairshare: PBS tracks past usage of specified resources, and starts jobs based on specified usage ratios. See section 4.9.19, "Using Fairshare", on page 140.
- Sorting jobs on keys: PBS can sort jobs according to one or more keys, such as requested CPUs or memory; see section 4.9.45, "Sorting Jobs on a Key", on page 223.
- Entity shares (strict priority): Jobs are prioritized according to the owner's fairshare allocation. See section 4.9.14, "Sorting Jobs by Entity Shares (Was Strict Priority)", on page 133.
- FIFO: Jobs can be run in submission order. See section 4.9.20, "FIFO Scheduling", on page 150.
- Job's requested priority: you can sort jobs on the priority requested for the job; see section 4.9.46, "Sorting Jobs by Requested Priority", on page 225.

4.3.5.13.iii Other Job Prioritization Tools

- Strict ordering: you can specify that jobs must be run in priority order, so that a job that cannot run because resources are unavailable is not skipped. See section 4.9.49, “Using Strict Ordering”, on page 227.
- Waiting time: PBS can assign increased priority to jobs that have been waiting to run. See section 4.9.13, “Eligible Wait Time for Jobs”, on page 128, and section 4.9.48, “Starving Jobs”, on page 225.
- Setting job execution priority: PBS can set job execution priority according to a set of rules. See section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- Preemption: PBS preempts lower-priority jobs in order to run higher-priority jobs. See section 4.9.33, “Using Preemption”, on page 182.
- Starving jobs: Jobs that have been waiting for a specified amount of time can be given increased priority. See section 4.9.48, “Starving Jobs”, on page 225.
- Preventing preemption: You can prevent certain jobs from being preempted. See section 4.3.5.8, “Preventing Jobs from Being Preempted”, on page 69.
- Making preempted jobs top jobs: PBS can backfill around preempted jobs. See section 4.9.3.5, “Backfilling Around Preempted Jobs”, on page 108.
- Behavior overrides: you can intervene manually in how jobs are run. See section 4.9.30, “Overrides”, on page 164.

4.3.6 Resource Allocation to Users, Projects & Groups

If you need to ensure fairness, you may need to make sure that resources are allocated fairly. If different users, groups, or projects own or pay for different amounts of hardware or machine time, you may need to allocate resources according to these amounts or proportions.

You can allocate hardware-based resources such as CPUs or memory, and/or time-based resources such as walltime or CPU time, according to to the agreed amounts or proportions. You can also control who starts jobs.

4.3.6.1 Limiting Amount of Resources Used

4.3.6.1.i Allocation Using Resource Limits

You can use resource limits as a way to enforce agreed allocation amounts. This is probably the most straightforward way, and the easiest to explain to your users. PBS provides a system for limiting the total amount of each resource used by projects, users, and groups at the server and at each queue. For example, you can set a limit on the number of CPUs that any generic user can use at one time at QueueA, but set three different individual limits for each of three users that have special requirements, at the same queue. See section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

4.3.6.1.ii Allocation Using Fairshare

The PBS fairshare tool allows you to start jobs according to a formula based on resource usage by job owners. You can designate who the valid job owners are, which resources are being tracked, and how much of the resources each owner is allowed to be using. Fairshare uses a moving average of resource usage, so that a user who in the recent past has not used their share can use more now. For example, you can track usage of the cput resource, and give one group 40 percent of usage, one 50 percent, and one group, 10 percent. See section 4.9.19, “Using Fairshare”, on page 140.

4.3.6.1.iii Allocation Using Routing

If you do not want to place usage limits directly on projects, users, or groups, you can instead route their jobs to specific queues, where those queues have their own resource usage limits.

To route jobs this way, force users to submit jobs to a routing queue, and set access control limits at each execution queue. See section 8.3, “Using Access Control Lists”, on page 364. Make the routing queue be the default queue:

```
Qmgr: set server default_queue = <routing queue name>
```

Using this method, you place a limit for total resource usage at each queue, for each resource you care about. See section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

You can also route jobs to specific queues, where those queues can send jobs only to specific vnodes. See section 4.9.2, “Associating Vnodes with Queues”, on page 105.

4.3.6.2 Limiting Jobs

4.3.6.2.i Limiting Number of Jobs per Project, User, or Group

You can set limits on the numbers of jobs that can be run by projects, users, and groups. You can set these limits for each project, user, and group, and you can set them at the server and at each queue. You can set a generic limit for all projects, users, or groups, and individual limits that override the generic limit. For example, you can set a limit that says that no user at its partition can run more than 8 jobs. Then you can set a more specific limit for QueueA, so that users at QueueA can run 4 jobs. Then you can set a limit for User1 and User2 at QueueA, so that they can run 6 jobs. See section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

4.3.6.2.ii Allocation Using Round-robin Queue Selection

PBS can select jobs from queues by examining groups of queues in round-robin fashion, where all queues in each group have the same priority. When using the round-robin method, a scheduler considers the first queue in a group, tries to run the top job from that queue, then considers the next queue, tries to run the top job from that queue, then considers the next queue, and so on, in a circular fashion. A scheduler runs all the jobs it can from the highest-priority group first, then moves to the group with the next highest priority.

If you want a simple way to control how jobs are started, you can use round-robin where each queue in a group belongs to a different user or entity. See section 4.9.38, “Round Robin Queue Selection”, on page 206.

4.3.6.2.iii Limiting Resource Usage per Job

If you are having trouble with large jobs taking up too much of a resource, you can limit the amount of the resource being used by individual jobs. You can set these limits at each queue, and at the server. See section 5.15.2, “Placing Resource Limits on Jobs”, on page 307.

4.3.6.3 Resource Allocation Tools

The following is a list of scheduling tools that you can use for allocating resources or limiting resources or jobs:

- Matching: PBS places jobs where the available resources match the job's resource requirements; see section 4.9.28, "Matching Jobs to Resources", on page 161.
- Reservations: Users can create advance and standing reservations for specific resources for specific time periods. See section 4.9.37, "Reservations", on page 199.
- Fairshare: PBS tracks past usage of specified resources, and starts jobs based on specified usage ratios. See section 4.9.19, "Using Fairshare", on page 140.
- Routing: You can set up a queue system so that jobs with certain characteristics are routed to specific queues. See section 2.3.6, "Routing Queues", on page 27 and section 4.9.39, "Routing Jobs", on page 207.
- Limits on resource usage by projects, users, and groups: You can set limits on user and group resource usage. See section 4.9.26, "Limits on Project, User, and Group Resource Usage", on page 158.
- Round-robin job selection: PBS can select jobs from queues that have the same priority in a round-robin fashion. See section 4.9.38, "Round Robin Queue Selection", on page 206.
- Sorting queues: PBS always sorts queues into priority order. See section 4.9.47, "Sorting Queues into Priority Order", on page 225.
- Limits on number of jobs for projects, users, and groups: You can set limits on the numbers of jobs that can be run by projects, users, and groups. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.
- Limits on resources used by each job: You can set limits on the amount of each resource that any job can use. See section 4.9.24, "Limits on Per-job Resource Usage", on page 158.
- Using custom resources to limit resource usage: You use custom resources to manage usage. See section 4.9.8, "Using Custom and Default Resources", on page 115.
- Gating and admission requirements: You can specify admission requirements for jobs. See section 4.9.22, "Gating Jobs at Server or Queue", on page 157.
- Making jobs inherit default resources: You can use default resources to manage jobs. See section 4.9.8, "Using Custom and Default Resources", on page 115.

4.3.7 Time Slot Allocation

Time slot allocation is the process of creating time slots within which only specified jobs are allowed to run.

4.3.7.1 Why Allocate Time Slots

You may want to set up blocks of time during which only certain jobs are allowed to run. For example, you might need to ensure that specific high-priority jobs have their own time slot, so that they are guaranteed to be able to run and finish before their results are required.

You may want to divide jobs into those that run at night, when no one is around, and those that run during the day, because their owners need the results then.

You might want to run jobs on desktop clusters only at night, when the primary users of the desktops are away.

When you upgrade PBS, a chunk of dedicated time can come in very handy. You set up dedicated time for a time period that is long enough for you to perform the upgrade, and you make sure the time slot starts far enough out that no jobs will be running.

You may want to run different scheduling policies at different times or on different days.

4.3.7.2 How to Allocate Time Slots

Time slots are controlled by queues: primetime queues, non-primetime queues, dedicated time queues, and reservation queues. For this, you use your favorite routing method to move jobs into the desired queues. See section 4.9.39, "Routing Jobs", on page 207.

4.3.7.2.i Allocation Using Primetime and Holidays

You can specify how to divide up days or weeks, and designate each time period to be either primetime or non-primetime. You can use this division in the following ways:

- You can run a different policy during primetime from that during non-primetime
- You can run specific jobs during primetime, and others during non-primetime

See section 4.9.34, "Using Primetime and Holidays", on page 193.

4.3.7.2.ii Allocation Using Dedicated Time

Dedicated time is a time period where the only jobs that are allowed to run are the ones in dedicated time queues. The policy you use during dedicated time is controlled by the normal primetime and non-primetime policies; those times overlap dedicated time.

If you don't allow any jobs into a dedicated time queue, you can use it to perform maintenance, such as an upgrade.

See section 4.9.10, "Dedicated Time", on page 127.

4.3.7.2.iii Allocation Using Reservations

You and any other PBS user can create advance and standing reservations. These are time periods with a defined start and end, for a specific, defined set of resources. Reservations are used to make sure that specific jobs can run on time. See section 4.9.37, "Reservations", on page 199.

4.3.7.2.iv Allocation Using `cron` Jobs

You can use `cron` to run jobs at specific times. See section 4.9.7, "cron Jobs", on page 114.

4.3.7.3 Time Slot Allocation Tools

The following is a list of scheduling tools that you can use to create time slots:

- Primetime and holidays: You can specify days and times that are to be treated as prime execution time. See section 4.9.34, "Using Primetime and Holidays", on page 193.
- Dedicated time: You can set aside blocks of time reserved for certain system operations. See section 4.9.30.6, "Using Dedicated Time", on page 166.
- `cron` jobs: You can use `cron` to run jobs. See section 4.9.30.7, "Using cron Jobs", on page 166.
- Reservations: Users can create advance and standing reservations for specific resources for specific time periods. See section 4.9.37, "Reservations", on page 199.

4.3.8 Job Placement Optimization

PBS automatically places jobs where they can run, but you can refine how jobs are placed.

Optimizations are the techniques you use to increase throughput, turnaround, or efficiency, by taking advantage of where jobs can be run.

PBS places jobs according to placement optimization settings in tools to specify how vnodes should be organized, how jobs should be distributed, and how resources should be used.

4.3.8.1 Why Optimize Placement

PBS automatically places jobs where they can run, matching jobs to resources, so why optimize placement?

- You can help PBS refine its understanding of hardware topology, so that PBS can place jobs where they will run most efficiently.
- If you have some vnodes that are faster than others, you can preferentially place jobs on those vnodes.
- You may need to place jobs according to machine ownership, so that for example only jobs owned by a specific group run on a particular machine.
- You can take advantage of unused workstation computing capacity.
- You can balance the workload between two or more PBS partitions or complexes, trading jobs around depending on the workload on each partition or complex.
- You can specify whether or not certain vnodes should be used for more than one job at a time.
- You can tell PBS to avoid placing jobs on highly-loaded vnodes

4.3.8.2 Matching Jobs to Resources

By default, PBS places jobs where the available resources match the job's resource requirements. See section 4.9.28, "Matching Jobs to Resources", on page 161.

4.3.8.3 Organizing and Selecting Vnodes

By default, the order in which PBS examines vnodes is undefined. The default setting for vnode sorting is the following:

```
node_sort_key: "sort_priority HIGH all"
```

However, sort_priority means sort on each vnode's priority attribute, but by default, that attribute is unset.

PBS can organize vnodes into groups. By default, PBS does not organize vnodes into groups.

By default, when PBS chooses vnodes for a job, it runs down its list of vnodes, searching until it finds vnodes that can supply the job with the requested resources. You can improve this in two ways:

- PBS provides a way to organize your vnodes so that jobs can run on groups of vnodes, where the selected group of vnodes provides the job with good connectivity. This can improve memory access and interprocess communication timing. PBS then searches through these groups of vnodes, called *placement sets*, looking for the smallest group that satisfies the job's requirements. Each placement set is a group of vnodes that share a value for a resource. An illustrative example is a group of vnodes that are all connected to the same high speed switch, so that all of the vnodes have the same value for the switch resource. For detailed information on how placement sets work and how to configure them, see section 4.9.32, "Placement Sets", on page 170.
- By default, the order in which PBS examines vnodes, whether in or outside of placement sets, is undefined. PBS can sort vnodes on one or more keys. Using this tool, you can specify which vnodes should be selected first. For information on sorting vnodes on keys, see section 4.9.50, "Sorting Vnodes on a Key", on page 228.

You can sort vnodes in conjunction with placement sets.

4.3.8.4 Distributing Jobs

All of the following methods for distributing jobs can be used together.

4.3.8.4.i Filtering Jobs to Specific Vnodes

If you want to run certain kinds of jobs on specific vnodes, you can route those jobs to specific execution queues, and tie those queues to the vnodes you want. For example, if you want to route jobs requesting large amounts of memory to your large-memory machines, you can set up an execution queue called LMemQ, and associate that queue with the large-memory vnodes. You can route any kind of job to its own special execution queue. For example, you can route jobs owned by the group that owns a cluster to a special queue which is associated with the cluster. For details on routing jobs, see section 4.9.39, “Routing Jobs”, on page 207. For details on associating vnodes and queues, see section 4.9.2, “Associating Vnodes with Queues”, on page 105.

4.3.8.4.ii Running Jobs at Least-loaded Partition or Complex

You can set up cooperating PBS partitions and complexes that automatically run jobs from each other's queues. This allows you to dynamically balance the workload across multiple, separate PBS partitions and complexes. See section 4.9.31, “Peer Scheduling”, on page 167.

4.3.8.4.iii Using Idle Workstations

You can run jobs on workstations whenever they are not being used by their owners. PBS can monitor workstations for user activity or load, and run jobs when those jobs won't interfere with the user's operation. See section 4.9.9, “Using Idle Workstation Cycle Harvesting”, on page 117.

4.3.8.4.iv Avoiding Highly-loaded Vnodes

You can tell PBS not to run jobs on vnodes that are above a specified load. This is in addition to the default behavior, where PBS does not run jobs that request more of a resource than it thinks each vnode can supply. See section 4.9.27, “Using Load Balancing”, on page 158.

4.3.8.4.v Placing Job Chunks on Desired Hosts

You can tell PBS to place each job on as few hosts as possible, to place each chunk of a job on a separate host, a separate vnode, or on any vnode. You can specify this behavior for the jobs at a queue and at the server.

You can do the following

- Set default placement behavior for the queue or server: jobs inherit placement if they do not request it; see section 5.9.3.5, “Specifying Default Job Placement”, on page 248
- Use a hook to set each job's placement request (Resource_List.place). See the PBS Professional Hooks Guide

For more on placing chunks, see section 4.9.6, “Organizing Job Chunks”, on page 114.

For information on how jobs request placement, see section 2.59.2.6, “Requesting Resources and Placing Jobs”, on page 217.

4.3.8.5 Shared or Exclusive Resources and Vnodes

PBS can give jobs their own vnodes, or fill vnodes with as many jobs as possible. A scheduler uses a set of rules to determine whether a job can share resources or a host with another job. These rules specify how the vnode sharing attribute should be combined with a job's placement directive. The vnode's sharing attribute supersedes the job's placement request.

You can set each vnode's sharing attribute so that the vnode or host is always shared, always exclusive, or so that it honors the job's placement request. See section 4.9.41, “Shared vs. Exclusive Use of Resources by Jobs”, on page 212.

4.3.8.6 Tools for Organizing Vnodes

- Placement sets: PBS creates sets of vnodes organized by the values of multiple resources. See section 4.9.32, “Placement Sets”, on page 170.
- Sorting vnodes on keys: PBS can sort vnodes according to specified keys. See section 4.9.50, “Sorting Vnodes on a Key”, on page 228.

4.3.8.7 Tools for Distributing Jobs

- Routing: You can set up a queue system so that jobs with certain characteristics are routed to specific queues. See section 2.3.6, “Routing Queues”, on page 27 and section 4.9.39, “Routing Jobs”, on page 207.
- Associating vnodes with queues: You can specify that jobs in a given queue can run only on specific vnodes, and vice versa. See section 4.9.2, “Associating Vnodes with Queues”, on page 105.
- Idle workstation cycle harvesting: PBS can take advantage of unused workstation CPU time. See section 4.9.9, “Using Idle Workstation Cycle Harvesting”, on page 117.
- Peer scheduling: PBS partitions and complexes can exchange jobs. See section 4.9.31, “Peer Scheduling”, on page 167.
- Load balancing: PBS can place jobs so that machines have balanced loads. See section 4.9.27, “Using Load Balancing”, on page 158.
- SMP cluster distribution (**deprecated**): PBS can place jobs in a cluster as you specify. See section 4.9.43, “SMP Cluster Distribution”, on page 220.

4.3.9 Resource Efficiency Optimizations

PBS automatically runs each job where the resources required for the job are available. You can refine the choices PBS makes.

Resource optimizations are the techniques you use to increase throughput, turnaround, or efficiency, by taking advantage of how resources are used.

Before reading this section, please make sure you understand how resources are used by reading section 4.9.28, “Matching Jobs to Resources”, on page 161.

4.3.9.1 Why Optimize Use of Resources

You may want to take advantage of the following:

- If you are using strict ordering, you can prevent resources from standing idle while the top job waits for its resources to become available
- PBS can estimate the start times of jobs, so that users can stay informed
- PBS can provision vnodes with the environments that jobs require
- PBS can track resources that are outside of the control of PBS, such as scratch space
- You can take advantage of unused workstation computing capacity
- You can balance the workload between two or more PBS partitions or complexes, trading jobs around depending on the workload on each partition or complex.
- You can specify whether or not certain vnodes should be used for more than one job at a time.
- Users can specify that jobs that are dependent on the output of other jobs run only after the other jobs complete
- You can tell PBS to avoid placing jobs on highly-loaded vnodes

4.3.9.2 How to Optimize Resource Use

4.3.9.2.i Backfilling Around Top Jobs

PBS creates a list of jobs ordered by priority, and tries to run the jobs in order of priority. You can force all jobs to be run in exact order of their priority, using strict ordering. See section 4.9.49, “Using Strict Ordering”, on page 227. However, this can reduce resource utilization when the top job cannot run now and must wait for resources to become available, idling the entire partition or complex. You can offset this problem by using backfilling, where PBS tries to fit smaller jobs in around the top job that cannot run. The start time of the top job is not delayed. Job walltimes are required in order to use backfilling. You can specify the number of jobs around which to backfill. You can also disable this feature. See section 4.9.3, “Using Backfilling”, on page 107.

PBS can shrink the walltime of shrink-to-fit jobs into available time slots. These jobs can be used to backfill around top jobs and time boundaries such as dedicated time or reservations. See section 4.9.42, “Using Shrink-to-fit Jobs”, on page 213.

If you do not use strict ordering, PBS won't necessarily run jobs in exact priority order. PBS will instead run jobs so that utilization is maximized, while trying to preserve priority order.

4.3.9.2.ii Using Dependencies

Job submitters can specify dependencies between jobs. For example, if you have a data analysis job that must run after data collection and cleanup jobs, you can specify that. See section 4.9.11, “Dependencies”, on page 128.

4.3.9.2.iii Estimating Start Time for Jobs

You can tell PBS to estimate start times and execution vnodes for either the number of jobs being backfilled around, or all jobs. Users can then see when their jobs are estimated to start, and the vnodes on which they are predicted to run. See section 4.9.15, “Estimating Job Start Time”, on page 133.

4.3.9.2.iv Provisioning Vnodes with Required Environments

PBS can provision vnodes with environments (applications or operating systems) that jobs require. This means that a job can request a particular environment that is not yet on a vnode, but is available to be instantiated there. See section 4.9.35, “Provisioning”, on page 198.

4.3.9.2.v Tracking Dynamic Resources

You can use dynamic PBS resources to represent elements that are outside of the control of PBS, typically for application licenses and scratch space. You can represent elements that are available to the entire partition or PBS complex as server-level resources, or elements that are available at a specific host or hosts as host-level resources. For an example of configuring a server-level dynamic resource, see section 5.14.3.1.iii, “Example of Configuring Dynamic Server-level Resource”, on page 269. For an example of configuring a dynamic host-level resource, see section 5.14.4.1.i, “Example of Configuring Dynamic Host-level Resource”, on page 272.

For a complete description of how to create and use dynamic resources, see section 5.14, “Custom Resources”, on page 257.

4.3.9.3 Optimizing Resource Use by Job Placement

4.3.9.3.i Sending Jobs to Partition or Complex Having Lightest Workload

You can set up cooperating PBS partitions or complexes that automatically run jobs from each other's queues. This allows you to dynamically balance the workload across multiple, separate partitions or complexes. See section 4.9.31, “Peer Scheduling”, on page 167.

4.3.9.3.ii Using Idle Workstations

You can run jobs on workstations whenever they are not being used by their owners. PBS can monitor workstations for user activity or load, and run jobs when those jobs won't interfere with the user's operation. See section 4.9.9, "Using Idle Workstation Cycle Harvesting", on page 117.

4.3.9.3.iii Avoiding Highly-loaded Vnodes

You can tell PBS not to run jobs on vnodes that are above a specified load. This is in addition to the default behavior, where PBS does not run jobs that request more of a resource than it thinks each vnode can supply. See section 4.9.27, "Using Load Balancing", on page 158.

4.3.9.4 Resource Efficiency Optimization Tools

The following is a list of scheduling tools that you can use to optimize how resources are used:

- Backfilling around most important job(s): PBS can place small jobs in otherwise-unused blocks of resources. See section 4.9.3, "Using Backfilling", on page 107.
- Dependencies: Users can specify requirements that must be met by previous jobs in order for a given job to run. See section 4.9.11, "Dependencies", on page 128.
- Estimating start time of jobs: PBS can estimate when jobs will start, so that users can be informed. See section 4.9.15, "Estimating Job Start Time", on page 133.
- Provisioning vnodes with required environments: PBS can provision vnodes with the environments that jobs require. See section 4.9.35, "Provisioning", on page 198.
- Using dynamic resources: PBS can track resources such as scratch space and licenses. See section 4.9.12, "Dynamic Resources", on page 128.
- Idle workstation cycle harvesting: PBS can take advantage of unused workstation CPU time. See section 4.9.9, "Using Idle Workstation Cycle Harvesting", on page 117.
- Peer scheduling: PBS partitions and complexes can exchange jobs. See section 4.9.31, "Peer Scheduling", on page 167.
- Load balancing: PBS can place jobs so that machines have balanced loads. See section 4.9.27, "Using Load Balancing", on page 158.

4.3.10 Overrides

Overrides are the techniques you use to override the specified scheduling behavior of PBS.

4.3.10.1 Why and How to Override Scheduling

- If you need to run a job immediately, you can tell PBS to run a job now. You can optionally specify the vnodes and resources to run it. See section 4.9.30.1, “Run a Job Manually”, on page 164.
- If you need to prevent a job from running, you can tell PBS to place a hold on a job. See section 4.9.30.2, “Hold a Job Manually”, on page 165.
- If you need to change how the formula computes job priority, you can make on-the-fly changes to how the formula is computed. See section 4.9.30.5, “Change Formula On the Fly”, on page 166.
- If you need a block of time where you can control what's running, for example for upgrading PBS, you can create dedicated time. See section 4.9.30.6, “Using Dedicated Time”, on page 166.
- If you need to submit jobs at a certain time, you can use `cron` to run jobs. See section 4.9.30.7, “Using cron Jobs”, on page 166.
- If you need to change job resource requests, programs, environment, or attributes, you can use hooks to examine jobs and alter their characteristics. See the *PBS Professional Hooks Guide*.
- If you need to prevent a scheduler from calendaring jobs, you can set their topjob_ineligible attribute to *True*. See section 4.9.17, “Calendaring Jobs”, on page 139.

4.4 Choosing a Policy

4.4.1 Overview of Kinds of Policies

You can tune PBS to produce any of a wide selection in scheduling behaviors. You can choose from a wide variety of behaviors for each sub-goal, resulting in many possible scheduling policies. However, policies can be grouped into the following kinds:

- FIFO, where you essentially run jobs in the order in which they were submitted; see section 4.4.2, “FIFO: Submission Order”, on page 81
- According to user or group priority, where the job's priority is determined by the owner's priority; see section 4.4.3, “Prioritizing Jobs by User, Project or Group”, on page 82
- According to resource allocation rules, where jobs are run so that they use resources following a set of rules for how resources should be awarded to users or groups; see section 4.4.4, “Allocating Resources by User, Project or Group”, on page 82
- According to the size of the job, for example measured by CPU or memory request; see section 4.4.5, “Scheduling Jobs According to Size Etc.”, on page 84
- By setting up time slots for specific uses; see section 4.4.6, “Scheduling Jobs into Time Slots”, on page 86

4.4.2 FIFO: Submission Order

If you want jobs to run in the order in which they are submitted, use FIFO. You can use FIFO across the entire partition or complex, or within each queue.

If it's important that jobs run exactly in submission order, use FIFO with strict ordering. However, if you don't want resources to be idle while a top job is stuck, you can use FIFO with strict ordering and backfilling.

To run jobs in submission order, see section 4.9.20.1, “Configuring Basic FIFO Scheduling”, on page 150 .

To run jobs in submission order across the entire partition or complex, see section 4.9.20.2, “FIFO for Entire Partition Or Complex”, on page 150.

To run jobs in submission order, examining queues in order of queue priority, see section 4.9.20.3, “Queue by Queue FIFO”, on page 151.

To run jobs in submission order, with strict ordering, see section 4.9.20.4, “FIFO with Strict Ordering”, on page 151.

To run jobs in submission order, with strict ordering and backfilling, see section 4.9.20.5, “FIFO with Strict Ordering and Backfilling”, on page 151.

4.4.3 Prioritizing Jobs by User, Project or Group

If you need to run jobs from some users, groups, or projects before others, you can prioritize jobs using the following techniques:

- Routing each entity's jobs to its own execution queue, assigning the queue the desired priority, and examining jobs queue by queue. See the following:
  - For routing: section 2.3.6, “Routing Queues”, on page 27
  - For setting queue priority: section 2.3.5.3, “Prioritizing Execution Queues”, on page 26
  - For examining jobs queue by queue: section 4.9.4, “Examining Jobs Queue by Queue”, on page 112
- Routing each entity's jobs to its own execution queue, where the jobs inherit a custom resource that you use in the job sorting formula. See the following:
  - For routing: section 2.3.6, “Routing Queues”, on page 27
  - For inherited resources: section 14.3, “Allocating Resources to Jobs”, on page 507
  - For the job sorting formula: section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151
- Using a hook to allocate a custom resource to each job, where the hook sets the value according to the priority of the job's owner, group, or project, then using the resource in the job sorting formula. See the following:
  - For hooks: the PBS Professional Hooks Guide
  - For custom resources: section 5.14, “Custom Resources”, on page 257
  - For the job sorting formula: section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151
- Assigning a greater fairshare allocation in the fairshare tree to the users or groups whose jobs must run first, and running jobs according to entity shares. See the following:
  - For fairshare: section 4.9.19, “Using Fairshare”, on page 140
  - For entity shares: section 4.9.14, “Sorting Jobs by Entity Shares (Was Strict Priority)”, on page 133

4.4.4 Allocating Resources by User, Project or Group

When you want to divide up hardware usage among users, groups, or projects, you can make sure you allocate resources along those lines. You can do this in the following ways:

- Allocate portions of the entire partition or complex to each entity; see section 4.4.4.1, “Allocating Portions of Partition Or Complex”, on page 83
- Allocate portions of all machines or clusters to each entity, or use controlled allocation for some hardware, with a free-for-all elsewhere; see section 4.4.4.2, “Allocating Portions of Machines or Clusters”, on page 83
- Lock entities into using specific hardware; see section 4.4.4.3, “Locking Entities into Specific Hardware”, on page 84

4.4.4.1 Allocating Portions of Partition Or Complex

4.4.4.1.i Allocating Specific Amounts

To allocate specific amounts of resources across the entire partition or complex, you can use resource limits at the server. These limits set the maximum amount that can be used, ensuring that projects, users, or groups stay within their bounds. You can set a limit for each resource, and make it different for each project, user, and group. You can set a different limit for each project, user, and group, for each resource.

For example, you can set a limit of 48 CPUs in use at once by most groups, but give groupA a limit of 96 CPUs. You can give each individual user a limit of 8 CPUs, but give UserA a limit of 10 CPUs, and UserB a limit of 4 CPUs.

To set limits for usage across the entire partition or complex, set the limits at the server.

See section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

4.4.4.1.ii Allocating Percentages

To allocate a percentage of the resources being used in the partition managed by a scheduler, you can use fairshare. Fairshare tracks a moving average of resource usage, so it takes past use into account. You choose which resources to track. You can tune the influence of past usage.

To use fairshare across the entire partition or complex, make sure that both by_queue and round_robin are *False*.

Fairshare is described in section 4.9.19, “Using Fairshare”, on page 140.

4.4.4.2 Allocating Portions of Machines or Clusters

You can allocate fixed amounts of a machine or groups of machines. You can do this for as many machines as you want. For example, on HostA, you can give GroupA 100 CPUs, GroupB 150 CPUs, and GroupC 50 CPUs, while at HostB, GroupA gets 10, GroupB gets 8, and GroupC gets 25.

To allocate fixed portions of a specific machine or group of machines, you use these tools in combination:

- Create an execution queue for this machine; see section 2.3.3, “Creating Queues”, on page 24.
- Route jobs belonging to the users or groups who share this machine into a queue. Each machine or cluster that requires controls gets its own queue. See section 4.9.39, “Routing Jobs”, on page 207.
- Associate the queue with the vnodes in question; see section 4.9.2, “Associating Vnodes with Queues”, on page 105.
- Set a limit at the queue for each resource that you care about, for each project, user, or group. These limits control use of the vnodes associated with the queue only. See section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

You can prevent unauthorized usage by setting generic project, user, and group limits for the machine's queue to zero. However, you probably don't want users to submit their jobs to a queue where they are not allowed to run, only to have those jobs languish. You can avoid this by doing the following:

- Setting up a routing queue; see section 2.3.6, “Routing Queues”, on page 27.
- Making the routing queue be the default queue:

  ```
  Qmgr: set server default_queue = <routing queue name>
  ```
- Making the routing queue the only queue that accepts job submission: set from_route_only to *True* on execution queues tied to hardware. See section 2.3.5.1, “Where Execution Queues Get Their Jobs”, on page 25.
- Using queue access control to limit which jobs are routed into the execution queue; see section 2.3.6.5, “Using Access Control to Route Jobs”, on page 31.

You can either set up allocations for every machine, or you can set up allocations for only some machines, leaving a free-for-all for the others. If you want access to be unrestricted for some machines, do not set limits at the server.

4.4.4.3 Locking Entities into Specific Hardware

You can send all jobs from some projects, users, or groups to designated hardware, essentially limiting them to a sandbox. To do this, do the following:

- Create an execution queue for the sandbox hardware; see section 2.3.3, "Creating Queues", on page 24.
- Create at least one other execution queue; see section 2.3.3, "Creating Queues", on page 24.
- Create a routing queue; see section 2.3.3, "Creating Queues", on page 24.
- Make the routing queue be the default queue:

  ```
  Qmgr: set server default_queue = <routing queue name>
  ```
- Force all users to submit jobs to the routing queue: set from_route_only to *True* on all other queues. See section 2.3.5.1, "Where Execution Queues Get Their Jobs", on page 25.
- Use queue access control to route according to user or group: route jobs from the controlled users or groups into the sandbox queue only. See section 2.3.6.5, "Using Access Control to Route Jobs", on page 31.
- Use a job submission hook to route according to project: route the jobs from the desired project(s) to the sandbox queue. See the PBS Professional Hooks Guide.
- Associate the sandbox queue with the sandbox vnodes. See section 4.9.2, "Associating Vnodes with Queues", on page 105.

Note that you can either allow all projects, users, or groups into the sandbox queue, or allow only the controlled projects, users, or groups into the sandbox queue.

4.4.5 Scheduling Jobs According to Size Etc.

You may need to treat jobs differently depending on their size or other characteristics. For example, you might want to run jobs differently depending on the number of CPUs or amount of memory requested by the job, or whether the job requests GPUs.

- Give special priority to a group of jobs
- Run a group of jobs on designated hardware
- Run a group of jobs in designated time slots: reservations, dedicated time, and primetime or non-primetime

There are two main approaches to doing this. You can route jobs into queues, or you can use hooks to set values. Here is an outline:

- Route certain kinds of jobs into their own queues, in order to treat each kind differently. This works for priority, hardware, and time slots. See section 4.4.5.1, "Special Treatment via Routing", on page 84
  - Route each kind to its own queue, using queue-based routing or a submission hook;
  - Use queue-based methods to set job priority or to run the jobs on certain hardware or in certain time slots
- Use hooks to set priority for jobs or to set a custom resource that will send jobs to certain hardware. This does not work for time slots. See section 4.4.5.2, "Special Treatment via Hooks", on page 86.
  - Use a submission hook to set each job's Priority attribute, or set a value for a custom resource used in the job sorting formula
  - Use a submission hook to set a custom host-level resource value for each job, where the value matches the value at the desired hardware

4.4.5.1 Special Treatment via Routing

Use a routing queue or a hook to route jobs into a special queue, where the jobs are given special priority, or are run on special hardware, or are run in special time slots.

4.4.5.1.i Routing via Queues

- Create your destination queues. See section 2.3.3, "Creating Queues", on page 24.
- Set limits at the destination queues, so that each queue receives the correct jobs. See section 2.3.6.4, "Using Resources to Route Jobs Between Queues", on page 28.
- Create a routing queue, and set its destination queues. See section 2.3.6, "Routing Queues", on page 27.
- Make the routing queue be the default queue:

  ```
  Qmgr: set server default_queue = <routing queue name>
  ```

4.4.5.1.ii Using Hooks to Route Jobs

You can use a submission hook to move jobs into the queues you want. See section 4.9.39.2.ii, "Hooks as Mechanism to Move Jobs", on page 209.

4.4.5.1.iii Giving Routed Jobs Special Priority

You can give routed jobs special priority in the following ways:

- Have the jobs inherit a custom resource from the special queue, and use this resource in the job sorting formula.
  - For how to have jobs inherit custom resources, see section 14.3, "Allocating Resources to Jobs", on page 507.
  - For how to use the job sorting formula, see section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.
- Give the queue itself special priority, and use queue priority in the job sorting formula.
  - For how to assign priority to queues, see section 2.3.5.3, "Prioritizing Execution Queues", on page 26
  - For how to use the job sorting formula, see section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

4.4.5.1.iv Running Jobs on Special Vnodes

Now that the special jobs are routed to a special queue, associate that queue with the special vnodes. See section 4.9.2, "Associating Vnodes with Queues", on page 105.

4.4.5.1.v Running Jobs in Special Time Slots

If you want to run jobs during dedicated time, route the jobs into one or more dedicated time queues. In the same way, for primetime or non-primetime, route jobs into primetime or non-primetime queues. You can also route jobs into reservation queues for reservations that you have created for this purpose.

For using dedicated time, see section 4.9.10, "Dedicated Time", on page 127

For using primetime and non-primetime, see section 4.9.34, "Using Primetime and Holidays", on page 193

For using reservations, see section 4.9.37, "Reservations", on page 199

4.4.5.2 Special Treatment via Hooks

4.4.5.2.i Setting Job Priority Via Hook

You can set a job's Priority attribute using a hook. Note that users can `qalter` the job's Priority attribute. Use a job submission hook to set the job priority, by doing one of the following:

- Set a custom numeric resource for the job, and use the resource in the job sorting formula
  - For how to use hooks, see the PBS Professional Hooks Guide
  - For how to use the job sorting formula, see section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.
- Set the job's Priority attribute, and sort jobs on a key, where the key is the job's Priority attribute.
  - For how to set job attributes, see the PBS Professional Hooks Guide
  - For how to sort jobs on a key, see section 4.9.45, "Sorting Jobs on a Key", on page 223

4.4.5.2.ii Routing Jobs to Hardware via Hooks

You can send jobs to particular hardware without using a particular queue, by using a hook. See section 4.9.39.4.i, "Using Hooks to Tag Jobs", on page 210.

4.4.6 Scheduling Jobs into Time Slots

You can schedule jobs in time slots in the following ways:

- Set aside time slots for specific entities; see section 4.4.6.1, "Setting Aside Time Slots for Entities", on page 86
- Lock entities into specific time slots; see section 4.4.6.2, "Locking Entities into Time Slots", on page 87

4.4.6.1 Setting Aside Time Slots for Entities

You can set aside time slots that are reserved exclusively for certain users or groups. You can use reservations, dedicated time, primetime, or non-primetime.

4.4.6.1.i Reservations

Reservations set aside one or more blocks of time on the requested resources. Users can create their own reservations, or you can create them and set their access control to allow only specified users to submit jobs to them. See section 4.9.37, "Reservations", on page 199.

4.4.6.1.ii Dedicated Time

During dedicated time, the only jobs allowed to run are those in dedicated queues. The drawback to dedicated time is that it applies to the entire partition or complex. If you want to set aside one or more dedicated time slots for a user or group, do the following:

- Create a dedicated queue. See section 2.3.5.2.i, "Dedicated Time Queues", on page 26.
- Define dedicated time. See section 4.9.10, "Dedicated Time", on page 127.
- Set access control on the dedicated queue so that only the particular users or groups you want can submit jobs to the queue. See section 2.3.6.5, "Using Access Control to Route Jobs", on page 31.
- If you want to limit access on a dedicated queue to a specific project, set the generic limit for queued jobs for projects at that queue to zero, and then set the individual limit for the specific project higher.

4.4.6.1.iii Non-primetime

You can set up primetime and non-primetime so that one of them, for example, non-primetime, is used as a special time slot allocated to particular users or groups. The advantage of using non-primetime is that you can set up a separate scheduling policy for it, for example, using fairshare during non-primetime and sorting jobs on a key during primetime. Note that the formula, if defined, is in force all of the time. To use non-primetime, do the following:

- Create a non-primetime queue; see section 2.3.3, "Creating Queues", on page 24 and section 2.3.5.2.ii, "Primetime and Non-Primetime Queues", on page 26.
- Define primetime and non-primetime; see section 4.9.34, "Using Primetime and Holidays", on page 193.
- Set access control on the non-primetime queue so that only the particular users or groups you want can submit jobs to the queue. See section 2.3.6.5, "Using Access Control to Route Jobs", on page 31.
- Make sure that the scheduling policy you want is in force during non-primetime. See section 4.9.34.1, "How Primetime and Holidays Work", on page 194.

4.4.6.2 Locking Entities into Time Slots

You can make all jobs from some users or groups run during designated time slots. You can run them during a reservation, dedicated time, or non-primetime.

4.4.6.2.i Locking Entities into Reservations

To allow a user to submit jobs only into a reservation, do the following:

- Create a reservation for the resources and time(s) you want the controlled user(s) to use. When creating the reservation, set access control to allow the controlled user(s). See section 4.9.37, "Reservations", on page 199 and section 8.3.8.3, "Setting and Changing Reservation Access", on page 374.
- Set access control on all queues except the reservation's queue to deny the controlled user(s); see section 2.3.6.5, "Using Access Control to Route Jobs", on page 31.

4.4.6.2.ii Locking Entities into Dedicated Time

You can create a dedicated time queue, and send all jobs from controlled projects, users, or groups to that queue. You can route their jobs to it, and you can allow them to submit directly to it. To lock one or more projects, users, or groups into one or more dedicated time slots, do the following:

- Create a dedicated time queue; see section 2.3.3, "Creating Queues", on page 24 and section 2.3.5.2.i, "Dedicated Time Queues", on page 26.
- Create at least one other execution queue; see section 2.3.3, "Creating Queues", on page 24.
- Create a routing queue; see section 2.3.3, "Creating Queues", on page 24.
- Prevent controlled users from submitting to non-dedicated time execution queues: set from_route_only to *True* on the non-dedicated time execution queues. See section 2.3.5.1, "Where Execution Queues Get Their Jobs", on page 25.
- Use queue access control to allow jobs from the controlled users or groups into the dedicated time queue only. See section 2.3.6.5, "Using Access Control to Route Jobs", on page 31
- Use a job submission hook to route jobs from controlled projects into the dedicated time queue. See the PBS Professional Hooks Guide
- .Make the routing queue be the default queue:

  ```
  Qmgr: set server default_queue = <routing queue name>
  ```

Note that you can either allow all users into the dedicated time queue, or allow only the controlled users into the dedicated time queue.

4.4.6.2.iii Locking Entities into Non-primetime

You can create a non-primetime queue, and send all jobs from controlled users, groups, or projects to that queue. You can route their jobs to it, and you can allow them to submit directly to it. To lock one or more users, groups, or projects into one or more non-primetime slots, do the following:

- Create a non-primetime queue; see section 2.3.3, “Creating Queues”, on page 24 and section 2.3.5.2.ii, “Primetime and Non-Primetime Queues”, on page 26.
- Create at least one other execution queue; see section 2.3.3, “Creating Queues”, on page 24.
- Create a routing queue; see section 2.3.3, “Creating Queues”, on page 24.
- Prevent controlled users from submitting to primetime execution queues: set from_route_only to *True* on the primetime execution queues. See section 2.3.5.1, “Where Execution Queues Get Their Jobs”, on page 25.
- Make the routing queue be the default queue:

  ```
  Qmgr: set server default_queue = <routing queue name>
  ```
- Use queue access control to allow jobs from the controlled users or groups into the non-primetime queue only. See section 2.3.6.5, “Using Access Control to Route Jobs”, on page 31.
- Use a job submission hook to route jobs from controlled projects into the non-primetime queue. See the PBS Professional Hooks Guide
- Define primetime and non-primetime; see section 4.9.34, “Using Primetime and Holidays”, on page 193.
- Make sure that the scheduling policy you want is in force during non-primetime. See section 4.9.34.1, “How Primetime and Holidays Work”, on page 194.

Note that you can either allow all users into the non-primetime queue, or allow only the controlled users into the non-primetime queue.

4.4.7 Default Scheduling Policy

The default scheduling policy is determined by the default settings for all of the attributes, parameters, etc. that determine a scheduler's behavior. For a list of all of these elements, see section 4.5.1, “Configuring a Scheduler”, on page 91.

The default behavior of a scheduler is the following:

- A scheduler matches jobs with available resources. This means that a scheduler places each job only where that job has enough resources to run. See section 4.9.28, “Matching Jobs to Resources”, on page 161.
- A scheduler will not over-allocate the resources that are listed in the scheduler's resources parameter. The defaults for these are ncpus, mem, arch, host, vnode, aoe. See section 4.9.28.1, “Scheduling on Consumable Resources”, on page 161.
- A scheduler sorts vnodes according to its node_sort_key parameter, whose default setting is the following:

  ```
  node_sort_key: "sort_priority HIGH all"
  ```

  This means that vnodes are sorted by the value of their priority attribute, with high-priority vnodes used first. A scheduler places jobs first on vnodes that are first in the sorted list.

  Note that all vnodes have the same default priority upon creation, so the default sorted order for vnodes is undefined.

See section 4.9.50, “Sorting Vnodes on a Key”, on page 228.

- Queues are sorted according to the value of their priority attribute, so that queues with a higher priority are considered before those with a lower priority. See section 2.3.5.3, “Prioritizing Execution Queues”, on page 26.
- Jobs are considered according to the priority of their queues. A scheduler runs all of the jobs that it can from the highest-priority queue before moving to the next queue, and so on. See section 4.9.4, “Examining Jobs Queue by Queue”, on page 112.
- Within each queue, jobs are considered in submission order.
- Starving jobs are given a special priority called *starving*. The default time required to become a starving job is 24 hours. See section 4.9.48, “Starving Jobs”, on page 225.
- Jobs in an express queue are placed in the *express_queue* preemption priority level. They are also placed in the *Express* execution priority class. The default priority for a queue to be an express queue is 150. See section 2.3.5.3.i, “Express Queues”, on page 26.
- Queued jobs are sorted according to their priority. Special jobs are all prioritized ahead of normal jobs, without regard to the queue in which they reside. The order for job priority for special jobs, highest first, is reservation jobs, jobs in express queues, preempted jobs, starving jobs. After this, a scheduler looks at normal jobs, queue by queue. All jobs in express queues, all preempted jobs, and all starving jobs are considered before a scheduler looks at the individual queues.

  See section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- A scheduler will preempt lower-priority jobs in order to run higher-priority jobs (preemptive_sched is *True* by default). By default, it has two levels of job priority, *express_queue*, and *normal_jobs*, where *express_queue* jobs can preempt *normal_jobs*. This is set in the scheduler's preempt_prio attribute.

  When a scheduler chooses among jobs of the same priority for a job to preempt, it uses the only setting for preempt_sort, which is *min_time_since_start*, choosing jobs that have been running for the shortest time.

  When a scheduler chooses how to preempt a job, it uses the default setting for its preempt_order attribute, which is *SCR*, meaning that first it will attempt suspension, then checkpointing, then if necessary requeueing.

  See section 4.9.33, “Using Preemption”, on page 182.
- A scheduler will do its best to backfill smaller jobs around the job it has decided is the most important job. See section 4.9.3, “Using Backfilling”, on page 107.
- Primetime by default is 24/7. Any holiday is considered non-primetime. You can define primetime and holidays in the file `<sched_priv directory>/holidays`. These dates should be adjusted yearly to reflect your local holidays. See section 4.9.34, “Using Primetime and Holidays”, on page 193.
- A scheduler runs every 10 minutes unless a new job is submitted or a job finishes execution. See section 4.5.5, “The Scheduling Cycle”, on page 98.
- In TPP mode, a scheduler runs with the throughput_mode scheduler attribute set to *True* by default, so the scheduler runs asynchronously, and doesn't wait for each job to be accepted by MoM, which means it also doesn't wait for an execjob_begin hook to finish. Especially for short jobs, this can give better scheduling performance.

  When throughput_mode is *True*, jobs that have been changed can run in the same scheduling cycle in which they were changed, for the following changes:
  - Jobs that are qaltered
  - Jobs that are changed via server_dyn_res scripts
  - Jobs that are peered to a new queue

  See “Scheduler Attributes” on page 300 of the PBS Professional Reference Guide.

4.4.8 Examples of Workload and Policy

- If you need to have high-priority jobs run soon, and nothing distinguishes the high-priority jobs from the rest:
  - Create advance reservations for the high-priority jobs, and have users submit those jobs to the reservations; see section 4.9.37, “Reservations”, on page 199
- If you want to run jobs in submission order:
  - FIFO; see section 4.9.20, “FIFO Scheduling”, on page 150
- If you have low-priority jobs that should run only when other jobs don't need the resources:
  - Set up an anti-express queue; see section 4.9.1, “Anti-Express Queues”, on page 104
- If you have a mix of jobs, and want to run big jobs first:
  - Sort jobs on a key, using ncpus as the key, to run big jobs first; see section 4.4.5, “Scheduling Jobs According to Size Etc.”, on page 84
- If you have a mix of jobs, and want to give big jobs high priority, but avoid having idle resources:
  - Sort jobs on a key, using ncpus as the key, to run big jobs first; see section 4.4.5, “Scheduling Jobs According to Size Etc.”, on page 84
  - Use backfilling; see section 4.9.3, “Using Backfilling”, on page 107
- If you want to have all users start about the same number of jobs:
  - Use round robin, give each user their own queue, and give each queue the same priority; see section 4.9.38, “Round Robin Queue Selection”, on page 206
- If you want to always give each user access to a certain amount of a resource, but allow more if no one else is using it:
  - Use soft limits for the amount each user can use; see section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290 and section 4.9.33, “Using Preemption”, on page 182
- If your partition or site has more than one funding source:
  - See section 4.4.4, “Allocating Resources by User, Project or Group”, on page 82
- If you have lots of users in a partition or complex:
  - Use resource limits; see section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290, or
  - Use fairshare; see section 4.9.19, “Using Fairshare”, on page 140
- If you have jobs that must run at the end of the day:
  - Use dependencies for end-of-day accounting; see section 4.9.11, “Dependencies”, on page 128
- If you need to ensure that jobs run in certain hours on desktops:
  - Use cycle harvesting; see section 4.9.9, “Using Idle Workstation Cycle Harvesting”, on page 117, or
  - Use primetime & non-primetime for nighttime; see section 4.9.34, “Using Primetime and Holidays”, on page 193
- If you want to be sure a job will run:
  - Create an advance reservation; see section 4.9.37, “Reservations”, on page 199
- If you have more than one partition or complex, and you want to balance the workload across the partitions or complexes:
  - Use peer scheduling; see section 4.9.31, “Peer Scheduling”, on page 167
- If you have some jobs that should prefer to run on one set of vnodes, and other jobs that should prefer to run on another set of vnodes, but if the preferred vnodes are busy, a job can run on the non-preferred vnodes:
  - Use peer scheduling. Set up two partitions or complexes, give the pulling queues low priority, and use queue

priority in the job sorting formula. See section 4.9.31, "Peer Scheduling", on page 167, section 2.3.5.3, "Prioritizing Execution Queues", on page 26, and section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151. You can use a routing queue to initially send jobs to the correct partition or complex. See section 2.3.6, "Routing Queues", on page 27

- If you have two (or more) sets of vnodes, and jobs should run on one set or the other, but not both. Additionally, jobs should not have to request where they run. For example, one set of vnodes is new, and one is old:
  - Use a routing queue and two execution queues. Associate each execution queue with one set of vnodes. Put the execution queue for the preferred set of vnodes first in the routing list, but put a limit on the number of queued jobs in the execution queues, so that both queues will fill up. Otherwise the routing queue will preferentially fill the first in its routing list. See section 2.3.6, "Routing Queues", on page 27, and section 4.9.2, "Associating Vnodes with Queues", on page 105
- If you need to apportion a single vnode or cluster according to ownership:
  - See section 4.4.4, "Allocating Resources by User, Project or Group", on page 82
- If you have more than one high-priority queue, and at least one low-priority queue, and you want all jobs in high-priority queues to be considered as one group, and run in submission order:
  - Use the job sorting formula to sort jobs on queue priority:

    ```
    set server job_sort_formula = queue_priority
    ```
  - Give all queues whose jobs should be considered together the same priority
  - Set the by_queue scheduler attribute to *False*
- If you want to place jobs on the vnodes with the fewest CPUs first, saving bigger vnodes for larger jobs:
  - Sort vnodes so that those with fewer CPUs come first:

    ```
    node_sort_key: "ncpus LOW"
    ```

4.5 About Schedulers

Each scheduler, `pbs_sched`, implements its own scheduling policy.

4.5.1 Configuring a Scheduler

4.5.1.1 Where a Scheduler Gets Its Information

Each scheduler has its own `sched_priv` directory, where it keeps scheduler-specific files. For a multisched, this is `$PBS_HOME/sched_priv_<scheduler name>`; for the default scheduler, it is always `$PBS_HOME/sched_priv/`.

The behavior of a scheduler is controlled by the information provided by the following sources:

PBS_est

Hook that runs estimator process which calculates estimated start time and vnodes for jobs. See section 4.9.15, "Estimating Job Start Time", on page 133.

<sched_priv directory>/resource_group

Contains the description of the fairshare tree. Created by you. Can be edited. Read on startup and HUP of scheduler.

<sched_priv directory>/usage

Contains the usage database. Do not edit. Instead, use the `pbsfs` command while a scheduler is stopped; see "pbsfs" on page 32 of the PBS Professional Reference Guide.

<sched_priv directory>/sched_config

Contains scheduler configuration options, also called scheduler parameters, e.g. fairshare_decay_time, job_sort_key. Read on startup and HUP.

Can be edited. Each entry must be a single, unbroken line. Entries must be double-quoted if they contain whitespace.

See "Scheduler Parameters" on page 251 of the PBS Professional Reference Guide.

<sched_priv directory>/dedicated_time

Contains definitions of dedicated time. Can be edited. Read on startup and HUP.

<sched_priv directory>/holidays

Where you define primetime, non-primetime, and holidays. Can be edited. Read on startup and HUP.

Options to `pbs_sched` command

Control some scheduler behavior. Set on invocation. See "pbs_sched" on page 106 of the PBS Professional Reference Guide.

Scheduler attributes

Control some scheduler behavior. Can be set using `qmgr`. Read every scheduling cycle. See "Scheduler Attributes" on page 300 of the PBS Professional Reference Guide.

Server attributes

Several server attributes control scheduler behavior. Can be set using `qmgr`. The following table lists the server attributes that affect scheduling, along with a brief description. Read every scheduling cycle.

Some limit attributes are marked as "old". These are incompatible with, and are replaced by, the new limit attributes described in section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

For a complete description of each attribute, see "Server Attributes" on page 283 of the PBS Professional Reference Guide.

Table 4-1: Server Attributes Involved in Scheduling

Attribute	Effect
backfill_depth	Specifies backfilling behavior. Sets the number of jobs that are to be backfilled around.
default_queue	Specifies queue for jobs that don't request a queue
eligible_time_enable	Controls starving behavior.
est_start_time_freq	**Obsolete**. Not used. Interval at which PBS calculates estimated start times and vnodes for all jobs.
job_sort_formula	Formula for computing job priorities.
max_group_res	Old. The maximum amount of the specified resource that any single group may consume in this PBS complex.
max_group_res_soft	Old. The soft limit for the specified resource that any single group may consume in this complex.

Table 4-1: Server Attributes Involved in Scheduling

Attribute	Effect
max_group_run	Old. The maximum number of jobs owned by the users in one group allowed to be running within this complex at one time.
max_group_run_soft	Old. The maximum number of jobs owned by the users in one group allowed to be running in this complex at one time.
max_queued	The maximum number of jobs allowed to be queued or running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_queued_res.<resource name>	The maximum amount of the specified resource allowed to be allocated to jobs queued or running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_run	The maximum number of jobs allowed to be running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_run_res.<resource name>	The maximum amount of the specified resource allowed to be allocated to jobs running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_run_res_soft.<resource name>	Soft limit on the amount of the specified resource allowed to be allocated to jobs running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_run_soft	Soft limit on the number of jobs allowed to be running in the partition managed by a scheduler. Can be specified for users, groups, or all.
max_running	Old. The maximum number of jobs allowed to be selected for execution at any given time, from all possible jobs.
max_user_res	Old. The maximum amount within this complex that any single user may consume of the specified resource.
max_user_res_soft	Old. The soft limit on the amount of the specified resource that any single user may consume within a complex.
max_user_run	Old. The maximum number of jobs owned by a single user allowed to be running within the partition managed by a scheduler at one time.
max_user_run_soft	Old. The soft limit on the number of jobs owned by a single user that are allowed to be running within this complex at one time.
node_fail_requeue	Controls whether running jobs are automatically requeued or are deleted when the primary execution host fails. Number of seconds to wait after losing contact with the primary execution host MoM before requeueing or deleting jobs. See "node_fail_requeue" on page 292 of the PBS Professional Reference Guide.
node_group_enable	Specifies whether node grouping is enabled.
node_group_key	Specifies the resource to use for node grouping.

Table 4-1: Server Attributes Involved in Scheduling

Attribute	Effect
resources_available	The list of available resources and their values defined on the server.
resources_max	The maximum amount of each resource that can be requested by any single job in this complex, if there is not a resources_max value defined for the queue at which the job is targeted.
scheduler_iteration **deprecated**	The time between scheduling iterations.
scheduling **deprecated**	Enables scheduling of jobs.
resources_assigned	The total of each type of resource allocated to jobs running and exiting in this complex, plus the total of each type of resource allocated to any started reservations.

Vnode attributes

Several vnode attributes control scheduler behavior. Can be set using `qmgr`. The following table lists the vnode attributes that affect scheduling, along with a brief description. Read every scheduling cycle. For a complete description of each attribute, see "Vnode Attributes" on page 322 of the PBS Professional Reference Guide.

Table 4-2: Vnode Attributes Involved in Scheduling

Attribute	Effect
current_aoe	This attribute identifies the AOE currently instantiated on this vnode.
no_multinode_jobs	Controls whether jobs which request more than one chunk are allowed to execute on this vnode.
partition	The partition to which this vnode is assigned.
pcpus	The number of physical CPUs on the vnode.
priority	The priority of this vnode compared with other vnodes.
provision_enable	Controls whether this vnode can be provisioned.
queue **deprecated**	The queue with which this vnode is associated.
resources_assigned	The total amount of each resource allocated to running and exiting jobs and started reservations running on this vnode.
resources_available	The list of resources and the amounts available on this vnode
sharing	Specifies whether more than one job at a time can use the resources of the vnode or the vnode's host.
state	Shows or sets the state of the vnode.

Queue attributes

Several queue attributes control scheduler behavior. Can be set using `qmgr`. The following table lists the queue attributes that affect scheduling, along with a brief description. Read every scheduling cycle. For a complete description of each attribute, see "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

Table 4-3: Queue Attributes Involved in Scheduling

Attribute	Effect
backfill_depth	Specifies backfilling behavior. Sets the number of jobs that are to be backfilled around.
enabled	Specifies whether this queue accepts new jobs.
from_route_only	Specifies whether this queue accepts jobs only from routing queues.
max_array_size	The maximum number of subjobs that are allowed in an array job.
max_group_res	Old. The maximum amount of the specified resource that any single group may consume in this queue.
max_group_res_soft	Old. The soft limit for the specified resource that any single group may consume in this queue.
max_group_run	Old. The maximum number of jobs owned by the users in one group allowed to be running within this queue at one time.
max_group_run_soft	Old. The maximum number of jobs owned by the users in one group allowed to be running in this queue at one time.
max_queuable	Old. The maximum number of jobs allowed to reside in the queue at any given time.
max_queued	The maximum number of jobs allowed to be queued in or running from the queue. Can be specified for users, groups, or all.
max_queued_res.<resource name>	The maximum amount of the specified resource allowed to be allocated to jobs queued in or running from the queue. Can be specified for users, groups, or all.
max_run	The maximum number of jobs allowed to be running from the queue. Can be specified for users, groups, or all.
max_run_res.<resource name>	The maximum amount of the specified resource allowed to be allocated to jobs running from the queue. Can be specified for users, groups, or all.
max_run_res_soft.<resource name>	Soft limit on the amount of the specified resource allowed to be allocated to jobs running from the queue. Can be specified for users, groups, or all.
max_run_soft	Soft limit on the number of jobs allowed to be running from the queue. Can be specified for users, groups, or all.
max_running	Old. The maximum number of jobs allowed to be selected for execution at any given time, from all possible jobs.

Table 4-3: Queue Attributes Involved in Scheduling

Attribute	Effect
max_user_res	Old. The maximum amount of the specified resource that the jobs of any single user may consume.
max_user_res_soft	Old. The soft limit on the amount of the specified resource that any single user may consume in this queue.
max_user_run	Old. The maximum number of jobs owned by a single user allowed to be running from the queue at one time.
max_user_run_soft	Old. The soft limit on the number of jobs owned by a single user that are allowed to be running from this queue at one time.
node_group_key	Specifies the resource to use for node grouping.
Priority	The priority of this queue compared to other queues of the same type in this PBS partition or complex.
resources_assigned	The total of each type of resource allocated to jobs running and exiting in this queue.
resources_available	The list of available resources and their values defined on the queue.
resources_max	The maximum amount of each resource that can be requested by any single job in this queue.
resources_min	The minimum amount of each resource that can be requested by a single job in this queue.
route_destinations	The list of destinations to which jobs may be routed.
route_held_jobs	Specifies whether jobs in the held state can be routed from this queue.
route_lifetime	The maximum time a job is allowed to reside in a routing queue. If a job cannot be routed in this amount of time, the job is aborted.
route_retry_time	Time delay between routing retries. Typically used when the network between servers is down.
route_waiting_jobs	Specifies whether jobs whose execution_time attribute value is in the future can be routed from this queue.
started	Specifies whether jobs in this queue can be scheduled for execution.
state_count	The number of jobs in each state currently residing in this queue.

List of jobs and server-level resources queried from server

Read every scheduling cycle.

Resources in Resource_List job attribute

Read every scheduling cycle.

List of host-level resources queried from MoMs

Read every scheduling cycle.

4.5.1.2 Reference Copies of Files

PBS is installed with a reference copy of the holidays file in which everything is commented out, in `PBS_EXEC/etc/pbs_holidays`.

4.5.2 Making a Scheduler Read its Configuration

If you change a scheduler's configuration file, the scheduler must re-read it for the changes to take effect. To get a scheduler to re-read its configuration information, without stopping the scheduler, you can HUP the scheduler:

```
kill -HUP <scheduler PID>
```

If you set a scheduler attribute using `qmgr`, the change takes effect immediately and you do not need to HUP the scheduler.

4.5.3 Scheduling on Resources

A scheduler honors all resources listed in the `resources:` line in `<sched_priv directory>/sched_config`. If this line is not present, a scheduler honors all resources, built-in and custom. It is more efficient to list just the resources that you want a scheduler to schedule on.

4.5.4 Starting, Stopping, and Restarting a Scheduler

4.5.4.1 When and How to Start a Scheduler

During normal operation, startup of the scheduler is handled automatically. The PBS daemons are started automatically at bootup by the PBS start/stop script. During failover, the secondary server automatically tries to use the primary scheduler, and if it cannot, it starts its own scheduler.

To start the default scheduler by hand:

```
PBS_EXEC/sbin/pbs_sched [options]
```

See "pbs_sched" on page 106 of the PBS Professional Reference Guide.

For how to start a multisched, see section 4.2.2, "Starting a Multisched", on page 59.

4.5.4.2 When and How to Stop a Scheduler

You must stop a scheduler for the following operations:

- (Recommended) Using the `pbsfs` command; see "pbsfs" on page 32 of the PBS Professional Reference Guide.
- Upgrading PBS Professional; see "Upgrading" on page 65 in the PBS Professional Installation & Upgrade Guide.

A scheduler traps signals during the scheduling cycle. You can kill a scheduler at the end of the cycle, or if necessary, immediately. A scheduler does not write the fairshare usage file when it is killed with -9, but it does write the file when it is killed without -9.

You must be root on the scheduler's host.

To stop a scheduler at the end of a cycle:

```
kill <scheduler PID>
```

To stop a scheduler immediately:

```
kill -9 <scheduler PID>
```

4.5.4.3 When and How to Restart a Scheduler

Under most circumstances, when you restart a scheduler, you do not need to specify any options to the `pbs_sched` command. See "pbs_sched" on page 106 of the PBS Professional Reference Guide. Start a scheduler this way:

```
PBS_EXEC/sbin/pbs_sched [options]
```

4.5.5 The Scheduling Cycle

A scheduler runs in a loop. Inside each loop, it starts up, performs all of its work, and then stops. The scheduling cycle is triggered by a timer and by several possible events.

When there are no events to trigger the scheduling cycle, it is started by a timer. The time between starts is set in each scheduler's scheduler_iteration server attribute. The default value is 10 minutes.

The maximum duration of the cycle is set in each scheduler's sched_cycle_length attribute. A scheduler will terminate its cycle if the duration of the cycle exceeds the value of the attribute. The default value for the length of the scheduling cycle is 20 minutes. A scheduler does not include the time it takes to query dynamic resources in its cycle measurement.

4.5.5.1 Triggers for Scheduling Cycle

A scheduler starts when the following happen:

- The specified amount of time has passed since the previous start
- A job is submitted
- A job finishes execution.
- A new reservation is created
- A reservation starts
- Scheduling is enabled
- The server comes up
- A job is qrun
- A queue is started
- A job is moved to a local queue
- Eligible wait time for jobs is enabled
- A reservation is re-confirmed after being degraded
- A hook restarts the scheduling cycle

4.5.5.1.i Logging Scheduling Triggers

The server triggers scheduler cycles. The reason for triggering a scheduling cycle is logged by the server. See section 15.3.4.2, "Scheduler Commands", on page 552.

4.5.5.2 Actions During Scheduling Cycle

The following is a list of a scheduler's actions during a scheduling cycle. The list is not in any special order.

- A scheduler gets the state of the world:
  - A scheduler queries the server for the following:
    - Status of jobs in queues
    - All global server, queue, and host-level resources
    - Server, queue, vnode, and scheduler attribute settings
    - Reservations
  - A scheduler runs dynamic server resource queries for resources listed in the "server_dyn_res" line in `sched_config`
  - A scheduler runs dynamic host-level resource queries for resources listed in the "mom_resources" line (**deprecated** as of 18.2.1) in `sched_config`
- A scheduler logs a message at the beginning of each scheduling cycle saying whether it is primetime or not, and when this period of primetime or non-primetime will end. The message is of this form:

  `"It is primetime and it will end in NN seconds at MM/DD/YYYY HH:MM:SS"`

  or

  `"It is non-primetime and it will end in NN seconds at MM/DD/YYYY HH:MM:SS"`
- Given scheduling policy, available jobs and resources, and scheduling cycle length, a scheduler examines as many jobs as it can, and runs as many jobs as it can.

4.5.6 How Available Consumable Resources are Counted

When a scheduler checks for available consumable resources, it uses the following calculation:

resouces_available.<resource name> - total resources assigned for this resource

total resources assigned is the total amount of resources_assigned.<resource name> for all other running and exiting jobs and, at the server and vnodes, for started reservations.

For example, if a scheduler is calculating available memory, and two other jobs are running, each with 2GB of memory assigned, and resources_available.mem is 8GB, the scheduler figures that it has 4GB to work with.

4.5.7 Improving Scheduler Performance

4.5.7.1 Improving Throughput of Jobs

You can tell a scheduler to run asynchronously, so it doesn't wait for each job to be accepted by MoM, which means it also doesn't wait for an execjob_begin hook to finish. For short jobs, this can give you better scheduling performance. To run a scheduler asynchronously, set the scheduler's throughput_mode attribute to *True* (this attribute is *True* by default).

When throughput_mode is *True*, jobs that have been changed can run in the same scheduling cycle in which they were changed, for the following changes:

- Jobs that are qaltered (for example, in `cron` jobs)
- Jobs that are changed via server_dyn_res scripts
- Jobs that are peered to a new queue

throughput_mode

Scheduler attribute. When set to *True*, this scheduler runs asynchronously and can start jobs faster. Only available when complex is in TPP mode.

Format: *Boolean*

Default: *True*

Example:

```
qmgr -c "set sched throughput_mode=<Boolean value>"
```

You can run a scheduler asynchronously only when the complex is using TPP mode. For details about TPP mode, see "Communication" on page 45 in the PBS Professional Installation & Upgrade Guide. Trying to set the value to a non-Boolean value generates the following error message:

```
qmgr obj= svr=default: Illegal attribute or resource value
qmgr: Error (15014) returned from server
```

4.5.7.2 Limiting Number of Jobs Queued in Execution Queues

If you limit the number of jobs queued in execution queues, you can speed up the scheduling cycle. You can set an individual limit on the number of jobs in each queue, or a limit at the server, and you can apply these limits to generic and individual users, groups, and projects, and to overall usage. You specify this limit by setting the queued_jobs_threshold queue or server attribute. See section 5.15.1.9, "How to Set Limits at Server and Queues", on page 299.

If you set a limit on the number of jobs that can be queued in execution queues, we recommend that you have users submit jobs to a routing queue only, and route jobs to the execution queue as space becomes available. See section 4.9.39, "Routing Jobs", on page 207.

4.5.7.3 Setting Number of Scheduler Threads

By default, each scheduler starts one thread on its host. You can modify the number of threads a scheduler starts, either by starting the scheduler with `pbs_sched -t <num threads>`, or by setting the PBS_SCHED_THREADS configuration parameter in `pbs.conf`, or the PBS_SCHED_THREADS environment variable. The `pbs_sched -t` option overrides the environment variable, which overrides the value in `pbs.conf`.

4.6 Using Queues in Scheduling

A queue is a PBS mechanism for holding jobs. PBS has queue-based tools for handling jobs; for example, you can set queue-based limits on resource usage by jobs. PBS uses queues for a variety of purposes. Before reading this section, please familiarize yourself with the mechanics of creating and configuring queues, by reading section 2.3, "Queues", on page 23.

Queues are used in the following ways:

- Holding submitted jobs
- Prioritizing jobs and ordering job selection:
    - PBS provides tools for selecting jobs according to the queue they are in; see section 4.3.5.3, "Using Queue-based Tools to Prioritize Jobs", on page 67
    - Queue priority can be used in calculating job priority; see section 4.9.36, "Queue Priority", on page 198
- Providing tools for managing time slots
    - Reservations: you can reserve specific resources for defined time slots. Queues are used for advance and standing reservations; see section 4.9.37, "Reservations", on page 199, and "Reserving Resources", on page 135 of the PBS Professional User's Guide
    - Dedicated time; see section 4.9.10, "Dedicated Time", on page 127
    - Primetime and holidays; see section 4.9.34, "Using Primetime and Holidays", on page 193
- Routing jobs: Many ways to route jobs are listed in section 4.9.39, "Routing Jobs", on page 207
- Providing tools for managing resources
    - Managing resource usage by users; see section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290
    - Managing resource usage by jobs; see section 5.15.2, "Placing Resource Limits on Jobs", on page 307
    - Setting resource and job limits used for preemption: you can specify how much of a resource or how many jobs a user or group can use before their jobs are eligible to be preempted. See section 5.15.1.4, "Hard and Soft Limits", on page 293 and section 4.9.33, "Using Preemption", on page 182.
    - Assigning default resources to jobs; see section 5.9.4, "Allocating Default Resources to Jobs", on page 249

4.7 Scheduling Restrictions and Caveats

4.7.1 One Policy Per Scheduler

Each scheduler runs a single scheduling policy.

4.7.2 Jobs that Cannot Run on Current Resources

A scheduler checks to see whether each job could possibly run now, counting resources as if there were no other jobs, and all current resources could be used by this job. A scheduler counts resources only from those vnodes that are on line. If a vnode is marked *offline*, its resources are not counted.

A scheduler determines whether a job cannot run on current resources only when backfilling is used. If backfilling is turned off, then a scheduler won't determine whether or not a job has requested more than can be supplied by current resources. It decides only that it can't run now. If the job cannot run now because vnodes are unavailable, there is no log message. If the job requests more than is available in the partition managed by a scheduler, there is a log message. In both cases, the job stays queued.

4.7.3 Resources Not Controlled by PBS

When a scheduler runs each cycle, it gets the state of its world, including dynamic resources outside of the control of PBS. If non-PBS processes are running on the vnodes PBS uses, it is possible that another process will use enough of a dynamic resource such as scratch space to prevent a PBS job that requested that resource from running.

4.7.4 No Pinning of Processes to Cores

PBS does not pin processes to cores. This can be accomplished in the job launch script using, for example, `taskset` or `dplace`.

4.8 Errors and Logging

4.8.1 Logfile for scheduler

You can set a scheduler's logging to record different kinds of events. See section 15.3.3.1.iii, “Specifying Scheduler Log Events”, on page 550.

The server triggers scheduler cycles. The reason for triggering a scheduling cycle is logged by the server. See section 15.3.4.2, “Scheduler Commands”, on page 552.

4.9 Scheduling Tools

In this section (all of section 4.9, “Scheduling Tools”, on page 102, and its subsections), we describe each scheduling tool, including how to configure it.

The following table lists PBS scheduling tools, with links to descriptions:

Table 4-4: List of Scheduling Tools

Scheduling Tool	Incompatible Tools	Link
Anti-express queue	soft queue limits	See section 4.9.1, “Anti-Express Queues”, on page 104
Associating vnodes with queues		See section 4.9.2, “Associating Vnodes with Queues”, on page 105
Backfilling	fairshare or preemption w/backfilling+strict ordering	See section 4.9.3, “Using Backfilling”, on page 107
Examining jobs queue-by-queue	round robin, queues as fair-share entities	See section 4.9.4, “Examining Jobs Queue by Queue”, on page 112
Checkpointing		See section 4.9.5, “Checkpointing”, on page 113
Organizing job chunks		See section 4.9.6, “Organizing Job Chunks”, on page 114
`cron` jobs		See section 4.9.7, “cron Jobs”, on page 114
Custom resources		See section 4.9.8, “Using Custom and Default Resources”, on page 115
Cycle harvesting	reservations	See section 4.9.9, “Using Idle Workstation Cycle Harvesting”, on page 117
Dedicated time		See section 4.9.10, “Dedicated Time”, on page 127
Default resources		See section 4.9.8, “Using Custom and Default Resources”, on page 115

Table 4-4: List of Scheduling Tools

Scheduling Tool	Incompatible Tools	Link
Dependencies		See section 4.9.11, "Dependencies", on page 128
Dynamic resources (server & host)		See section 4.9.12, "Dynamic Resources", on page 128
Eligible wait time for jobs		See section 4.9.13, "Eligible Wait Time for Jobs", on page 128
Entity shares (was strict priority)	formula, fairshare, FIFO	See section 4.9.14, "Sorting Jobs by Entity Shares (Was Strict Priority)", on page 133
Estimating job start time		See section 4.9.15, "Estimating Job Start Time", on page 133
Calculating job execution priority		See section 4.9.16, "Calculating Job Execution Priority", on page 136
Express queues		See section 4.9.18, "Express Queues", on page 139
Fairshare	starving, strict ordering, using the fairshare_perc option to job_sort_key	See section 4.9.19, "Using Fairshare", on page 140
FIFO		See section 4.9.20, "FIFO Scheduling", on page 150
Formula		See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151
Gating jobs at server or queue		See section 4.9.22, "Gating Jobs at Server or Queue", on page 157
Managing application licenses		See section 4.9.23, "Managing Application Licenses", on page 157
Limits on per-job resource usage		See section 4.9.24, "Limits on Per-job Resource Usage", on page 158
Limits on project, user, and group jobs		See section 4.9.25, "Limits on Project, User, and Group Jobs", on page 158
Limits on project, user, and group resource usage		See section 4.9.26, "Limits on Project, User, and Group Resource Usage", on page 158
Load balancing	node_sort_key using unused or assigned options,	See section 4.9.27, "Using Load Balancing", on page 158
Matching jobs to resources		See section 4.9.28, "Matching Jobs to Resources", on page 161
Node grouping		See section 4.9.29, "Node Grouping", on page 164
Overrides		See section 4.9.30, "Overrides", on page 164
Peer scheduling		See section 4.9.31, "Peer Scheduling", on page 167
Placement sets		See section 4.9.32, "Placement Sets", on page 170
Preemption	cgroups hook cannot be used with suspend/resume	See section 4.9.33, "Using Preemption", on page 182

Table 4-4: List of Scheduling Tools

Scheduling Tool	Incompatible Tools	Link
Preemption targets		See section 4.9.33.4, “Using Preemption Targets”, on page 184
Primetime and holidays		See section 4.9.34, “Using Primetime and Holidays”, on page 193
Provisioning		See section 4.9.35, “Provisioning”, on page 198
Queue priority		See section 4.9.36, “Queue Priority”, on page 198
Advance and standing reservations	cycle harvesting	See section 4.9.37, “Reservations”, on page 199
Round robin queue examination	by_queue	See section 4.9.38, “Round Robin Queue Selection”, on page 206
Routing jobs		See section 4.9.39, “Routing Jobs”, on page 207
Shared or exclusive vnodes and hosts		See section 4.9.41, “Shared vs. Exclusive Use of Resources by Jobs”, on page 212
Shrinking jobs to fit		See section 4.9.42, “Using Shrink-to-fit Jobs”, on page 213
SMP cluster distribution	avoid_provision	See section 4.9.43, “SMP Cluster Distribution”, on page 220
Soft walltime		See section 4.9.44, “Using Soft Walltime”, on page 221.
Sorting jobs using job_sort_key		See section 4.9.45, “Sorting Jobs on a Key”, on page 223
Sorting jobs on job's requested priority		See section 4.9.46, “Sorting Jobs by Requested Priority”, on page 225
Sorting queues (**deprecated** in 13.0)		See section 4.9.47, “Sorting Queues into Priority Order”, on page 225
Starving jobs	fairshare	See section 4.9.48, “Starving Jobs”, on page 225
Strict ordering	Backfilling combined with fairshare	See section 4.9.49, “Using Strict Ordering”, on page 227
Sorting vnodes on a key	smp_cluster_dist set to other than pack, or load balancing, with unused or assigned options to node_sort_key	See section 4.9.50, “Sorting Vnodes on a Key”, on page 228

4.9.1 Anti-Express Queues

An anti-express queue is a preemptable low-priority queue, designed for jobs that should run only when no other jobs need the resources. These jobs are preempted if any other job needs the resources. An anti-express queue has the lowest priority of all queues in this queue's partition. Jobs in this queue have a soft limit of zero, so that any job running from this queue is over its queue soft limit.

See section 4.9.33, “Using Preemption”, on page 182.

4.9.1.1 Configuring Anti-express Queues via Priority

To configure an anti-express queue by using queue priority, do the following:

- Create an execution queue called *lowprio*:
  ```
  Qmgr: create queue lowprio
  Qmgr: set queue lowprio queue_type=e
  Qmgr: set queue lowprio started=true
  Qmgr: set queue lowprio enabled=true
  ```
- By default, all new queues have a priority of zero. Make sure all queues have a value set for priority, and that lowprio has the lowest priority:
  ```
  Qmgr: set queue workq priority=10
  ```
- Set the soft limit on the number of jobs that can run from that queue to zero for all users:
  ```
  Qmgr: set queue lowprio max_run_soft = "[u:PBS_GENERIC=0]"
  ```
- Make sure that jobs over their queue soft limits have lower preemption priority than normal jobs. Edit `<sched_priv directory>/sched_config`, and do the following:
  - Put "normal_jobs" before "queue_softlimits". For example:
    ```
    preempt_prio: "express_queue, normal_jobs, queue_softlimits"
    ```
  - Use preemption:
    ```
    preemptive_sched: True ALL
    ```

4.9.1.2 Configuring Anti-express Queues via Preemption Targets

To use preemption targets, include this queue in Resource_List.preempt_targets for all jobs. You can do this with a hook, with server and/or queue defaults, or by qaltering the jobs. Set each job's `Resource_List.preempt_targets=queue=<name of anti-express queue>`.

4.9.1.3 Anti-express Queue Caveats

If you use soft limits on the number of jobs that users can run at other queues, jobs that are over their soft limits at other queues will also have the lowest preemption priority.

4.9.2 Associating Vnodes with Queues

You can associate each vnode with one or more queues. When a vnode is associated with a queue, that means it accepts jobs from that queue only. You can associate one or more vnodes with multiple queues.

You do not need to associate vnodes with queues in order to have jobs run on the vnodes that have the right application, as long as the application is a resource that can be requested by jobs.

You can use custom host-level resources to associate one or more vnodes with more than one queue. A scheduler will use the resources for scheduling just as it does with any resource.

In order to map a vnode to more than one queue, you must define a new host-level string array custom resource. This string array holds a string that has the same value for the queue and vnode you wish to associate. The mechanism of association is that a job that lands in the queue inherits that value for the resource, and then the job can run only on vnodes having a matching value for the resource. You can associate more than one queue with a vnode by setting the resource to the same value at each queue.

In some cases, you can use the same resource to route jobs and to associate vnodes with queues. For the method described here, you use host-level resources to associate vnodes with queues. The rules for which resources can be used for routing are given in section 2.3.6.4.iii, “Resources Used for Routing and Admittance”, on page 29. How jobs inherit resources is described in section 5.9.4, “Allocating Default Resources to Jobs”, on page 249.

4.9.2.1 Procedure to Associate Vnodes with Queues

To associate one or more vnodes with one or more queues, do the following:

1. Define the new host-level resource:

   ```
   qmgr -c 'create resource <new resource> type=string_array, flag=h'
   ```

2. Instruct the scheduler to honor the resource. Add the new resource to `$<sched_priv directory>/sched_config`:

   ```
   resources: "ncpus, mem, arch, host, vnode, <new resource>"
   ```

3. HUP the scheduler:

   ```
   kill -HUP <scheduler PID>
   ```

4. Set each queue's default_chunk for the new resource to the value you are using to associate it with vnodes:

   ```
   Qmgr: set queue <queue name> default_chunk.<new resource> = <value>
   ```

   For example, if one queue is "MathQ" and one queue is "SpareQ", and the new resource is "Qlist", and you want to associate a set of vnodes and queues based on ownership by the math department, you can make the queue resource value be "math":

   ```
   Qmgr: set queue MathQ default_chunk.Qlist = math
   Qmgr: set queue SpareQ default_chunk.Qlist = math
   ```

5. Set the value for the new resource at each vnode:

   ```
   Qmgr: set node <vnode name> resources_available.<new resource> = <associating value>
   ```

   For example, to have the vnode named "Vnode1" associated with the queues owned by the math department:

   ```
   Qmgr: set node Vnode1 resources_available.Qlist = math
   ```

4.9.2.2 Example of Associating Multiple Vnodes with Multiple Queues

Now, as an example, assume you have 2 queues: "PhysicsQ" and "ChemQ", and you have 3 vnodes: vn[1], vn[2], and vn[3]. You want Physics jobs to run on vn[1] and vn[2], and you want Chem jobs to run on vn[2] and vn[3]. Each department gets exclusive use of one vnode, but both must share a vnode.

To achieve the following mapping:

PhysicsQ -->vn[1], vn[2]

ChemQ --> vn[2], vn[3]

Which is the same as:

vn[1] <-- PhysicsQ

vn[2] <-- PhysicsQ, ChemQ

vn[3] <-- ChemQ

1. Define the new host-level resource:
   ```
   Qmgr: create resource Qlist type=string_array, flag=h
   ```
2. Instruct the scheduler to honor the resource. Add the new resource to `$<sched_priv directory>/sched_config`:
   ```
   resources: "ncpus, mem, arch, host, vnode, Qlist"
   ```
3. HUP the scheduler:
   ```
   kill -HUP <scheduler PID>
   ```
4. Add queue to vnode mappings:
   ```
   Qmgr: s n vn[1] resources_available.Qlist="PhysicsQ"
   Qmgr: s n vn[2] resources_available.Qlist= "PhysicsQ,ChemQ"
   Qmgr: s n vn[3] resources_available.Qlist="ChemQ"
   ```
5. Force jobs to request the correct Qlist values:
   ```
   Qmgr: s q PhysicsQ default_chunk.Qlist=PhysicsQ
   Qmgr: s q ChemQ default_chunk.Qlist=ChemQ
   ```

4.9.3 Using Backfilling

Backfilling means fitting smaller jobs around the higher-priority jobs that a scheduler is going to run next, in such a way that the higher-priority jobs are not delayed. When a scheduler is using backfilling, the scheduler considers highest-priority jobs *top jobs*. Backfilling changes the algorithm that a scheduler uses to run jobs:

- When backfilling is not being used, a scheduler looks at each job in priority order, tries to run the job now, and if it cannot, it moves on to the next-highest-priority job.
- When backfilling is being used, a scheduler tries to run the top job now, and if it cannot, it makes sure that no other job that it runs in this cycle will delay the top job. It also fits smaller jobs in around the top job.

Backfilling allows you to keep resources from becoming idle when the top job cannot run.

Backfilling applies all of the time; it is not a prime option.

4.9.3.1 Glossary

Top job

A top job has the highest execution priority according to scheduling policy, and a scheduler plans resources and start time for this job first. Top jobs exist only when a scheduler is using backfilling.

Filler job

Smaller job that fits around top jobs. Running a filler job does not change the start time or resources for a top job. This job runs next only when backfilling is being used (meaning that a top job cannot start next because insufficient resources are available for the top job, but whatever is available is enough for the filler job).

4.9.3.2 Backfilling Separately at the Server and Queues

You can configure the number of top jobs that PBS backfills around by setting the value of the backfill_depth server and queue attributes. For example, if you set backfill_depth to *3*, PBS backfills around the top 3 jobs. See “Server Attributes” on page 283 of the PBS Professional Reference Guide.

You can specify a different number of top jobs for each queue. You can also specify the number of top jobs for the server. Any queues that do not have their own backfill depth share in the server's backfill depth count. For example, you have three queues Q1, Q2, and Q3, and you set the backfill depth at Q1 to be 5 and the backfill depth at the server to be 3. In this example, the top 5 jobs in Q1 will run as soon as possible, and be backfilled around, but there are only 3 top job slots allocated to the jobs in Q2 and Q3.

If you do not set a value for the backfill depth at the server, it defaults to *1*.

4.9.3.3 How Backfilling Works

A scheduler makes a list of jobs to run in order of priority, for any queue that has an individual backfill depth, for the server if there are queues without a backfill depth set. These lists are composed according to execution priority described in section 4.9.16, “Calculating Job Execution Priority”, on page 136. These are top jobs.

If you use backfilling, a scheduler looks for smaller jobs that can fit into the usage gaps around the highest-priority jobs in each list. A scheduler looks in each prioritized list of jobs and chooses the highest-priority smaller jobs that fit. Filler jobs are run only if they will not delay the start time of top jobs.

A scheduler creates a fresh list of top jobs at every scheduling cycle, so if a new higher-priority job has been submitted, it will be considered.

You can use shrink-to-fit jobs to backfill into otherwise unusable time slots. PBS checks whether a shrink-to-fit job could shrink into the available slot, and if it can, runs it. See section 4.9.42, “Using Shrink-to-fit Jobs”, on page 213.

Backfilling is useful in the following circumstances:

- When the strict_ordering scheduler parameter is turned on, filler jobs are fitted around higher-priority jobs. Without backfilling, no job runs if the top job cannot run. See section 4.9.49, “Using Strict Ordering”, on page 227
- When the help_starving_jobs scheduler parameter is turned on, filler jobs are fitted around starving jobs. See section 4.9.48, “Starving Jobs”, on page 225

4.9.3.4 Backfilling Around *N* Jobs

You can configure the number of top jobs that PBS backfills around by setting the value of the backfill_depth server attribute. For example, if you set backfill_depth to *3*, PBS backfills around the top 3 jobs. See “Server Attributes” on page 283 of the PBS Professional Reference Guide.

4.9.3.5 Backfilling Around Preempted Jobs

When you set the sched_preempt_enforce_resumption scheduler attribute to *True*, a scheduler adds preempted jobs to the set of jobs around which it backfills. A scheduler ignores backfill_depth when backfilling around jobs in the *Preempted* execution class. By default the sched_preempt_enforce_resumption scheduler attribute is *False*.

4.9.3.6 Backfilling Around Starving Jobs

When you take starving jobs into consideration, by setting the help_starving_jobs scheduler parameter to *True*, starving jobs can be added to the top jobs. They can continue to wait for resources once they are the top job, blocking other jobs from running. See section 4.9.48, “Starving Jobs”, on page 225.

4.9.3.7 Configuring Backfilling

To configure backfilling, do the following:

1. Choose how many jobs to backfill around. If you want to backfill around more than 1 job, set the backfill_depth server attribute to the desired number. The default is *1*. Set this parameter to less than *100*.
2. Choose whether you want any queues to share the list of top jobs at the server. Do not set backfill_depth at those queues. If you want any queues to share this list, set the server's backfill_depth attribute to the desired value. The default is *1*. Set this parameter to less than *100*.
3. For the queues where you want a separate backfill depth, choose how many jobs to backfill around at each queue. Set the backfill_depth queue attribute to the desired number.
4. Make sure that jobs request walltime by making them inherit a walltime resource if they don't explicitly request it. For options, see section 4.9.3.11.i, “Ensure Jobs Are Eligible for Backfilling”, on page 111.
5. Choose whether you want to backfill around preempted jobs. To do this, set the sched_preempt_enforce_resumption scheduler attribute to *True*.
6. Make sure that the strict_ordering scheduler parameter is set to *True* for all time if you use backfilling.
7. Choose whether you want to backfill around starving jobs. If you do, make sure that the help_starving_jobs scheduler parameter is set to *True*.

When most jobs become top jobs, they are counted toward the limit set in backfill_depth. Some top jobs are not counted toward backfill_depth. The following table shows how backfilling can be configured and which top jobs affect backfill_depth. Unless explicitly stated, top jobs are counted towards backfill_depth. A scheduler stops considering jobs as top jobs when it has reached backfill_depth, except for preempted jobs, which do not count toward that limit. When backfill is off, a scheduler does not have a notion of "top jobs". When help_starving_jobs is off, a scheduler has no notion of starving jobs.

Table 4-5: Configuring Backfilling

Parameter and Attribute Settings				When Classes Are Top Jobs			
backfill_depth	**strict_ordering**	**sched_preempt_enforce_resumption**	**help_starving_jobs**	**Express**	**Preempted**	**Starving**	**Normal**
>0	*T*	*T*	*T*	Top jobs	Top jobs, not counted in backfill_depth	Top jobs	Top jobs
>0	*T*	*T*	*F*	Top jobs	Top jobs, not counted in backfill_depth	Starving class does not exist	Top jobs
>0	*T*	*F*	*T*	Top jobs	Top jobs	Top jobs	Top jobs
>0	*T*	*F*	*F*	Top jobs	Top jobs	Starving class does not exist	Top jobs
>0	*F*	*T*	*T*	No	Top jobs, not counted in backfill_depth	Top jobs	No
>0	*F*	*T*	*F*	No	Top jobs, not counted in backfill_depth	Starving class does not exist	No
>0	*F*	*F*	*T*	No	No	Top jobs	No
>0	*F*	*F*	*F*	No	No	Starving class does not exist	No

4.9.3.8 Backfilling and Strict Ordering

When you use strict ordering, a scheduler runs jobs in exactly the order of their priority. If backfill_depth is set to zero and the top job cannot run, no job is able to run. Backfilling can prevent resources from standing idle while the top job waits for its resources to become available. See section 4.9.49, "Using Strict Ordering", on page 227.

4.9.3.9 Backfilling and Scheduler Cycle Speed

You can choose a trade-off between scheduling cycle speed and the fineness of the granularity with which estimated start times are calculated. You do this by setting the opt_backfill_fuzzy scheduler attribute via `qmgr`. You can choose *off*, *low*, *medium*, or *high*. For no speedup, choose *off*. For maximum speedup, choose *high*.

```
Qmgr: set sched opt_backfill_fuzzy [off | low | medium | high]
```

See section 4.9.40, "Scheduler Cycle Speedup", on page 211.

4.9.3.10 Attributes and Parameters Affecting Backfilling

backfill_depth

Server and queue attribute. Specifies backfilling behavior. Sets the number of jobs that are to be backfilled around. See "Server Attributes" on page 283 of the PBS Professional Reference Guide and "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

opt_backfill_fuzzy

Scheduler attribute. You can use this setting to trade between scheduling cycle speed and estimated start time granularity. See "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

sched_preempt_enforce_resumption

Scheduler attribute. When this attribute is *True* and backfill_depth is greater than zero, a scheduler treats pre-empted jobs like top jobs and backfills around them. This effectively increases the value of backfill_depth by the number of preempted jobs.

The configuration parameters backfill_prime and prime_exempt_anytime_queues do not relate to backfilling. They control the time boundaries of regular jobs with respect to primetime and non-primetime. See section 4.9.34, "Using Primetime and Holidays", on page 193.

4.9.3.11 Backfilling Recommendations and Caveats

4.9.3.11.i Ensure Jobs Are Eligible for Backfilling

When calculating backfilling, PBS treats a job that has no walltime specified as if its walltime is eternity. A scheduler will never use one of these jobs as a filler job. You can avoid this by ensuring that each job has a realistic walltime, by using the following methods:

- At `qsub` time via a hook
- By setting the queue's resources_default.walltime attribute
- By setting the server's resources_default.walltime attribute
- At `qsub` time via the server's default_qsub_arguments

4.9.3.11.ii Number of Jobs to Backfill Around

The more jobs being backfilled around, the longer the scheduling cycle takes.

4.9.3.11.iii Dynamic Resources and Backfilling

Using dynamic resources and backfilling may result in some jobs not being run because a dynamic resource is temporarily unavailable. This may happen when a job requesting a dynamic resource is selected as the top job. A scheduler must estimate when resources will become available, but it can only query for resources available at the time of the query, not resources already in use, so it will not be able to predict when resources in use become available. Therefore the scheduler won't be able to schedule the job. In addition, since dynamic resources are outside of the control of PBS, they may be consumed between the time a scheduler queries for the resource and the time it starts a job.

4.9.3.11.iv Avoid Using Strict Ordering, Backfilling, and Fairshare

It is inadvisable to use strict ordering and backfilling with fairshare.

The results may be non-intuitive. Fairshare will cause relative job priorities to change with each scheduling cycle. It is possible that while a large job waits for a slot, jobs from the same entity or group will be chosen as the filler jobs, and the usage from these small jobs will lower the priority of the large job.

For example, if a user has a large job that is the most deserving but cannot run, smaller jobs owned by that user will chew up the user's usage, and prevent the large job from ever being likely to run. Also, if the small jobs are owned by a user in one area of the fairshare tree, no large jobs owned by anyone else in that section of the fairshare tree are likely to be able to run.

4.9.3.11.v Using Preemption, Strict Ordering, and Backfilling

Using preemption with strict ordering and backfilling may reshuffle the top job(s) if high-priority jobs are preempted.

4.9.3.11.vi Warning About Backfilling and Provisioning

A scheduler will not run a job requesting an AOE on a vnode that has a top job scheduled on it in the future.

A scheduler will not use a job requesting an AOE as a top job.

4.9.3.11.vii Backfilling and Estimating Job Start Time

When a scheduler is backfilling around jobs, it estimates the start times and execution vnodes for the top jobs being backfilled around. See section 4.9.15, “Estimating Job Start Time”, on page 133.

4.9.3.11.viii Using Strict Ordering and Backfilling with Only One of Primetime or Non-primetime

If you use backfilling, it is used all of the time. However, you can use strict ordering during primetime, non-primetime, or all the time. When PBS is using strict ordering and backfilling, a scheduler saves a spot for each high-priority job around which it is backfilling. If you configure PBS to use strict ordering and backfilling for only one of primetime or non-primetime, and you have large jobs that must wait a long time before enough resources are available, the saved spots can be lost in the transition.

4.9.4 Examining Jobs Queue by Queue

When a scheduler examines waiting jobs, it can either consider all of the jobs in its partition as a whole, or it can consider jobs queue by queue. When considering jobs queue by queue, a scheduler runs all the jobs it can from the first queue before examining the jobs in the next queue, and so on. This behavior is controlled by the by_queue scheduler parameter.

When the by_queue scheduler parameter is set to *True*, jobs in the highest-priority queue are evaluated as a group, then jobs in the next-highest priority queue are evaluated. In this case, PBS runs all the jobs it can from each queue before moving to the next queue, with the following exception: if there are jobs in the *Reservation, Express*, *Preempted*, or *Starving* job execution classes, those are considered before any queue. These classes are described in section 4.9.16, “Calculating Job Execution Priority”, on page 136.

The by_queue parameter applies to all of the queues in a scheduler's partition. This means that either all jobs are scheduled as if they are in one large queue, or jobs are scheduled queue by queue.

All queues are always sorted by queue priority. To set queue priority, set each queue's priority attribute to the desired value. A queue with a higher value is examined before a queue with a lower value. If you do not assign priorities to queues, their ordering is undefined. See section 4.9.36, “Queue Priority”, on page 198.

The by_queue parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

See “by_queue” on page 252 of the PBS Professional Reference Guide.

4.9.4.1 Configuring PBS to Consider Jobs Queue by Queue

- Set the by_queue scheduler parameter to *True*
- Assign a priority to each queue
- Choose whether you want queue by queue during primetime, non-primetime, or both. If you want separate behavior for primetime and non-primetime, list by_queue twice. For example:

```
by_queue True prime
by_queue False non_prime
```

4.9.4.2 Parameters and Attributes Affecting Queue by Queue

- The by_queue scheduler parameter; see "by_queue" on page 252 of the PBS Professional Reference Guide.
- The priority queue attribute; see "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

4.9.4.3 Caveats and Advice for Queue by Queue

- The by_queue scheduler parameter is overridden by the round_robin scheduler parameter when round_robin is set to *True*.
- When by_queue is *True*, queues cannot be designated as fairshare entities, and fairshare will work queue by queue instead of on all jobs at once.
- When by_queue is *True*, job execution priority may be affected. See section 4.9.16, "Calculating Job Execution Priority", on page 136.
- The by_queue parameter is not required when using express queues.
- You can have FIFO scheduling for all your jobs across a given scheduler's partition, if you are using a single execution queue or have by_queue set to *False*. However, you can have FIFO scheduling for the jobs within each queue if you set by_queue to *True* and specify a different priority for each queue. See section 4.9.20, "FIFO Scheduling", on page 150.

4.9.5 Checkpointing

You can use checkpointing as a scheduling tool, by including it as a preemption method, an aid in recovery, a way to capture progress from a shrink-to-fit job, and when using the `qhold` command.

For a complete description of how to use and configure checkpointing, see section 9.3, "Checkpoint and Restart", on page 420.

4.9.5.1 Checkpointing as a Preemption Method

When a job is preempted via checkpointing, MoM runs the checkpoint_abort script, and PBS kills and requeues the job. When a scheduler elects to run the job again, the MoM runs the restart script to restart the job from where it was checkpointed. See section 4.9.33, "Using Preemption", on page 182.

4.9.5.2 Checkpointing as a Way to Capture Progress and Help Recover Work

When you use checkpointing to capture a job's progress before the job is terminated, for example when a shrink-to-fit job's wall time is exceeded, MoM runs the snapshot checkpoint script, and the job continues to run. See section 9.3, "Checkpoint and Restart", on page 420.

4.9.5.3 Checkpointing When Using the `qhold` Command

When the qhold command is used to hold a checkpointable job, MoM runs the checkpoint_abort script, and PBS kills, requeues, and holds the job. A job with a hold on it must have the hold released via the qrls command in order to be eligible to run. For a discussion of the use of checkpointing for the `qhold` command, see section 9.3.7.6, "Holding a Job", on page 432. See "qhold" on page 148 of the PBS Professional Reference Guide and "qrls" on page 181 in the PBS Professional Installation & Upgrade Guide.

4.9.6 Organizing Job Chunks

You can specify how job chunks should be organized onto hosts or vnodes. Jobs can request their placement arrangement, and you can set defaults at queues and at the server to be inherited by jobs that do not request a placement. You can tell PBS to do the following:

- Put all chunks from a job onto a single host using the `place=pack` statement.
- Put each chunk on a separate host using the `place=scatter` statement. The number of chunks must be fewer than or equal to the number of hosts.
- Put each chunk on a separate vnode using the `place=vscatter` statement. The number of chunks must be fewer than or equal to the number of vnodes.
- Put each chunk anywhere using the `place=free` statement.

To specify a placement default, set resources_default.place=<arrangement>, where arrangement is *pack*, *scatter*, *vscatter*, or *free*. For example, to have the default at QueueA be *pack*:

```
Qmgr: set queue QueueA resources_default.place=pack
```

You can specify that job chunks must be grouped in a certain way. For example, to require that chunks all end up on a shared router, use this:

```
place=group=router
```

For more about jobs requesting placement, see "Requesting Resources and Placing Jobs" on page 217 of the PBS Professional Reference Guide.

4.9.6.1 Caveats for Organizing Job Chunks

A placement specification for arrangement, sharing, and grouping is treated as one package by PBS. This means that if a job requests only one, any defaults set for the others are not inherited. For example, if you set a default of `place=pack:excl:group=router`, and a job requests only `place=pack`, the job does not inherit `excl` or `group=router`. See "Requesting Resources and Placing Jobs" on page 217 of the PBS Professional Reference Guide.

4.9.7 cron Jobs

You can use `cron` jobs to make time-dependent modifications to settings, where you are scheduling according to time slots. For example, you can change settings for primetime and non-primetime configurations, making the following changes:

- Set nodes *offline* or not *offline*
- Change the number of ncpus on workstations
- Change the priority of queues, for example to change preemption behavior
- Start or stop queues
- Set primetime & non-primetime options

4.9.7.1 Caveats for `cron` Jobs

- Make sure that your `cron` jobs behave correctly when PBS is not running.
- Be careful when changing available resources, such as when offlining vnodes. You might prevent jobs from running that would otherwise run. For details, see section 4.7.2, "Jobs that Cannot Run on Current Resources", on page 101.

  If PBS is down when your `cron` job runs, the change specified in the `cron` job won't happen. For example, if you use `cron` to offline a vnode and then bring it online later, it won't come online if PBS is down during the second operation.

4.9.8 Using Custom and Default Resources

The information in this section relies on understanding how jobs are allocated resources via inheriting defaults or via hooks. Before reading this section, please read section 14.3, "Allocating Resources to Jobs", on page 507.

For complete details of how to configure and use custom resources, please see section 5.14, "Custom Resources", on page 257.

You can use custom and default resources for several purposes:

- Routing jobs to the desired vnodes; see section 4.9.8.2, "Using Custom Resources to Route Jobs", on page 115
- Assigning execution priority to jobs; see section 4.9.8.3, "Using Custom Resources to Assign Job Execution Priority", on page 116
- Tracking and controlling the allocation of resources; see section 4.9.8.4, "Using Custom Resources to Track and Control Resource Allocation", on page 116
- Representing elements such as GPUs, FPGAs, and switches; see section 4.9.8.5, "Using Custom Resources to Represent GPUs, FPGAs, Switches, Etc.", on page 116
- Allowing users to request platform-specific resources, for example Cray-specific resources; see section 4.9.8.6, "Using Custom Resources to Allow Platform-specific Resource Requests", on page 116
- Allowing users to submit jobs that run on a Cray as they would if using the `aprun` command; see section 4.9.8.7, "Using Custom Resources to Allow Platform-specific Behavior", on page 117
- Shrinking job walltimes so that they can run in time slots that are less than the expected maximum. See section 4.9.42, "Using Shrink-to-fit Jobs", on page 213.

4.9.8.1 Techniques for Allocating Custom Resources to Jobs

In addition to using custom resources to represent physical elements such as GPUs, you can use custom resources as tags that you attach to jobs in order to help schedule the jobs. You can make these custom resources into tools that can be used only for managing jobs, by making them unalterable and unrequestable, and if desired, invisible to users.

For how to assign custom and default resources to jobs, see section 14.3, "Allocating Resources to Jobs", on page 507.

4.9.8.2 Using Custom Resources to Route Jobs

You can use several techniques to route jobs to the desired queues and/or vnodes. Depending on your partition's or site's configuration, you may find it helpful to use custom resources with one or more of these techniques.

- You can force users to submit jobs to the desired queues by setting resource limits at queues. You can use custom resources to represent arbitrary elements, for example, department. In this case you could limit which department uses each queue. You can set a default value for the department at the server, or create a hook that assigns a value for the department.

For how queue resource limits are applied to jobs, see section 2.3.6.4.i, “How Queue and Server Limits Are Applied, Except Running Time”, on page 28.

- Use default resources or a hook to assign custom resources to jobs when the jobs are submitted. Send the jobs to routing queues, then route them, using the resources, to other queues inside or outside the PBS partition or complex. Again, custom resources can represent arbitrary elements.

  For how routing queues work, see section 2.3.6, “Routing Queues”, on page 27

- Use peer scheduling to send jobs between PBS partitions or complexes. You can set resource limits on the furnishing queue in order to limit the kinds of jobs that are peer scheduled. You can assign custom resources to jobs to represent arbitrary elements, for example peer queueing only those jobs from a specific project. You can assign the custom resource by having the job inherit it or via a hook.

  For how to set up peer scheduling, see section 4.9.31, “Peer Scheduling”, on page 167

- You can route jobs from specific execution queues to the desired vnodes, by associating the vnodes with the queues. See section 4.9.2, “Associating Vnodes with Queues”, on page 105.
- You can create placement sets so that jobs are placed according to resource values. Placement sets are created where vnodes share a value for a resource; you can use custom resources to create the placement sets you want. See section 4.9.32, “Placement Sets”, on page 170.

4.9.8.3 Using Custom Resources to Assign Job Execution Priority

You can use custom resources as coefficients in the job sorting formula. You can assign custom resources to jobs using the techniques listed in section 14.3, “Allocating Resources to Jobs”, on page 507. The value of each custom resource can be based on a project, an application, etc.

For example, you can create a custom resource called "ProjPrio", and the jobs that request the "Bio" project can be given a value of 5 for ProjPrio, and the jobs that request the "Gravel" project can be given a value of 2 for ProjPrio. You can assign this value in a hook or by routing the jobs into special queues from which the jobs inherit the value for ProjPrio.

For information on using the job sorting formula, see section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151.

4.9.8.4 Using Custom Resources to Track and Control Resource Allocation

You can use resources to track and control usage of things like CPUs and memory. For example, you might want to limit the number of jobs using a particular vnode. See section 5.10, “Using Resources to Track and Control Allocation”, on page 254.

4.9.8.5 Using Custom Resources to Represent GPUs, FPGAs, Switches, Etc.

You can use custom resources to represent GPUs, FPGAs, high performance switches, etc. For examples, see section 5.14.7, “Using GPUs”, on page 286, and section 5.14.8, “Using FPGAs”, on page 289.

4.9.8.6 Using Custom Resources to Allow Platform-specific Resource Requests

PBS is integrated with Cray, and provides special custom resources to represent Cray resources. You can create other custom resources to represent other platform-specific elements. For an example, see section 11.9.6, “Allowing Users to Request Login Node Groups on Cray XC”, on page 482.

4.9.8.7 Using Custom Resources to Allow Platform-specific Behavior

You can create custom resources that allow Cray users to run jobs that behave the same way they would if the user had used the `aprun` command.

4.9.9 Using Idle Workstation Cycle Harvesting

You can configure workstations at your partition or site so that PBS can run jobs on them when their "owners" are away and they are idle. This is called *idle workstation cycle harvesting*. This can give your partition or site additional resources to run jobs during nights and weekends, or even during lunch.

You can configure PBS to use the following methods to decide when a workstation is not being used by its owner:

- Keyboard/mouse activity
- X-Window monitoring
- Load average (not recommended)

On some systems cycle harvesting is simple to implement, because the console, keyboard, and mouse device access times are periodically updated by the operating system. The PBS MoM process can track this information, and mark the vnode *busy* if any of the input devices is in use. On other systems, however, this data is not available: on some machines, PBS can monitor the X-Window system in order to obtain interactive idle time, and on others, PBS itself monitors keyboard and mouse activity.

Jobs on workstations that become *busy* are not migrated; they remain on the workstation until they complete execution, are rerun, or are deleted.

4.9.9.1 Platforms Supporting Cycle Harvesting

Due to different operating system support for tracking mouse and keyboard activity, the availability and method of support for cycle harvesting varies based on the computer platform in question. The following table lists the method and support for each platform.

Table 4-6: Cycle Harvesting Support Methods

System	Status	Method	Reference
Linux	supported	keyboard/mouse	section 4.9.9.3, "Cycle Harvesting Based on Keyboard/Mouse Activity", on page 118
Windows	supported	keyboard/mouse	section 4.9.9.4, "Cycle Harvesting on Windows", on page 119

4.9.9.2 The $kbd_idle MoM Configuration Parameter

Cycle harvesting based on keyboard/mouse activity and X-Windows monitoring is controlled by the $kbd_idle MoM configuration parameter in `PBS_HOME/mom_priv/config` on the workstation in question. This parameter has the following format:

$kbd_idle <idle_wait> <min_use> <poll_interval>

Declares that the vnode will be used for batch jobs during periods when the keyboard and mouse are not in use.

idle_wait

Time, in seconds, that the workstation keyboard and mouse must be idle before being considered available for batch jobs.

Must be set to value greater than 0 for cycle harvesting to be enabled.

Format: Integer

No default

min_use

Time, in seconds, during which the workstation keyboard or mouse must continue to be in use before the workstation is determined to be unavailable for batch jobs.

Format: Integer

Default: *10*

poll_interval

Interval, in seconds, at which MoM checks for keyboard and mouse activity.

Format: Integer

Default: *1*

4.9.9.3 Cycle Harvesting Based on Keyboard/Mouse Activity

PBS can monitor a workstation for keyboard and mouse activity, and run batch jobs on the workstation when the keyboard and mouse are not being used. PBS sets the state of the vnode to either *free* or *busy*, depending on whether or not there is keyboard or mouse activity, and runs jobs only when the state of the vnode is *free*. PBS sets the state of the vnode to *free* when the vnode's mouse and keyboard have shown no activity for the specified amount of time. If PBS determines that the vnode is being used, it sets the state of the vnode to *busy* and suspends any running jobs, setting their state to *U (user busy)*.

This method is used for Linux operating systems.

4.9.9.3.i Configuring Cycle Harvesting Using Keyboard/Mouse Activity

To configure cycle harvesting using keyboard and mouse activity, do the following:

1. Set the $kbd_idle MoM configuration parameter by editing the $kbd_idle parameter in `PBS_HOME/mom_priv/config` on the workstation.
2. HUP the MoM on the workstation:

```
kill -HUP <pbs_mom PID>
```

4.9.9.3.ii Example of Cycle Harvesting Using Keyboard/Mouse Activity

The following is an example setting for the parameter:

```
$kbd_idle 1800 10 5
```

This setting for the parameter in MoM's `config` file specifies the following:

- PBS marks the workstation as *free* if the keyboard and mouse are idle for 30 minutes (1800 seconds)
- PBS marks the workstation as *busy* if the keyboard or mouse is used for 10 consecutive seconds
- The states of the keyboard and mouse are to be checked for activity every 5 seconds

Here, we walk through how this example would play out, to show the roles of the arguments to the $kbd_idle parameter:

Let's start with a workstation that has been in use for some time by its owner. The workstation is in state *busy*.

Now the owner goes to lunch. After 1800 seconds (30 minutes), PBS changes the workstation's state to *free* and starts a job on the workstation.

Some time later, someone walks by and moves the mouse or enters a command. Within the next 5 seconds (idle poll period), `pbs_mom` notes the activity. The job is suspended and placed in state *U,* and the workstation is marked *busy*.

If 10 seconds pass and there is no additional keyboard/mouse activity, the job is resumed and the workstation again is either *free* (if any CPUs are available) or *job-busy* (if all CPUs are in use.)

However, if keyboard/mouse activity continues during that 10 seconds, the workstation remains *busy* and the job remains suspended for at least the next 1800 seconds.

4.9.9.3.iii Caveats for Cycle Harvesting Using Keyboard/Mouse Activity

- There is no default for idle_wait; you must set it to a value greater than 0 in order to enable cycle harvesting using keyboard/mouse activity.

4.9.9.4 Cycle Harvesting on Windows

A process called `pbs_idled` monitors keyboard and mouse activity and keeps MoM informed of user activity. The user being monitored can be sitting at the machine, or using a remote desktop.

The `pbs_idled` process is managed in one of two ways. PBS can use a service called *PBS_INTERACTIVE* to monitor the user's session. If the PBS_INTERACTIVE service is registered, MoM starts the service, and the service starts and stops `pbs_idled`. The PBS_INTERACTIVE service runs under a local system account. PBS uses the PBS_INTERACTIVE service only where partition or site policy allows a local system account to be a service account. If this is not allowed (so the service is not registered), `pbs_idled` is started and stopped using the log on/log off script. Do not use both the PBS_INTERACTIVE service and a log on/log off script.

A `pbs_idled` process monitors the keyboard and mouse activity while a user is logged in. This process starts when the user logs on, and stops when the user logs off. Only a user with administrator privileges, or the user being monitored, can stop `pbs_idled.`

MoM uses two files to communicate with `pbs_idled`:

- MoM creates `PBS_HOME/spool/idle_poll_time` and writes the value of her $kbd_idle polling interval parameter to it. The `pbs_idled` process reads the value of the polling interval from `idle_poll_time`.
- MoM creates `PBS_HOME/spool/idle_touch`. The `pbs_idled` process updates the time stamp of the `idle_touch` file when a user is active, and MoM reads the time stamp.

4.9.9.4.i Configuring Cycle Harvesting on Windows

To configure cycle harvesting, do the following:

1. Make sure that you are a user with administrator privileges.
2. Set the $kbd_idle MoM configuration parameter by editing the $kbd_idle parameter in `PBS_HOME/mom_priv/config` on the workstation.
3. Configure how `pbs_idled` starts:
   a. If your policy allows a local system account to be a service account, register the PBS_INTERACTIVE service:
      ```
      pbs_interactive -R
      ```
   b. If your policy does not allow a local system account to be a service account:
      1. Configure the log on script as described in section 4.9.9.4.ii, “Configuring pbs_idled in Log On Script in Domain Environment”, on page 120.
      2. Configure the log off script as described in section 4.9.9.4.iii, “Configuring pbs_idled in Log Off Script in Domain Environment”, on page 121.
4. Restart the MoM.

4.9.9.4.ii Configuring `pbs_idled` in Log On Script in Domain Environment

1. You must be a user with administrator privileges.
2. On the domain controller host, open *Administrator Tools*.
3. In *Administrator Tools*, open *Active Directory Users and Computers*.
4. Right-click on the Organizational Unit where you want to apply the group policy for logging on and logging off.
5. Click on *Properties*.
6. Go to the *Group Policy* tab under the *Properties* window.
7. Click on *New*.
8. Type "LOG-IN-OUT-SCRIPT" as the name of the policy.
9. Select the Group Policy Object you have just created; click *Edit*. The Group Policy Object editing window will open.
10. Open *Window Settings* in *User Configuration*.
11. Open *Scripts (Logon/Logoff)*.
12. Open *Logon*. A *Logon Properties* window will open.
13. Open Notepad in another window. In Notepad, you create the command that starts the `pbs_idled` process:
    ```
    pbs_idled start
    ```
14. Save that document as "*pbs_idled_logon.bat*".
15. In the *Logon Properties* window, click on *Show Files*. A logon script folder will open in a new window.
16. Copy `pbs_idled_logon.bat` into the logon script folder and close the logon script folder window.
17. In the *Logon Properties* window, click on *Add*, and then click on *Browse*. Select *pbs_idled_logon.bat* and then click on *Open*.
18. Click on *OK*, then *Apply*, then again *OK*.
19. Close the Group Policy Object editor and the *Properties* window.
20. Close the *Active Directory Users and Computers* window.
21. Close the *Administrator Tools* window.

4.9.9.4.iii Configuring `pbs_idled` in Log Off Script in Domain Environment

1. You must be a user with administrator privileges.
2. On the domain controller host, open *Administrator Tools*.
3. In *Administrator Tools*, open *Active Directory Users and Computers*.
4. Right-click on the Organizational Unit where you want to apply the group policy for logging on and logging off.
5. Click on *Properties*.
6. Go to the *Group Policy* tab under the *Properties* window.
7. Click on *New*.
8. Type "LOG-IN-OUT-SCRIPT" as the name of the policy.
9. Select the Group Policy Object you have just created; click *Edit*. The Group Policy Object editing window will open.
10. Open *Window Settings* in *User Configuration*.
11. Open *Scripts (Logon/Logoff)*.
12. Open *Logoff*. A *Logoff Properties* window will open.
13. Open Notepad in another window. In Notepad, you create the command that stops the `pbs_idled` process:
    ```
    pbs_idled stop
    ```
14. Save that document as "*pbs_idled_logoff.bat*".
15. In the *Logoff Properties* window, click on *Show Files*. A logoff script folder will open in a new window.
16. Copy `pbs_idled_logoff.bat` into the logoff script folder and close the logoff script folder window.
17. In the *Logoff Properties* window, click on *Add*, and then click on *Browse*. Select *pbs_idled_logoff.bat* and then click on *Open*.
18. Click on *OK*, then *Apply*, then again *OK*.
19. Close the Group Policy Object editor and the *Properties* window.
20. Close the *Active Directory Users and Computers* window.
21. Close the *Administrator Tools* window.

4.9.9.4.iv The PBS_INTERACTIVE Service

The PBS_INTERACTIVE service starts the `pbs_idled` process, as the current user, in the current active user's session. Each time a user logs on, the service starts a `pbs_idled` for that user, and when that user logs off, the service stops that user's `pbs_idled` process.

The service runs under a local system account. If your policy allows a local system account to be a service account, you can use PBS_INTERACTIVE. Otherwise you must configure `pbs_idled` in log on/log off scripts.

If you have configured the $kbd_idle MoM parameter, and you have registered the service, MoM starts the service. The service cannot be started manually.

If you will use PBS_INTERACTIVE, you must register the service. The installer cannot register the service.

- To register the PBS_INTERACTIVE service:
  ```
  pbs_interactive -R
  ```

Upon successful execution of this command, the following message is displayed:

```
"Service PBS_INTERACTIVE installed successfully"
```

- To unregister the PBS_INTERACTIVE service:
  `pbs_interactive -U`

  Upon successful execution of this command, the following message is displayed:

  ```
  "Service PBS_INTERACTIVE uninstalled successfully"
  ```

- To see the version number for PBS_INTERACTIVE service:
  `pbs_interactive --version`

4.9.9.4.v Errors and Logging

If the $kbd_idle MoM parameter is configured, MoM attempts to use cycle harvesting. MoM looks for the PBS_INTERACTIVE service in the Service Control Manager. If she finds the service, she starts it.

1. If she cannot find the service, MoM logs the following message at event class 0x0002:
   ```
   "Can not find PBS_INTERACTIVE service, Continuing Cycle Harvesting with Logon/Logoff Script"
   ```
2. MoM looks for PBS_HOME/spool/idle_touch. If she finds it, she uses cycle harvesting.
3. If she cannot find the file, MoM disables cycle harvesting and logs the following message at event class 0x0002:
   ```
   "Cycle Harvesting Failed, Please contact Admin"
   ```

MoM logs the following messages at event class 0x0001.

- If MoM fails to open the Service Control Manager:
  ```
  "OpenSCManager failed for PBS_INTERACTIVE"
  ```
- If MoM fails to open the PBS_INTERACTIVE service:
  ```
  "OpenService failed for PBS_INTERACTIVE"
  ```
- If MoM fails to start the PBS_INTERACTIVE service:
  ```
  "Could not start PBS_INTERACTIVE service"
  ```
- If MoM fails to get status information about the PBS_INTERACTIVE service:
  ```
  "Can not get information about PBS_INTERACTIVE service"
  ```
- If MoM fails to send a stop control message to the PBS_INTERACTIVE service:
  ```
  "Could not stop PBS_INTERACTIVE service"
  ```
- If the PBS_INTERACTIVE service does not respond in a timely fashion:
  ```
  "PBS_INTERACTIVE service did not respond in timely fashion"
  ```
- If MoM fails to create idle_touch and idle_poll_time in PBS_HOME/spool directory:
  ```
  "Can not create file < full path of idle file >"
  ```
- If MoM fails to write the idle polling interval into PBS_HOME/spool/idle_poll_time:
  ```
  "Can not write idle_poll time into < full path of idle_poll_time file > file"
  ```

4.9.9.4.vi Caveats for Cycle Harvesting on Windows

- Under Windows, if the `pbs_idled` process is killed, cycle harvesting will not work.
- Under Windows, cycle harvesting may not work correctly on machines where more than one user is logged in, and users are not employing Switch User.
- Do not use both the PBS_INTERACTIVE service and a log on/log off script.

4.9.9.5 Cycle Harvesting by Monitoring X-Windows

On Linux machines where the OS does not periodically update console, keyboard, and mouse device access times, PBS can monitor X-Window activity instead. PBS uses an X-Window monitoring process called `pbs_idled`. This process runs in the background and monitors X and reports to the `pbs_mom` whether or not the vnode is idle. `pbs_idled` is located in `$PBS_EXEC/sbin`.

To configure PBS for cycle harvesting by monitoring X-Windows, perform the following steps:

1. Create a directory for `pbs_idled`. This directory must have the same permissions as `/tmp` (i.e. mode *1777*). This will allow the `pbs_idled` program to create and update files as the user, which is necessary because the program runs as the user. For example:

   ```
   mkdir PBS_HOME/spool/idledir
   chmod 1777 PBS_HOME/spool/idledir
   ```

2. Turn on keyboard idle detection in the MoM `config` file:

   ```
   $kbd_idle <idle wait value>
   ```

3. Include `pbs_idled` as part of the X-Windows startup sequence.

   The best and most secure method of starting `pbs_idled` is via the system-wide `Xsession` file. This is the script which is run by `xdm` (the X login program) and sets up each user's X-Windows environment.

   You **must** place the startup line for `pbs_idled` before that of the window manager.

   You **must** make sure that `pbs_idled` runs in the background.

   On systems that use `Xsession` to start desktop sessions, insert a line invoking `pbs_idled` near the top of the file.

   For example, insert the following line in a Linux `Xsession` file:

   ```
   /usr/pbs/sbin/pbs_idled &
   ```

   If access to the system-wide `Xsession` file is not available, you can add `pbs_idled` to every user's personal `.xsession` or `.xinitrc` file, depending on the local OS requirements for starting X-windows programs upon login.

4.9.9.6 Cycle Harvesting Based on Load Average

As of version 2020.1, the load_balancing scheduler parameter is deprecated.

Cycle harvesting based on load average means that PBS monitors each workstation's load average, runs jobs where workstations have loads below a specified level, and suspends any batch jobs on workstations whose load has risen above the limit you set. When a workstation's owner uses the machine, the workstation's load rises.

When you configure cycle harvesting based on load average, you are performing the same configuration as for load balancing using load average. For a complete description of load balancing, see section 4.9.27, "Using Load Balancing", on page 158.

4.9.9.6.i Attributes and Parameters Affecting Cycle Harvesting Based on Load Average

load_balancing

Deprecated (2020.1).

Scheduler parameter. When set to *True*, this scheduler places jobs only where the load average is below the specified limit.

Format: *Boolean*

Default: *False all*

$ideal_load <load>

MoM parameter. Defines the load below which the vnode is not considered to be *busy*. Used with the $max_load directive.

Example:

```
$ideal_load 1.8
```

Format: *Float*

No default

$max_load <load> [suspend]

MoM parameter. Defines the load above which the vnode is considered to be *busy*. Used with the $ideal_load directive. No new jobs are started on a *busy* vnode.

The optional suspend directive tells PBS to suspend jobs running on the node if the load average exceeds the $max_load number, regardless of the source of the load (PBS and/or logged-in users). Without this directive, PBS will not suspend jobs due to load.

We recommend setting this to a slightly higher value than your target load (which is typically the number of CPUs), for example *.25 + ncpus*.

Example:

```
$max_load 3.25
```

Format: *Float*

Default: number of CPUs

resv_enable

Vnode attribute. Controls whether the vnode can be used for advance and standing reservations. When set to *True*, this vnode can be used for reservations.

Format: *Boolean*

Default: *True*

no_multinode_jobs

Vnode attribute. Controls whether jobs which request more than one chunk are allowed to execute on this vnode. When set to *True*, jobs requesting more than one chunk are not allowed to execute on this vnode.

Format: *Boolean*

Default: *False*

4.9.9.6.ii How Cycle Harvesting Based on Load Average Works

Cycle harvesting based on load average means that PBS monitors the load average on each machine. When the load on a workstation is below what is specified in the $ideal_load MoM parameter, PBS sets the state of the workstation to *free*. A scheduler will run jobs on vnodes whose state is *free*. When the load on a workstation exceeds the setting for $max_load, PBS sets the state of the workstation to *busy*, and suspends jobs running on the workstation. PBS does not start jobs on a vnode whose state is *busy*. When the load drops below the setting for $ideal_load, PBS sets the state to *free*, and resumes the jobs that were running on the workstation.

PBS thinks that a 1-CPU job raises a vnode's load by 1. On machines being used for cycle harvesting, you set the values for $max_load and $ideal_load to reasonable limits. On other machines, you set these to values that will never be exceeded, so that load is effectively ignored.

On machines where these parameters are unset, the vnode's state is not set according to its load, so jobs are not suspended because a vnode is busy. However, if $max_load and $ideal_load are unset, they are treated as if they have the same value as resources_available.ncpus, and because there is usually a small background load, PBS will lose the use of a CPU's worth of load.

The load_balancing scheduler parameter (**deprecated** as of version 2020.1) controls a behavior wherein a scheduler won't place a job where the anticipated load would exceed $max_load. For example if a machine has a load of 1.25, is running a 1-CPU job, and has 2 CPUs, PBS won't place another 1-CPU job there.

4.9.9.6.iii Configuring Cycle Harvesting Based on Load Average

To set up cycle harvesting for idle workstations based on load average, perform the following steps:

1. If PBS is not already installed on the target execution workstations, do so now, selecting the execution-only install option. See the PBS Professional Installation & Upgrade Guide.
2. Edit the `PBS_HOME/mom_priv/config` configuration file on each target execution workstation, adding the $max_load and $ideal_load configuration parameters. Make sure they have values that will not interfere with proper operation. See section 4.9.9.6.v, “Caveats for Cycle Harvesting Based on Load Average”, on page 126.

   ```
   $max_load <load limit that allows jobs to run>
   $ideal_load <load at which to start jobs>
   ```
3. Edit the `PBS_HOME/mom_priv/config` configuration file on each machine where you are not using cycle harvesting, adding the $max_load and $ideal_load configuration parameters. Make sure they have values that will never be exceeded.

   ```
   $max_load <load limit that will never be exceeded>
   $ideal_load <load limit that will never be exceeded>
   ```
4. HUP the MoM:

   ```
   kill -HUP <pbs_mom PID>
   ```
5. Edit the `<sched_priv directory>/sched_config` configuration file to direct the scheduler to perform scheduling based on `load_balancing`.

   ```
   load_balancing:  True   ALL
   ```
6. If you wish to oversubscribe the vnode's CPU(s), set its resources_available.ncpus to a higher number. Do this only on single-vnode machines. You must be cautious about matching ncpus and $max_load. See "Caveats for Cycle Harvesting Based on Load Average" on page 126 in the PBS Professional Administrator’s Guide.
7. HUP the scheduler:

   ```
   kill -HUP <pbs_sched PID>
   ```
8. Set the vnode's resv_enable attribute to *False*, to prevent the workstation from being used for reservations.

   ```
   Qmgr: set node <vnode name> resv_enable = False
   ```
9. Set the vnode's no_multinode_jobs attribute to *True*, to prevent the workstation from stalling multichunk jobs.

   ```
   Qmgr: set node <vnode name> no_multinode_jobs = True
   ```

4.9.9.6.iv Viewing Load Average Information

You can see the state of a vnode using the `pbsnodes -a` command.

4.9.9.6.v Caveats for Cycle Harvesting Based on Load Average

- Be careful with the settings for $ideal_load and $max_load. You want to make sure that when the workstation owner is using the machine, the load on the machine triggers MoM to report being busy, and that PBS does not start any new jobs while the user is working.
- For information about keeping your partition or site running smoothly using $max_load and $ideal_load, see section 9.6.5, "Managing Load Levels on Vnodes", on page 447
- If you set ncpus higher than the number of actual CPUs, and set $max_load higher to match, keep in mind that the workstation user could end up with an annoyingly slow workstation. This can happen when PBS runs jobs on the machine, but the combined load from the jobs and the user is insufficient for MoM to report being busy.

4.9.9.7 Cycle Harvesting and File Transfers

The cycle harvesting feature interacts with file transfers in one of two different ways, depending on the method of file transfer:

- If the user's job includes file transfer commands (such as `rcp` or `scp`) within the job script, and such a command is running when PBS decides to suspend the job on the vnode, then the file transfer is suspended as well.
- If the job has PBS file staging parameters (i.e. *stagein=*, *stageout=file1...*), and the load goes above $max_load, the file transfer is not suspended. This is because the file staging is not part of the job script execution, and is not subject to suspension. See "Detailed Description of Job Lifecycle", on page 37 of the PBS Professional User's Guide.

4.9.9.8 Parallel Jobs With Cycle Harvesting

Cycle harvesting is not recommended for hosts that will run multi-host jobs. However, you may find that your partition or site benefits from using cycle harvesting on these machines. We provide advice on how to prevent cycle harvesting on these machines, and advice on how to accomplish it.

4.9.9.8.i General Advice: Parallel Jobs Not Recommended

Cycle harvesting is somewhat incompatible with multi-host jobs. If one of the hosts being used for a parallel job running on several hosts is being used for cycle harvesting, and the user types at the keyboard, job execution will be delayed for the entire job because the tasks running on that host will be suspended.

To prevent a machine which is being used for cycle harvesting from being assigned a multi-host job, set the vnode's no_multinode_jobs attribute to *True*. This attribute prevents a host from being used by jobs that span multiple hosts.

4.9.9.8.ii How to Use Cycle Harvesting with Multi-host Jobs

When a single-host job is running on a workstation configured for cycle harvesting, and that host becomes *busy*, the job is suspended. However, suspending a multi-host parallel job may have undesirable side effects because of inter-process communications. For a job which uses multiple hosts when one or more of the hosts becomes *busy*, the default action is to leave the job running.

However, you can specify that the job should be requeued and subsequently re-scheduled to run elsewhere when any of the hosts on which the job is running becomes *busy*. To enable this action, add the following parameter to MoM's configuration file:

```
$action multinodebusy 0 requeue
```

where multinodebusy is the action to modify; "*0*" (zero) is the action timeout value (it is ignored for this action); and *requeue* is the new action to perform. The only action that can be performed is requeueing.

Multi-host jobs which are not rerunnable (i.e. those submitted with the `qsub -rn` option) will be killed if the requeue argument is configured for the multinodebusy action and a vnode becomes busy.

4.9.9.9 Cycle Harvesting Caveats and Restrictions

4.9.9.9.i Cycle Harvesting and Multi-host Jobs

Cycle harvesting is not recommended for hosts that will run multi-host jobs. See section 4.9.9.8.i, "General Advice: Parallel Jobs Not Recommended", on page 126.

4.9.9.9.ii Cycle Harvesting and Reservations

Cycle harvesting is incompatible with jobs in reservations. Reservations should not be made on a machine used for cycle harvesting, because the user may appear during the reservation period and use the machine's keyboard. This will suspend the jobs in the reservation, defeating the purpose of making a reservation.

To prevent a vnode which is being used for cycle harvesting from being used for reservations, set the vnode's resv_enable attribute to *False*. This attribute controls whether the vnode can be used for reservations.

4.9.9.9.iii File Transfers with Cycle Harvesting

File transfers behave differently depending on job details. See section 4.9.9.7, "Cycle Harvesting and File Transfers", on page 126.

4.9.9.9.iv Cycle Harvesting on Windows

- Under Windows, if the `pbs_idled` process is killed, cycle harvesting will not work.
- Under Windows, cycle harvesting may not work correctly on machines where more than one user is logged in.

4.9.10 Dedicated Time

PBS provides a feature called *dedicated time* which allows you to define times during which the only jobs that can run are the ones in dedicated queues. You can use dedicated time for things like upgrades.

You can define multiple dedicated times. Any job in a dedicated time queue must have a walltime in order to run. Jobs without walltimes will never run. PBS won't let a reservation conflict with dedicated time. Hooks should not access or modify the dedicated time file.

For information on configuring dedicated time queues, see section 2.3.5.2.i, "Dedicated Time Queues", on page 26.

4.9.10.1 Dedicated Time File

You define dedicated time by adding one or more time slots in the file `<sched_priv directory>/dedicated_time`. A time slot is a start date and start time and an end date and end time. Format:

<start date> <start time> <end date> <end time>

expressed as

MM/DD/YYYY   HH:MM   MM/DD/YYYY   HH:MM

Any line whose first non-whitespace character is a pound sign ("#") is a comment.

Example:

```
#Dedicated time for maintenance
04/15/2007 12:00 04/15/2007 15:30
```

A sample dedicated time file (`PBS_EXEC/etc/pbs_dedicated`) is included in the installation.

The dedicated time file is read on startup and HUP.

4.9.10.2 Steps in Defining Dedicated Time

You define dedicated time by performing the following steps:

1. Edit the file `<sched_priv directory>/dedicated_time` and add one or more time slots.
2. HUP or restart the scheduler:

   Linux:

   ```
   kill -HUP <pbs_sched PID>
   ```

4.9.10.3 Recommendations for Dedicated Time

If you need to set up dedicated time for something like system maintenance, you may want to avoid having the machines become idle for a significant period before dedicated time starts. You can allow jobs to shrink their walltimes to fit into those shorter-than-normal slots before dedicated time. See section 4.9.42, “Using Shrink-to-fit Jobs”, on page 213.

4.9.11 Dependencies

PBS allows job submitters to specify dependencies between jobs, for example specifying that job J2 can only run if job J1 finishes successfully. In addition, you can add dependencies to existing jobs via a hook, default arguments to `qsub`, or via the `qalter` command.

For a description of how job dependencies work, see "Using Job Dependencies", on page 107 of the PBS Professional User’s Guide.

For how to use hooks, see the PBS Professional Hooks Guide.

For how to add default `qsub` arguments, see “Server Attributes” on page 283 of the PBS Professional Reference Guide.

For how to use the `qalter` command, see “qalter” on page 128 of the PBS Professional Reference Guide.

4.9.12 Dynamic Resources

You can use dynamic PBS resources to represent elements that are outside of the control of PBS, typically for application licenses and scratch space. You can represent elements that are available to the entire PBS partition or complex as server-level resources, or elements that are available at a specific host or hosts as host-level resources. For an example of configuring a server-level dynamic resource, see section 5.14.3.1.iii, “Example of Configuring Dynamic Server-level Resource”, on page 269. For an example of configuring a dynamic host-level resource, see section 5.14.4.1.i, “Example of Configuring Dynamic Host-level Resource”, on page 272.

For a complete description of how to create and use dynamic resources, see section 5.14, “Custom Resources”, on page 257.

4.9.13 Eligible Wait Time for Jobs

PBS provides a method for tracking how long a job that is eligible to run has been waiting to run. By "eligible to run", we mean that the job could run if the required resources were available. The time that a job waits while it is not running can be classified as "eligible" or "ineligible". Roughly speaking, a job accrues eligible wait time when it is blocked due to a resource shortage, and accrues ineligible wait time when it is blocked due to project, user, or group limits. A job can be accruing any of the following kinds of time. A job can only accrue one kind of wait time at a time, and cannot accrue wait time while it is running.

4.9.13.1 Types of Time Accrued

eligible_time

Job attribute. The amount of wall clock wait time a job has accrued because the job is blocked waiting for resources, or any other reason not covered by the other kinds of time. For a job currently accruing eligible_time, if we were to add enough of the right type of resources, the job would start immediately. Viewable via `qstat -f` by job owner, Manager and Operator. Settable by Operator or Manager.

ineligible_time

The amount of wall clock time a job has accrued because the job is blocked by limits on the job's project, owner, or group, or because the job is blocked because of its state.

run_time

The amount of wall clock time a job has spent running.

exiting

The amount of wall clock time a job has spent exiting.

initial_time

The amount of wall clock wait time a job has accrued before the type of wait time has been determined.

4.9.13.2 How Eligible Wait Time Works

A job accrues ineligible_time while it is blocked by project, user, or group limits, such as:

max_run

max_run_soft

max_run_res.<resource name>

max_run_res_soft.<resources>

A job also accrues ineligible_time while it is blocked due to a user hold or while it is waiting for its start time, such as when submitted via

```
qsub -a <run-after> …
```

A job accrues eligible_time when it is blocked by a lack of resources, or by anything not qualifying as ineligible_time or run_time. A job's eligible_time will only increase during the life of the job, so if the job is requeued, its eligible_time is preserved, not set to zero. The job's eligible_time is not recalculated when a job is qmoved or moved due to peer scheduling.

For information on project, user, and group limits, see section 5.15.1, “Managing Resource Usage By Users, Groups, and Projects, at Server & Queues”, on page 290.

The kind of time a job is accruing is sampled periodically, with a granularity of seconds.

A job's eligible_time attribute can be viewed via `qstat -f`.

4.9.13.3 Configuring Eligible Wait Time

To enable using eligible time as the job's wait time, set the eligible_time_enable server attribute to *True*.

4.9.13.4 How Eligible Wait Time Is Used

- If eligible time is enabled, it is used as each job's starving time.
- You can choose to use each job's eligible wait time as the amount of time it is starving. See section 4.9.48, "Starving Jobs", on page 225.
- When a job is requeued, for example being checkpointed and aborted or preempted, its accumulated queue waiting time depends on how that time is calculated:
  - If you are using eligible time, the accumulated waiting time is preserved
  - If you are not using eligible time, the accumulated waiting time is lost

  See section 9.3, "Checkpoint and Restart", on page 420 and section 4.9.33, "Using Preemption", on page 182.

4.9.13.5 Altering Eligible Time

A Manager or Operator can set the value for a job's eligible_time attribute using the `qalter` command, for example:

```
qalter -Weligible_time=<time> <job ID>
```

4.9.13.6 Attributes Affecting Eligible Time

eligible_time_enable

Server attribute. Enables accumulation of eligible time for jobs. Controls whether a job's eligible_time attribute is used as its starving time. See section 4.9.48, "Starving Jobs", on page 225.

On an upgrade from versions of PBS prior to 9.1 or on a fresh install, eligible_time_enable is set to *False* by default.

When eligible_time_enable is set to *False*, PBS does not track eligible_time. Whether eligible_time continues to accrue for a job or not is undefined. The output of `qstat -f` does not include eligible_time for any job. Accounting logs do not show eligible_time for any job submitted before or after turning eligible_time_enable off. Log messages do not include accrual messages for any job submitted before or after turning eligible_time_enable off. If the scheduling formula includes eligible_time, eligible_time evaluates to *0* for all jobs.

When eligible_time_enable is changed from *False* to *True*, jobs accrue eligible_time or ineligible_time or run_time as appropriate. A job's eligible_time is used for starving calculation starting with the next scheduling cycle; changing the value of eligible_time_enable does not change the behavior of an active scheduling cycle.

accrue_type

Job attribute. Indicates what kind of time the job is accruing.

Table 4-7: The accrue_type Job Attribute

Type	Numeric Representation	Type
JOB_INITIAL	*0*	initial_time
JOB_INELIGIBLE	*1*	ineligible_time
JOB_ELIGIBLE	*2*	eligible_time
JOB_RUNNING	*3*	run_time
JOB_EXIT	*4*	exit_time

The job's accrue_type attribute is visible via `qstat` only by Manager, and is set only by the server.

eligible_time

Job attribute. The amount of wall clock wait time a job has accrued because the job is blocked waiting for resources, or any other reason not covered by ineligible_time. For a job currently accruing eligible_time, if we were to add enough of the right type of resources, the job would start immediately. Viewable via `qstat -f` by job owner, Manager and Operator. Settable by Operator or Manager.

4.9.13.7 Logging

The server prints a log message every time a job changes its accrue_type, with both the new accrue_type and the old accrue_type. These are logged at the 0x0400 event class.

Server logs for this feature display the following information:

- Time accrued between samples
- The type of time in the previous sample, which is one of initial time, run time, eligible time or ineligible time
- The next type of time to be accrued, which is one of run time, eligible time or ineligible time
- The eligible time accrued by the job, if any, until the current sample

Example:

```
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 0 secs of initial_time, new
    accrue_type=eligible_time, eligible_time=00:00:00
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 1821 secs of eligible_time, new
    accrue_type=ineligible_time, eligible_time=01:20:22
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 2003 secs of ineligible_time, new
    accrue_type=eligible_time, eligible_time=01:20:22
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 61 secs of eligible_time, new
    accrue_type=run_time, eligible_time=01:21:23
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 100 secs of run_time, new
    accrue_type=ineligible_time, eligible_time=01:21:23
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 33 secs of ineligible_time, new
    accrue_type=eligible_time, eligible_time=01:21:23
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 122 secs of eligible_time, new
    accrue_type=run_time, eligible_time=01:23:25
08/07/2007 13:xx:yy;0040;Server@host1;Job;163.host1;job accrued 1210 secs of run_time, new
    accrue_type=exiting, eligible_time=01:23:25
```

The example shows the following changes in time accrual:

- initial to eligible
- eligible to ineligible
- ineligible to eligible
- eligible to running
- running to ineligible
- ineligible to eligible
- eligible to running
- running to exiting

The server also logs the change in accrual when the job's eligible_time attribute is altered using `qalter`. For example, if the job's previous eligible time was 123 seconds, and it has been altered to be 1 hour and 1 minute:

```
Accrue type is eligible_time, previous accrue type was eligible_time for 123 secs, due to qalter
    total eligible_time=01:01:00
```

4.9.13.8 Accounting

Each job's eligible_time attribute is included in the "E" and "R" records in the PBS accounting logs. See section 19.4, "Types of Accounting Log Records", on page 638.

Example:

```
08/07/2007 19:34:06;E;182.Host1;user=user1 group=user1 jobname=STDIN queue=workq ctime=1186494765
    qtime=1186494765 etime=1186494765 start=1186494767 exec_host=Host1/0
    exec_vnode=(Host1:ncpus=1) Resource_List.ncpus=1 Resource_List.nodect=1
    Resource_List.place=pack Resource_List.select=1:ncpus=1 session=4656 end=1186495446
    Exit_status=-12 resources_used.cpupercent=0 resources_used.cput=00:00:00
    resources_used.mem=3072kb resources_used.ncpus=1 resources_used.vmem=13356kb
    resources_used.walltime=00:11:21 eligible_time=00:10:00
```

4.9.13.9 Caveats for Eligible Time

- A job that is dependent on another job can accrue eligible time only after the job on which it depends has finished.
- The action of a hook may affect a job's eligible time. See "Effect of Hooks on Job Eligible Time" on page 73 in the PBS Professional Hooks Guide.
- A subjob that is not running because its array job has hit the max_run_subjobs limit accrues eligible time as long as no other limts have been hit.

4.9.14 Sorting Jobs by Entity Shares (Was Strict Priority)

You can sort jobs according to how much of the fairshare tree is allocated to the entity that owns the job. The fairshare percentages in the fairshare tree describe each entity's share. Using entity shares is sorting jobs on a key, using the fairshare_perc option to the job_sort_key scheduler parameter.

Using entity shares, the jobs from an entity with greater allocation in the fairshare tree run before the jobs with a smaller allocation.

4.9.14.1 Configuring Entity Shares

To configure entity shares, do the following:

- Define fairshare tree entity allocation in `<sched_priv directory>/resource_group`. See section 4.9.19, “Using Fairshare”, on page 140. You can use a simple fairshare tree, where every entity's `parent_group` is `root`.
  - Give each entity shares according to desired priority, with higher-priority entities getting larger allocations.
  - Set the unknown_shares scheduler parameter to *1*. This causes any entity not in your list of approved entities to have a tiny allocation, and the lowest priority.

  For example:

```
        usr1    60      root    5
        usr2    61      root    15
        usr3    62      root    15
        usr4    63      root    10
        usr5    64      root    25
        usr6    65      root    30
```

- Set fairshare_perc as the option to job_sort_key, for example:
  `job_sort_key: "fairshare_perc HIGH all"`

4.9.14.2 Viewing Entity Shares

When you are root, you can use the `pbsfs` command to view the fairshare tree allocations.

4.9.15 Estimating Job Start Time

PBS can use a built-in hook called *PBS_est* that runs the job start time estimator, to estimate when jobs will run, and which vnodes each job will use. PBS estimates job start times and vnodes for all jobs using an asynchronous process, not the PBS server, scheduler, or MoM daemons. This estimator process is started by the PBS_est hook, whose default interval is 120 seconds. By default, the PBS_est hook is disabled.

Jobs have an attribute called *estimated* for reporting estimated start time and estimated vnodes. This attribute reports the values of two read-only built-in resources, *start_time* and *exec_vnode*. Each job's estimated start time is reported in estimated.start_time, and its estimated vnodes are reported in estimated.exec_vnode.

PBS automatically sets the value of each job's estimated.start_time value to the estimated start time for each job.

4.9.15.1 Configuring Start Time Estimation

When a scheduler is backfilling around top jobs, it estimates the start times and exec_vnode for those jobs being backfilled around. By default, PBS_est is disabled. If you want PBS_est to estimate start times and exec_vnode for all jobs, enable it:

- Enable the built-in PBS_est hook:

```
qmgr -c "set pbshook PBS_est enabled = true"
```

The default frequency for PBS_est is 120 seconds. You can set the frequency:

```
qmgr -c "set pbshook PBS_est freq = <interval in seconds>"
```

You set the number of jobs to be backfilled around by setting the server and/or queue backfill_depth attribute to the desired number. See section 4.9.3, "Using Backfilling", on page 107.

Example 4-1: To estimate start times for the top 5 jobs every scheduling cycle, and for all jobs every 3000 seconds:

```
qmgr -c 'set server backfill_depth=5'
qmgr -c 'set pbshook PBS_est enabled = true'
qmgr -c 'set pbshook PBS_est freq = 3000'
```

At each interval, the PBS_est hook checks whether the estimator process is running. If the estimator process is running when the PBS_est hook hits an interval and performs this check, the PBS_est hook does not stop the estimator process or start a new one. It allows the estimator process to finish running. If the estimator process is not running when the PBS_est hook hits an interval, the PBS_est hook starts a new estimator process.

4.9.15.2 Controlling User Access to Start Times and Vnode List

4.9.15.2.i Making Start Time or Vnodes Invisible

You can make job estimated start times and vnodes invisible to unprivileged users by adding resource permission flags to the start_time or exec_vnode resources. To do this, use `qmgr` to add the resource, and include the `i` flag, in the same way you would for a custom resource being made invisible.

Example of making start_time and exec_vnode invisible to users:

```
qmgr -c 'set resource start_time flag=i'
qmgr -c 'set resource exec_vnode flag=i'
```

You can always make the start time and vnodes visible again to unprivileged users by removing the flags via `qmgr`.

See section 5.14.2.3.vi, "Resource Permission Flags", on page 262.

4.9.15.2.ii Allowing Users to See Only Their Own Job Start Times

If you want users to be able to see the start times for their own jobs, but not those of other users, set the server's query_other_jobs attribute to *False*, and do not set the i or r permission flags. Setting the server's query_other_jobs attribute to *False* prevents a user from seeing anything about other users' jobs.

4.9.15.3 Attributes and Parameters Affecting Job Start Time Estimation

backfill

Server attribute

backfill_depth

Server attribute

backfill_depth

Queue attribute

enabled

Hook attribute

estimated

Job attribute

freq

Hook attribute.

help_starving_jobs

Scheduler parameter

strict_ordering

Scheduler parameter

4.9.15.4 Viewing Estimated Start Times

You can view the estimated start times and vnodes of jobs using the `qstat` command. If you use the `-T` option to `qstat` when viewing job information, the *Est Start Time* field is displayed. Running jobs are shown above queued jobs.

See "qstat" on page 198 of the PBS Professional Reference Guide.

If the estimated start time or vnode information is invisible to unprivileged users, no estimated start time or vnode information is available via `qstat`.

Example output:

```
qstat -T
                                                          Est
                                              Req'd  Req'd   Start
Job ID   Username Queue Jobname SessID NDS TSK Memory Time  S Time
-------  -------- ----- -------- ----- --- --- ------ ----- - -----
5.host1   user1   workq  foojob  12345  1   1  128mb 00:10  R   --
9.host1   user1   workq  foojob   --    1   1  128mb 00:10  Q  11:30
10.host1  user1   workq  foojob   --    1   1  128mb 00:10  Q  Tu 15
7.host1   user1   workq  foojob   --    1   1  128mb 00:10  Q  Jul
8.host1   user1   workq  foojob   --    1   1  128mb 00:10  Q  2010
11.host1  user1   workq  foojob   --    1   1  128mb 00:10  Q  >5yrs
13.host1  user1   workq  foojob   --    1   1  128mb 00:10  Q   --
```

4.9.15.5 Selecting Jobs By Estimated Start Time

You can use the `qselect` command to select jobs according to their start times by using the `-t` suboption to the `-t` option. This selects jobs according to the value of the estimated.start_time attribute. See "qselect" on page 187 of the PBS Professional Reference Guide.

4.9.15.6 Logging

Whenever a scheduler estimates the start time of a job, it logs the start time. A scheduler does not log the estimated exec_vnode of a job.

4.9.15.7 Caveats and Advice

- The estimated.start_time of a job array is the time calculated for the first queued subjob only.
- Cached estimated start times are only as fresh as the last time PBS calculated them.This should be taken into account when setting the values of the PBS_est hook's freq attribute and backfill_depth.
- The frequency of calculating start times is a trade-off between having more current start time information and using fewer computing cycles for non-job work. The background task of calculating start times can be computationally intensive. This should be taken into account when setting the value of the PBS_est hook's freq attribute. Depending on the size of your partition or site, it is probably a good idea not to set it to less than 10 minutes.
- The best value for the PBS_est hook's freq attribute is workload dependent, but we recommend setting it to two hours as a starting point.
- If your partition or site has short scheduling cycles of a few minutes, and can use backfilling (and at least one of strict ordering or starving jobs), you can have the start times for all jobs calculated at each scheduling cycle. To do this, set backfill_depth to a value greater than the number of jobs the partition or site will ever have, and do not set the PBS_est hook's freq attribute.
- We recommend setting backfill_depth to a value that is less than 100.
- The process of computing the estimated start time for jobs is not instantaneous.
- Note that setting backfill_depth changes your scheduling policy. See section 4.9.3, “Using Backfilling”, on page 107.

4.9.16 Calculating Job Execution Priority

When a scheduler examines jobs, either at the whole partition or complex or within a queue, it gives each job an execution priority, and then uses this job execution priority to select which job(s) to run. Job execution priority is mostly independent of job preemption priority. We discuss only job execution priority in this section.

Some of a scheduler's policy for determining job execution priority is built into PBS, but you can specify how execution priority is determined for most of the policy.

First, a scheduler divides queued jobs into classes. Then it sorts the jobs within each class.

4.9.16.1 Dividing Jobs Into Classes

PBS groups all jobs into classes, and handles one class at a time. There are special classes that supersede queue order, meaning that whether or not queues are being examined separately, the jobs in each of those classes are handled before a scheduler takes queues into account. Those jobs are not ordered according to which queue they reside in. For example, all starving jobs are handled as a group. PBS has one non-special class called *Normal* for all non-special jobs. This class typically contains most PBS jobs. Queue order is imposed on this class, meaning that queue priority affects job execution order if queues are being handled separately.

Job execution classes have a built-in order of precedence. All jobs in the highest class are considered before any jobs in the next class, and so on. Classes are listed in the following table, highest first:

Table 4-8: Job Execution Classes

Class	Description	Sort Applied Within Class
Reservation	Jobs submitted to an advance, standing, or job-specific reservation	Formula, job sort key, submission time
Express	All jobs with preemption priority higher than normal jobs. Preemption priority is defined in scheduler's preempt_prio attribute. Jobs are sorted into this class only when preemption is enabled. See section 4.9.33, "Using Preemption", on page 182.	First by preemption priority, then by preemption time, then starving time, then by formula, then fairshare, then job sort key, followed by job submission time
Preempted	All jobs that have been preempted. See section 4.9.33, "Using Preemption", on page 182.	First by preemption time, then starving time, then by formula, then fairshare, then job sort key, followed by job submission time
Starving (deprecate)	Starving jobs. Jobs are sorted into this class only when starving is enabled by setting help_starving_jobs to *True*. See section 4.9.48, "Starving Jobs", on page 225	Amount of time counted toward starving, then by formula, then fairshare, then job sort key, followed by job submission time
Normal	Jobs that do not belong in any of the special classes	Queue order, if it exists, then formula, then fairshare, then job sort key, followed by job submission time

4.9.16.2 Selecting Job Execution Class

A scheduler places each job in the highest-priority class into which the job can fit. So, for example, if a job is both in a reservation and is starving, the job is placed in the Reservation class.

4.9.16.3 Sorting Jobs Within Classes

Jobs within each class are sorted according to rules specific to each class. The sorting applied to each class is listed in Table 4-8, "Job Execution Classes," on page 137.

- The Reservation class is made up of all jobs in reservations.
  - The Reservation class is sorted within each reservation.
  - The first sort is according to the formula or job_sort_key, depending on which is defined.
  - The second sort key is submission time.
- The Express class is made up of all the jobs that have a higher priority than "normal_jobs" in the preempt_prio scheduler attribute.
  - The Express class is sorted first by applying the rules for preemption priority you set in a scheduler's preempt_prio attribute, making preemption priority the first sort key.
  - The second sort key is the time the job was preempted (if that happened), with the earliest-preempted job having the highest priority (in this sort).
  - The third sort key is the job's starving time, if any.
  - The fourth sort key is the formula, fairshare, or job_sort_key, depending on which is defined.
  - The fifth sort key is job submission time.

Jobs are sorted into this class only when preemption is enabled. See section 4.9.33, "Using Preemption", on page 182. Please note that execution priority classes are distinct from preemption levels, and are used for different purposes.

For example, if preempt_prio is the following:

```
preempt_prio: "express_queue, starving_jobs, normal_jobs"
```

The Express class contains all jobs that have preemption priority that is greater than that of normal jobs. In this example, the Express class is prioritized with top priority for express queue jobs, followed by starving jobs.

Since preemption levels are applied so that a job is put into the highest preemption level possible, in this example, all starving jobs end up in the Express class.

- The Preempted class is made up of all preempted jobs.
    - The first sort key is the time the job was preempted, with the earliest-preempted job having the highest priority (in this sort).
    - The second sort key is the job's starving time, if any.
    - The third sort key is the formula, fairshare, or job_sort_key, depending on which is defined.
    - The fourth sort key is job submission time.

  When you set the sched_preempt_enforce_resumption scheduler attribute and the strict_ordering scheduler parameter to *True*, a scheduler tries harder to run preempted jobs. By default the attribute is *False*, and in each scheduling cycle, if a top job cannot run now, a scheduler moves on to the next top job and tries to run it. When the attribute and the parameter are *True*, a scheduler treats the job like a top job: it makes sure that no lower-priority job will delay this job, and it backfills around the job.
- The Starving class is made up of all jobs whose wait time qualifies them as starving.
    - The Starving class is sorted first according to the amount of time that counts toward starving for each job. You can use queue wait time or eligible time as starving time. Jobs are sorted into this class only when starving is enabled. See section 4.9.48, "Starving Jobs", on page 225.
    - The second sort key is the time the job was preempted (if that happened), with the earliest-preempted job having the highest priority (in this sort).
    - The third sort key is the formula, fairshare, or job_sort_key, depending on which is defined.
    - The fourth sort key is job submission time.
- The Normal class is for any jobs that don't fall into any of the other classes. Most jobs are in this class.
    - If queue ordering exists (there are multiple queues, and queues have different priorities set, and round_robin or by_queue is *True*), jobs are sorted first by queue order.
    - If defined, the formula, fairshare, or job sort key is the second sort key.
    - The third sort key is job submission time.

4.9.16.3.i Precedence of Sort Method Used Within Class

If the formula is defined, it overrides fairshare and the job sort key. If fair share is defined, it overrides the job sort key. If none are defined, jobs are ordered by their arrival time in the queue.

For the job sorting formula, see section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

For fairshare, see section 4.9.19, "Using Fairshare", on page 140.

For sorting jobs on a key, see section 4.9.45, "Sorting Jobs on a Key", on page 223.

4.9.16.4 Execution Priority Caveats

- Limits are not taken into account when prioritizing jobs for execution. Limits are checked only after setting priority, when selecting a job to run. The only exception is in the Express class, where soft limits may be taken into account, because execution priority for Express class jobs is calculated using preemption priority. For details, see section 4.9.33, “Using Preemption”, on page 182.
- When you issue "`qrun <job ID>`", without the `-H` option, the selected job has execution priority between Reservation and Express.
- Jobs are sorted into the Express class only when preemption is enabled. Similarly, jobs are sorted into the Starving class only when starving is enabled.

4.9.17 Calendaring Jobs

In each scheduling cycle, PBS runs through its list of jobs in the order that you have defined. The backfill depth determines the number of top jobs; these are the highest-priority jobs in its current list. When strict priority and backfilling are in force, and PBS cannot run a top job right now, PBS holds a spot open for that job: PBS finds a future spot in the calendar that fits the job's needs, and doesn't schedule any other jobs that would interfere with the top job.

PBS rebuilds the calendar with each scheduling cycle.

4.9.17.1 Making Jobs Ineligible to be Top Jobs

By default, a job is eligible to be a top job, meaning that PBS holds resources for it if it cannot run right now (the topjob_ineligible job attribute defaults to *False*). If you set the value of a job's topjob_ineligible attribute to *True*, that job cannot become a top job, and PBS does not hold a spot open for that job if it cannot run the job right now. Having the highest priority is not the same as being a top job.

4.9.17.1.i Caveats for Making Jobs Ineligible to be Top Jobs

When sched_preempt_enforce_resumption is set to *True*, all preempted jobs become top jobs, regardless of their setting for topjob_ineligible.

4.9.18 Express Queues

An express queue is a queue whose priority is high enough to qualify as an express queue; the default for qualification is 150, but the cutoff can be set using the preempt_queue_prio scheduler attribute. For information on configuring express queues, see section 2.3.5.3.i, “Express Queues”, on page 26.

You can use express queues as tools to manage job execution and preemption priority.

- You can set up execution priority levels that include jobs in express queues. For information on configuring job priorities in a scheduler, see section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- You can set up preemption levels that include jobs in express queues. For information on preemption, see section 4.9.33, “Using Preemption”, on page 182.

The term "express" is also used in calculating execution priority to mean all jobs that have a preemption level greater than that of the normal_jobs level.

4.9.19 Using Fairshare

Fairshare provides a way to enforce a partition's or site's resource usage policy. It is a method for ordering the start times of jobs based on two things: how a site's resources are apportioned, and the resource usage history of partition or site members. Fairshare ensures that jobs are run in the order of how deserving they are. A scheduler performs the fairshare calculations each scheduling cycle. If fairshare is enabled, all jobs have fairshare applied to them and there is no exemption from fairshare.

You can employ basic fairshare behavior, or a policy of the desired complexity.

The fair_share parameter is a primetime option, meaning that you can configure it for either primetime or non-primetime, or you can specify it for all of the time. You cannot configure different behaviors for fairshare during primetime and non-primetime.

You can use fairshare information calculated by PBS in the job sorting formula. See section 4.9.19.6, “Computing Fairshare Values”, on page 145 and section 4.9.21.7, “Using Fairshare in the Formula”, on page 153.

4.9.19.1 One Fairshare System Per Scheduler

Each scheduler runs one fairshare system. Each fairshare system is independent of any others. If you are running only the default scheduler (no multisheds), it runs one fairshare system for the entire site. If you are using one or more multischeds, each of the multischeds runs its own fairshare system, and the default scheduler runs one fairshare system.

Each scheduler has its own `usage`, `resource_group`, etc., fairshare files in its `sched_priv` directory, and its own `sched_config` configuration file.

The `pbsfs` command operates on one scheduler's fairshare database at a time. You specify which scheduler's database to operate on using the `pbsfs -I <scheduler name>` option.

In the following sections on fairshare, we describe the behavior for any single scheduler.

4.9.19.2 Outline of How Fairshare Works

The owner of a PBS job can be defined for fairshare purposes to be a user, a group, the job's accounting string, etc. For example, you can define owners to be groups, and can explicitly set each group's relationship to all the other groups by using the tree structure. If you don't explicitly list an owner, it will fall into the "unknown" catchall. All owners in "unknown" get the same resource allotment. You can define one group to be part of a larger department.

You specify which resources to track and how you want usage to be calculated. So if you defined job owners to be groups, then only the usage of groups is considered. PBS tries to ensure that each owner gets the amount of resources that you have set for it.

4.9.19.3 Enabling Basic Fairshare

If the default fairshare behavior is enabled, PBS enforces basic fairshare rules where all users with queued jobs will get an equal share of CPU time. The root vertex of the tree will have one child, the `unknown` vertex. All users will be put under the unknown vertex, and appear as children of the `unknown` vertex.

Enable basic fairshare by doing the following:

- In the scheduler's `sched_config` file, set the scheduler configuration parameter fair_share to *True*
- Uncomment the `unknown_shares` setting so that it is set to `unknown_shares: 10`
- Specify how you want fairshare to work with primetime and non-primetime. If you want separate behavior for primetime and non-primetime, list the fair_share parameter twice, once for each time slot. The default is both. For example:

  ```
  fair_share True prime
  fair_share False non_prime
  ```

Note that a variant of basic fairshare has all users listed in the tree as children of root. Each user can be assigned a different number of shares.

4.9.19.4 Configuring the Fairshare Tree

Fairshare uses a tree structure, where each vertex in the tree represents some set of job owners and is assigned usage *shares*. Shares are used to apportion the partition's or site's resources. The default tree always has a root vertex and an *unknown* vertex. The default behavior of fairshare is to give all users the same amount of the resource being tracked. In order to apportion a partition's or site's resources according to a policy other than equal shares for each user, you create a fairshare tree to reflect that policy. To do this, you edit the `resource_group` file in the scheduler's `sched_priv` directory, which describes that scheduler's fairshare tree.

To configure non-default fairshare, set up a hierarchical tree structure made up of interior vertices and leaves. Interior vertices are *departments*, which can contain both departments and leaves. Leaves are for *fairshare entities*, defined by setting fairshare_entity to one of the following: *euser, egroup, egroup:euser, Account_Name*, or *queue*. Apportioning of resources for the partition or site is among these entities. These entities' usage of the designated resource is used in determining the start times of the jobs associated with them. All fairshare entities must be the same type. If you wish to have a user appear in more than one department, you can use `egroup:euser` to distinguish between that user's different resource allotments. Note that in the `resource_group` file and in the output of `pbsfs`, interior (non-leaf) vertices are referred to as "groups", and exterior (leaf) vertices are referred to as "users".

Table 4-9: Using Fairshare Entities

Keyword	Fairshare Entities	Purpose
euser	Username	Individual users are allotted shares of the resource being tracked. Each username may only appear once, regardless of group.
egroup	OS group name	Groups as a whole are allotted shares of the resource being tracked.
egroup:euser	Combinations of username and group name	Useful when a user is a member of more than one group, and needs to use a different allotment in each group.
Account_Name	Account IDs	Shares are allotted by account string (Account_Name job attribute).
queue	Queues	Shares are allotted between queues.

4.9.19.4.i Allotting Shares in the Tree

You assign shares to each vertex in the tree. The actual number of shares given to a vertex or assigned in the tree is not important. What is important is the ratio of shares among each set of sibling vertices. Competition for resources is between siblings only. The sibling with the most shares gets the most resources.

4.9.19.4.ii Shares Among Unknown Entities

The root vertex always has a child called `unknown`. Any entity not listed in the scheduler's `resource_group` file will be made a child of `unknown`, designating the entity as unknown. The shares used by unknown entities are controlled by two parameters in the scheduler's `sched_config` file: unknown_shares and fairshare_enforce_no_shares.

The parameter unknown_shares controls how many shares are assigned to the `unknown` vertex. The shipped `sched_config` file contains this line:

```
#unknown_shares 10
```

If you leave unknown_shares commented out, the `unknown` vertex will have 0 shares. If you simply remove the "#", the `unknown` vertex's shares default to 10. The children of the `unknown` vertex have equal amounts of the shares assigned to the `unknown` vertex.

The parameter fairshare_enforce_no_shares controls whether an entity without any shares can run jobs. If fairshare_enforce_no_shares is *True*, entities without shares cannot run jobs. If it is set to *False*, entities without any shares can run jobs, but only when no other entities' jobs are available to run.

4.9.19.4.iii Format for Describing the Tree

The file describing the fairshare tree contains four columns to describe the vertices in the tree. Here is the format for the columns:

<Vertex name> <vertex fairshare ID> <parent of vertex> <#shares>

The columns are for a vertex's name, its fairshare ID, the name of its parent vertex, and the number of shares assigned to this (not the parent) vertex. Vertex names and IDs must be unique. Vertex IDs are integers. The top row in `resource_group` contains information for the first vertex, rather than column labels.

Neither the root vertex nor the `unknown` vertex is described in the `resource_group` file. They are always added automatically. Parent vertices must be listed before their children.

For example, we have a tree with two top-level departments, Math and Phys. Under Math are the users Bob and Tom as well as the department Applied. Under Applied are the users Mary and Sally. Under Phys are the users John and Joe. Our `<sched_priv directory>/resource_group` looks like this:

```
Math            100     root       30
Phys            200     root       20
Applied         110     Math       25
Bob             101     Math       15
Tom             102     Math       10
Mary            111     Applied    1
Sally           112     Applied    2
John            201     Phys       2
Joe             202     Phys       2
```

If you wish to use egroup:euser as your entity, and Bob to be in two groups pbsgroup1 and pbsgroup2, and Tom to be in two groups pbsgroup2 and pbsgroup3:

```
Math            100     root       30
Phys            200     root       20
Applied         110     Math       20
pbsgroup1:Bob   101     Phys       20
pbsgroup2:Bob   102     Math       20
pbsgroup2:Tom   103     Math       10
pbsgroup3:Tom   104     Applied    10
```

When a user submits a job using `-Wgroup_list=<group>`, the job's egroup will be <group>. For example, user Bob is in pbsgroup1 and pbsgroup2. Bob uses "`qsub -Wgroup_list= pbsgroup1`" to submit a job that will be charged to pbsgroup1, and "`qsub -Wgroup_list=pbsgroup2`" to submit a job that will be charged to pbsgroup2.

The first and third fields are alphanumeric. The second and fourth fields are numeric. Fields can be separated by spaces and tabs.

4.9.19.4.iv Moving Entities within Fairshare Tree

To move an entity within the fairshare tree, change its parent:

1. Edit `<sched_priv directory>/resource_group`. Change the parent (column 3) to the desired parent
2. HUP or restart the scheduler

4.9.19.4.v Removing Entities from Fairshare Tree

You may want to remove an entity from the fairshare tree, either because they no longer run jobs, or because you don't want them to have their own place in the tree. When an entity that is not in the fairshare tree runs a job, their past and future usage, including that for jobs running while you remove the entity, shows up in the Unknown group. To remove an entity from the fairshare tree:

1. Edit the `resource_group` file to remove the entity line
2. HUP or restart the scheduler

If you do not want an entity's usage to show up in the Unknown group, use `pbsfs -e [-I <multisched name>]` to remove the usage. If you are working on a partition managed by a multisched, you must specify the name of the multisched:

1. Prevent jobs from being scheduled
2. Run `pbsfs -e [-I <multisched name>]`
3. Resume scheduling jobs

If you have removed a user from the PBS partition or complex and don't want their usage to show up any more:

1. Prevent jobs from being scheduled
2. Edit the `resource_group` file
3. Run `pbsfs -e [-I <multisched name>]`
4. Resume scheduling jobs

4.9.19.5 Resource Usage for Fairshare

4.9.19.5.i Tracking Resource Usage

You choose which resources to track and how to compute the usage by setting the fairshare_usage_res scheduler configuration parameter in the `sched_config` file to the fairshare resource formula you want. This parameter can contain the following:

- Built-in and custom job resources

  When you use a resource in the fairshare resource formula, if a value exists for resources_used.<resource name>, this value is used in the fairshare resource formula. Otherwise, the value is taken from Resource_List.<resource name>.
- Mathematical operators

  You can use standard Python operators and the operators in the Python math module.

The default for the tracked resource is cput (CPU time).

4.9.19.5.ii Adding Usage

An entity's usage always starts at 1. Resource usage tracking begins when a scheduler is started. Each scheduler cycle, the scheduler adds the usage increment between this cycle and the previous cycle to its sum for the entity.

A static resource does not change its usage from one cycle to the next. If you use a static resource such as ncpus, the amount being tracked will not change during the lifetime of the job; it will only be added once when the job starts.

Note that if a job ends between two scheduling cycles, its resource usage for the time between the previous scheduling cycle and the end of the job will not be recorded. A scheduler's default cycle interval is 10 minutes. The scheduling cycle can be adjusted via the `qmgr` command. Use

```
Qmgr: set sched [sched name>] scheduler_iteration=<new value>
```

If the fairshare resource formula in fairshare_usage_res evaluates to a negative number, PBS uses zero instead. So there is no way to accumulate negative usage.

4.9.19.5.iii Decaying Usage

Each entity's usage is *decayed*, or reduced periodically, at the interval set in the fairshare_decay_time parameter in the `sched_config` file. This interval defaults to 24 hours.

The amount by which usage is decayed is set in the fairshare_decay_factor scheduler parameter.

An entity with a lot of current or recent usage will have low priority for starting jobs, but if the entity cuts resource usage, its priority will go back up after a few decay cycles.

4.9.19.5.iv Setting Decay Interval and Factor

You set the interval at which usage is decayed by setting the fairshare_decay_time scheduler parameter to the desired time interval. The default value for this interval is 24 hours. For example, to set this interval to 14 hours and 23 minutes, put this line in the `sched_config` file:

```
fairshare_decay_time: 14:23:00
```

You set the decay factor by setting the fairshare_decay_factor scheduler parameter to the desired multiplier for usage. At each decay interval, the usage is multiplied by the decay factor. This attribute is a float whose value must be between 0 and 1. The value must be greater than 0 and less than 1. The default value for this multiplier is 0.5. For example, to set this multiplier to 70 percent, put this line in `sched_config:`

```
fairshare_decay_factor: .7
```

4.9.19.5.v Examples of Setting Fairshare Usage

To use CPU time as the resource to be tracked, put this line in `sched_config`:

```
fairshare_usage_res: cput
```

To use ncpus multiplied by walltime as the resource to be tracked, put this line in `sched_config`:

```
fairshare_usage_res: ncpus*walltime
```

An example of a more complex formula:

```
fairshare_usage_res: "ncpus*pow(walltime,.25)*fs_factor"
```

4.9.19.5.vi Fairshare Resource Advice

We recommend including a time-based resource in the fairshare formula so that usage will grow over time.

4.9.19.5.vii Viewing and Managing Fairshare Usage Data

The `pbsfs` command provides a command-line tool for viewing and managing some fairshare data. You can display the data as a tree, a table, or by entity. You can print all information about an entity, or set an entity's usage to a new value. You can force an immediate decay of all the usage values in the tree. You can compare two fairshare entities. You can also remove all entities from the `unknown` department. This makes the tree easier to read. The tree can become unwieldy because entities not listed in the `resource_group` file all land in the `unknown` group. See "pbsfs" on page 32 of the PBS Professional Reference Guide.

To change fairshare resource usage data, do the following:

1. Stop scheduling:
   ```
   Qmgr: set sched [<sched name>] scheduling = false
   ```
2. Wait until the current scheduling cycle finishes. Check the scheduler's log.
3. Trim the fairshare tree:
   ```
   pbsfs -e  [-I <multisched name>]
   ```
4. Set each entity's usage to one (cannot be zero). For each leaf entity:
   ```
   pbsfs -s <entity name> 1  [-I <multisched name>]
   ```
5. Start scheduling:
   ```
   Qmgr: set sched [<sched name>] scheduling = true
   ```

The fairshare usage data is written to the file `usage` file at each scheduling cycle. The usage data is always up to date.

For more information on using the `pbsfs` command, see "pbsfs" on page 32 of the PBS Professional Reference Guide

4.9.19.6 Computing Fairshare Values

PBS provides fairshare_perc, fairshare_tree_usage, and fairshare_factor as terms to use in the job sorting formula. You can also use fairshare_perc as an argument to the job_sort_key scheduler parameter.

4.9.19.6.i Computing Target Usage for Each Vertex (fairshare_perc)

How much resource each entity should use is its target usage, computed in fairshare_perc. Target usage is the percentage of the shares in the tree allotted to the entity. Target usage does not take history into account.

A vertex's portion of all the shares in the tree is its fairshare_perc. This is computed for all of the vertices in the tree. Since the leaves of the tree represent the entities among which resources are to be shared, their fairshare_perc sums to 100 percent. Only the leaf nodes sum to 100%; if all of the nodes were summed, the result would be greater then 100%. Only the leaf nodes of the tree are fairshare entities.

A scheduler computes the fairshare_perc for the vertices this way:

First, it gives the root of the tree a fairshare_perc of 100 percent. It proceeds down the tree, finding the fairshare_perc first for immediate children of root, then their children, ending with leaves.

1. For each internal vertex A:

   sum the shares of its children;

2. For each child J of vertex A:

   divide J's shares by the sum to normalize the shares;

   multiply J's normalized shares by vertex A's fairshare_perc to find J's fairshare_perc.

The fairshare_perc value can be used in the job sorting formula and as an argument to the job_sort_key scheduler parameter.

4.9.19.6.ii Computing Effective Usage (fairshare_tree_usage)

An entity's effective usage is fairshare_tree_usage, and is a value between *0* and *1*.

PBS calculates the value for fairshare_tree_usage this way:

For root's children:

fairshare_tree_usage = percent total usage

For entities below root's children:

*fairshare_tree_usage = entity's percent total usage + ((parent's effective usage - entity's percent total usage) * entity's relative percent of shares within sibling group)*

where

entity's percent total usage = entity's usage / all usage in partition or complex

Summing effective usage for all leaves in the tree does not yield a useful number (such as 1).

4.9.19.6.iii Computing Relative Usage (fairshare_factor)

An entity's relative usage allows direct comparison between entities. Relative usage is fairshare_factor, and is a value between *0* and *1*. A value of *0.5* means that an entity is using exactly its target usage. A higher value indicates less resource usage by the entity, meaning that the entity is more deserving. Calculated this way:

2^-(fairshare_tree_usage / entity's fairshare_perc)

4.9.19.6.iv Example of Computing Fairshare Values

Example 4-2: The following fairshare tree shows shares and usage for two groups, each with two people:

Table 4-10: Example Fairshare Tree

Vertex			Shares	Actual Usage	% Total Usage	% Group Shares	Target Usage: fairshare _perc	Effective Usage: fairshare _tree_us age	Relative Usage: fairshare _factor
root				1200	100	1.0	1.0	1.0	1.0
	group1		40	200	0.1667	0.4	0.4	0.167	0.75
		Bob	50	100	0.0833	0.5	0.2	0.125	0.65
		Cathy	50	100	0.0833	0.5	0.2	0.125	0.65
	group2		60	1000	0.833	0.6	0.6	0.833	0.38
		Suzy	60	0	0	0	0.36	0.5	0.38
		Scott	40	1000	0.833	1	0.24	0.833	0.09

Comparing Suzy and Bob:

Bob:

Percent total usage: 100/1200 = 0.083

Parent's effective usage: 0.1667

Bob's percentage of shares in group: Bob's 50 shares / (Bob's 50 shares+ Cathy's 50 shares) = 0.5

Bob's effective usage: Bob's percent total usage: 0.0833 + (group1's effective usage: 0.1667 - Bob's percent total usage: 0.083) * 0.5 = 0.125

Relative usage formula: 2^-(0.125/0.2) = 0.648

Suzy:

Percent total usage: 0/1200 = 0

Parent's effective usage: 1000/1200 = 0.833

Suzy's percentage of shares in group: Suzy's 60 shares / (Suzy's 60 shares + Scott's 40 shares) = 0.6

Suzy's effective usage: Suzy's percent total usage: 0 + (group2's usage: 0.833 - Suzy's usage: 0) * 0.6 = 0.5

Relative usage formula: 2^-(0.5/0.36): 0.382

Even though Suzy had a higher fairshare_perc than Bob and less usage than Bob, her relative usage (fairshare_factor) is quite a bit lower than his, because of the huge amount Scott used.

Output of `pbsfs -g`:

Our `pbsfs` output uses the same fairshare data as the previous example.

```
# ./pbsfs -g scott
fairshare entity: scott
Resgroup                : 11
cresgroup               : 15
Shares                  : 40
Percentage              : 24.000000%
fairshare_tree_usage    : 0.832973
usage                   : 1000 (cput)
usage/perc              : 4167
Path from root:
TREEROOT  :     0       1201 / 1.000 = 1201
group2    :    11       1001 / 0.600 = 1668
scott     :    15       1000 / 0.240 = 4167
```

4.9.19.7 Choosing Which Job to Run

4.9.19.7.i Finding the Most Deserving Entity

The most deserving entity is found by starting at the root of the tree, comparing its immediate children, finding the most deserving, then looking among that vertex's children for the most deserving child. This continues until a leaf is found. In a set of siblings, the most deserving vertex will be the vertex with the lowest ratio of resource usage divided by fairshare_perc.

4.9.19.7.ii Sorting and Selecting Jobs to Run

The job to be run next is selected from the set of jobs belonging to the most deserving entity. The jobs belonging to the most deserving entity are sorted according to the methods a scheduler normally uses. This means that fairshare effectively becomes the primary sort key. If the most deserving job cannot run, then the next most is selected to run, and so forth. All of the most deserving entity's jobs are examined first, then those of the next most deserving entity, etcetera.

At each scheduling cycle, a scheduler attempts to run as many jobs as possible. It selects the most deserving job, runs it if it can, then recalculates to find the next most deserving job, runs it if it can, and so on.

When a scheduler starts a job, all of the job's requested usage is added to the sum for the owner of the job for one scheduling cycle. The following cycle, the job's usage is set to the actual usage that occurred between the first and second cycles. This prevents one entity from having all its jobs started and using up all of the resource in one scheduling cycle.

4.9.19.8 Files and Parameters Used in Fairshare

`sched_config`

File in the directory specified in the scheduler's sched_priv attribute

PBS uses the following parameters from `sched_config` to compute fairshare values:

Table 4-11: `sched_config` Parameters used in Fairshare

Parameter	Use
fair_share	[*True*/*False*] Enable or disable fairshare
fairshare_usage_res	Resource whose usage is to be tracked; default is cput
fairshare_decay_factor	Amount to decay usage at each decay interval
fairshare_decay_time	Decay interval; default is 24 hours
unknown_shares	Number of shares for unknown vertex; default 10, 0 if commented out
fairshare_entity	The kind of entity which is having fairshare applied to it. Leaves in the tree are this kind of entity. Default: euser.
fairshare_enforce_no_shares	If an entity has no shares, this controls whether it can run jobs. T: an entity with no shares cannot run jobs. F: an entity with no shares can only run jobs when no other jobs are available to run.
by_queue	If on, queues cannot be designated as fairshare entities, and fairshare will work queue by queue instead of on all jobs at once.

`resource_group`

File in the directory specified in the scheduler's sched_priv attribute

Contains the description of the fairshare tree.

`usage`

File in the directory specified in the scheduler's sched_priv attribute

Contains the usage database. Written by PBS. Do not edit. Written each scheduling cycle.

scheduler_iteration

Scheduler attribute. Specifies scheduler cycle frequency; default is 10 minutes.

```
Qmgr: set sched <scheduler name> scheduler_iteration=<new value>
```

resources_used.<resource name>

Job attribute. Contains resources used for tracking usage. Default is cput.

4.9.19.9 Ways to Use Fairshare

4.9.19.9.i Fairshare for Partition Or Complex or Within Queues

You can use fairshare to compare all jobs in the partition managed by a scheduler, or within each queue. Fairshare within a queue means that a scheduler examines the jobs in a queue, and compares them to each other, to determine which job to start next.

To use fairshare for the entire partition or complex, set the by_queue and round_robin scheduler configuration parameters to *False*.

To use fairshare within queues, set the by_queue scheduler parameter to *True*, and round_robin to *False*. If you want to examine queues in a particular order, prioritize the queues by setting each queue's priority attribute.

The scheduler configuration parameter by_queue in the `sched_config` file is set to *True* by default.

If by_queue is *True*, queues cannot be designated as fairshare entities.

4.9.19.9.ii Altering Fairshare According to Queue

You can introduce a fairshare factor that is different at each queue. To do this, create a custom floating point resource, and set each queue's resources_default.<resource name> to the desired value. Use this resource in the fairshare_usage_res computation. If you do not set this value at a queue, PBS uses zero for the value. To avoid having to set a value at multiple queues, you can set the servers's resources_default.<resource name> to the default value for all queues where the value is unset. The server value is used only where the queue value is unset; where the queue value is set, the queue value takes precedence.

For example, to reduce the priority for jobs in the "expensive" queue by assigning them twice the usage of the jobs in workq:

- Define the resource:
  ```
  Qmgr: create resource fs_factor type = float, flag = i
  ```
- Set the resource values:
  ```
  Qmgr: set server resources_default.fs_factor = 1
  Qmgr: set queue workq resources_default.fs_factor = 0.3
  Qmgr: set queue expensive resources_default.fs_factor = 0.6
  ```
- Edit `sched_config`:
  ```
  fairshare_usage_res: "fs_factor*ncpus*walltime"
  ```

4.9.19.9.iii Using Fairshare in Job Execution Priority

Jobs are sorted as specified by the formula in job_sort_formula, if it exists, then by fairshare, if it is enabled, or if neither of those is used, by job_sort_key. The job sorting formula can use the following calculated values: fairshare_perc, the percentage of the fairshare tree for this job's entity, fairshare_tree_usage, an entity's effective usage, and fairshare_factor, an entity's comparative usage. See section 4.9.16, "Calculating Job Execution Priority", on page 136.

4.9.19.9.iv Using Fairshare in Job Preemption Priority

You can use the *fairshare* preemption level in determining job preemption priority. This level applies to jobs whose owners are over their fairshare allotment. See section 4.9.33, "Using Preemption", on page 182.

4.9.19.10 Fairshare Restrictions

- Entity shares (strict priority):

  If you enable entity shares (strict priority), you use the same fairshare tree that you would use for fairshare. Fairshare and entity shares (strict priority) are incompatible, so in order to use entity shares, you disable fairshare by setting fair_share to *False*. For how to configure entity shares, see section 4.9.14, "Sorting Jobs by Entity Shares (Was Strict Priority)", on page 133.
- Requeued jobs:

  When a job is requeued, it normally retains its original place in its execution queue with its former priority. The job is usually the next job to be considered during scheduling, unless the relative priorities of the jobs in the queue have changed. This can happen when the job sorting formula assigns higher priority to another job, another higher-priority job is submitted after the requeued job started, this job's owner has gone over their fairshare limit, etc.
- With strict_ordering or backfilling:

  We do not recommend using fairshare with strict_ordering, or with strict_ordering and backfilling. The results may be non-intuitive. Fairshare will cause relative job priorities to change with each scheduling cycle. It is possible that a job from the same entity or group as the top job will be chosen as the filler job. The usage from the filler job will lower the priority of the most deserving, i.e. top, job. This could delay the execution of the top job.

However, if all of your leaf entities are children of root (the tree has only two levels), and all users tend to submit the same size jobs, results may be useful.

- With fairshare_perc option to job_sort_key:

  Do not use fairshare when using the fairshare_perc option to job_sort_key. You can still use the value of fairshare_perc in the job sorting formula.
- Static resources:

  Do not use static resources such as ncpus as the resource to track. A scheduler adds the incremental change in the tracked resource at each scheduling cycle, and a static resource will not change.
- With help_starving_jobs:

  Do not use fairshare with help_starving_jobs.

4.9.19.11 Fairshare Caveats and Advice

- The most deserving entity can change with every scheduling cycle, if each time a job is run, it changes usage sufficiently.
- Fairshare dynamically reorders the jobs with every scheduling cycle. Strict ordering is a rule that says we always run the next-most-deserving job. If there were no new jobs submitted, strict ordering could give you a snapshot of how the jobs would run for the next *n* days. Hence fairshare appears to break that. However, looked at from a dynamic standpoint, fairshare is another element in the strict order.
- The half_life parameter is **deprecated** and has been replaced by the fairshare_decay_time parameter.
- Beware of overflow: PBS stores fairshare allocations in a signed integer (32-bit on Linux x86_64 platforms), and fairshare usage in a long (64-bit on Linux x86_64 platforms)

4.9.20 FIFO Scheduling

With FIFO scheduling, PBS runs jobs in the order in which they are submitted. You can use FIFO order for all of the jobs in your partition or complex, or you can go queue by queue, so that the jobs within each queue are considered in FIFO order.

4.9.20.1 Configuring Basic FIFO Scheduling

To configure basic FIFO scheduling, whether across all a scheduler's partition or queue by queue, set the following scheduler parameters and queue/server attribute to these values:

```
round_robin:           False  ALL
job_sort_key:          (commented out)
fair_share             False  ALL
backfill_depth:        0
job_sort_formula: (unset)
```

4.9.20.2 FIFO for Entire Partition Or Complex

To configure FIFO across your entire partition or complex, follow the steps above and do one of the following:

- Use only one execution queue
- Set the by_queue scheduler parameter to *False*

4.9.20.3 Queue by Queue FIFO

To configure FIFO for each queue separately, first decide how you want queues to be selected. You can set the order in which PBS chooses queues from which to run jobs, or you can allow the queues to be selected in an undefined way. First configure this scheduler as in Section 4.9.20.1, "Configuring Basic FIFO Scheduling".

- To allow queues to be selected in an undefined way, set the by_queue scheduler parameter to *True*.
- To set the order in which queues are selected, do the following:
  - Specify a priority for each queue
  - Set the by_queue scheduler parameter to *True*

4.9.20.4 FIFO with Strict Ordering

If your jobs must run exactly in submission order, you can use strict ordering with FIFO scheduling. If you use strict ordering with FIFO scheduling, this means that when the job that is supposed to run next cannot run, no jobs can run. This can result in less throughput than you could otherwise achieve. To avoid that problem, you can use backfilling. See the following section.

To use strict ordering with FIFO scheduling, use the following scheduler parameter settings in `<sched_priv directory>/sched_config` and queue/server attribute settings:

```
strict_ordering:          True   ALL
round_robin:              False  ALL
job_sort_key:             (commented out)
fair_share                False  ALL
backfill_depth:           0
job_sort_formula: (unset)
```

4.9.20.5 FIFO with Strict Ordering and Backfilling

If you want to run your jobs in submission order, except for backfilling around top jobs that are stuck, use the following:

```
strict_ordering:          True   ALL
round_robin:              False  ALL
job_sort_key:             (commented out)
fair_share                False  ALL
backfill_depth:           <depth>
job_sort_formula: (unset)
```

4.9.21 Using a Formula for Computing Job Execution Priority

You can choose to use a formula by which to sort jobs at the finest-granularity level. The formula can only direct how jobs are sorted at the finest level of granularity. However, that is where most of the sorting work is done.

When a scheduler sorts jobs according to the formula, it computes a priority for each job. The priority computed for each job is the value produced by the formula. Jobs with a higher value get higher priority. See section 4.9.16.3, “Sorting Jobs Within Classes”, on page 137 for how the formula is used in setting job execution priority.

Only one formula is used to prioritize all jobs. At each scheduling cycle, the formula is applied to all jobs, regardless of when they were submitted. If you change the formula, the new formula is applied to all jobs.

For example, if you submit some jobs, change the formula, then submit more jobs, the new formula is used for all of the jobs, during the next scheduling cycle.

You can set a job priority threshold so that jobs with priority at or below the specified value do not run. See section 4.9.21.10, “Setting Minimum Job Priority Value for Job Execution”, on page 154.

You may find that the formula is most useful when you use it with custom resources inherited by or allocated to jobs. For example, you may want to route all jobs from a particular project to a queue where they inherit a specific value for a custom resource. Other jobs may end up at a different queue, where they inherit a different value, or they may inherit no value. You can then use this custom resource in the formula as a way to manage job priority. See section 14.3, “Allocating Resources to Jobs”, on page 507, and section 4.9.8, “Using Custom and Default Resources”, on page 115.

It may be helpful if these custom resources are invisible and unrequestable by users. See section 4.9.21.12, “Examples of Using Resource Permissions in Job Sorting Formula”, on page 155.

4.9.21.1 When the Formula is Applied

Once you set job_sort_formula via `qmgr`, it takes effect with the following scheduling cycle.

Variables are evaluated at the start of the scheduling cycle.

4.9.21.2 Configuring the Job Sorting Formula

- Define the formula:

  You specify the formula in the server's job_sort_formula attribute. To set the job_sort_formula attribute, use the `qmgr` command. When specifying the formula, be sure to follow the requirements for entering an attribute value via `qmgr`: strings containing whitespace, commas, or other special characters must be enclosed in single or double quotes. See “Caveats and Restrictions for Setting Attribute and Resource Values” on page 160 of the PBS Professional Reference Guide. Format:

  ```
  Qmgr: s s job_sort_formula = "<formula>"
  ```
- Optional: set a priority threshold. See section 4.9.21.10, “Setting Minimum Job Priority Value for Job Execution”, on page 154

4.9.21.3 Requirements for Creating Formula

The job sorting formula must be created at the server host.

Under Linux, root privilege is required in order to operate on the job_sort_formula server attribute.

4.9.21.4 Format of Formula

The formula must be valid Python, and must use Python syntax.The formula can be made up of any number of *expressions*, where expressions contain *terms* which are added, subtracted, multiplied, or divided. You can use parentheses, exponents, unary + and - operators, and the ternary operator (which must be Python). All operators use standard mathematical precedence. The formula can use standard Python mathematical operators and those in the Python math module.

The formula can be any length.

The range for the formula is defined by the IEEE floating point standard for a double.

4.9.21.5 Units in Formula

The variables you can use in the formula have different units. Make sure that some terms do not overpower others, by normalizing them where necessary. Resources like ncpus are integers, size resources like mem are in kb, so 1gb is 1048576kb, and time-based resources are in seconds (e.g. walltime). Therefore, if you want a formula that combines memory and ncpus, you'll have to account for the factor of 1024 difference in the units.

The following are the units for the supported built-in resources:

Table 4-12: Job Sorting Formula Units

Resource	Units	Example
Time resources	*Integer number of seconds*	300
Memory	*kb*	1gb => 1048576kb
ncpus	*Integer*	8

Example 4-3: If you use '1 * ncpus + 1 * mem', where mem=2mb, ncpus will have almost no effect on the formula result. However, if you use '1024 * ncpus + 1 * mem', the scaled mem won't overpower ncpus.

Example 4-4: You are using gb of mem:

```
Qmgr: s s job_sort_formula='1048576 * ncpus + 2 * mem'
```

Example 4-5: If you want to add days of walltime to queue priority, you might want to multiply the time by 0.0000115, equivalent to dividing by the number of seconds in a day:

```
Qmgr: s s job_sort_formula = '.0000115*walltime + queue_priority'
```

Note that a Python bug may make it necessary to multiply by 1.0 in order to prevent rounding to the nearest integer.

4.9.21.6 Resources in Formula

The formula can use resources in the job's Resource_List attribute, but no other resources. The resources in the job's Resource_List attribute are the numeric job-level resources, and may have been explicitly requested, inherited, or summed from consumable host-level resources. See section 5.9.2, "Resources Requested by Job", on page 247.

This means that all variables and coefficients in the formula must be resources that were either requested by the job or were inherited from defaults at the server or queue. These variables and coefficients can be custom numeric resources inherited by the job from the server or queue, or they are long integers or floats.

You may need to create custom resources at the server or queue level to be used for formula coefficients. See section 4.9.8, "Using Custom and Default Resources", on page 115.

4.9.21.7 Using Fairshare in the Formula

PBS provides the following fairshare values for use as keywords in the job sorting formula:

Table 4-13: Fairshare Terms in Formula

Keyword	Description
fairshare_perc (was fair_share_perc)	Percentage of fairshare tree allotted to this job's entity. See section 4.9.19.6.i, "Computing Target Usage for Each Vertex (fairshare_perc)", on page 145.
fairshare_tree_usage	Value between 0 and 1, reflecting an entity's effective usage. See *section 4.9.19.6.ii, "Computing Effective Usage (fairshare_tree_usage)", on page 145*.
fairshare_factor	Value between 0 and 1, which allows direct comparison between entities. A value of 0.5 means that an entity is using exactly its allotted usage. A higher value indicates less resource usage by the entity, meaning that the entity is more deserving. See *section 4.9.19.6.iii, "Computing Relative Usage (fairshare_factor)", on page 146*.

See section 4.9.19, "Using Fairshare", on page 140.

4.9.21.8 Terms in Formula

Table 4-14: Terms in Job Sorting Formula

Terms		Allowable Value
Constants		<number> or <number>.<number>
Attributes, keywords, parameters, etc.	queue_priority	Value of priority attribute for queue in which job resides
	job_priority	Value of the job's priority attribute
	fairshare_perc	Percentage of fairshare tree allotted to this job's entity
	fairshare_tree_usage	The effective usage by the entity
	fairshare_factor	Value allowing direct comparison between entities
	eligible_time	Amount of wait time job has accrued while waiting for resources
	accrue_type	Kind of time job is accruing. See section 4.9.13, “Eligible Wait Time for Jobs”, on page 128.
Resources		ncpus
		mem
		walltime
		cput
Custom numeric job-wide resources		Uses the amount requested, not the amount used. Must be of type long, float, or size. See section 5.14.2.2, “Custom Resource Values”, on page 260.

4.9.21.9 Modifying Coefficients For a Specific Job

Formula coefficients can be altered for each job by using the `qalter` command to change the value of that resource for that job. If a formula coefficient is a constant, it cannot be altered per-job.

4.9.21.10 Setting Minimum Job Priority Value for Job Execution

You can specify a minimum job priority value for jobs to run by setting the job_sort_formula_threshold scheduler attribute. If the value calculated for a job by the job sorting formula is at or below this value, the job cannot run during this scheduling cycle.

4.9.21.11 Examples of Using the Job Sorting Formula

Examples of formulas:

Example 4-6: 10 * ncpus + 0.01*walltime + A*mem

Here, "A" is a custom resource.

Example 4-7: ncpus + 0.0001*mem

Example 4-8: To change the formula on a job-by-job basis, alter the value of a resource in the job's Resource_List.<resource name>. So if the formula is A *queue_priority + B*job_priority + C*ncpus + D*walltime, where A-D are custom numeric resources. These resources can have a default value via resources_default.A ... resources_default.D. You can change the value of a job's resource through `qalter`.

Example 4-9: ncpus*mem

Example 4-10: Set via `qmgr`:

```
qmgr -c 'set server job_sort_formula= 5*ncpus+0.05*walltime'
```

Following this, the output from `qmgr -c 'print server'` will look like

```
set server job_sort_formula="5*ncpus+0.05*walltime"
```

Example 4-11:

```
Qmgr: s s job_sort_formula=ncpus
```

Example 4-12:

```
Qmgr: s s job_sort_formula='queue_priority + ncpus'
```

Example 4-13:

```
Qmgr: s s job_sort_formula='5*job_priority + 10*queue_priority'
```

Example 4-14: Sort jobs using the value of ncpus x walltime:

Formula expression: "ncpus * walltime"

Submit these jobs:

Job 1: ncpus=2 walltime=01:00:00 -> 2*60s = 120

Job 2: ncpus=1 walltime=03:00:00 -> 1*180s = 180

Job 3: ncpus=5 walltime=01:00:00 -> 5*60s = 300

The scheduler logs the following:

```
Job ;1.host1;Formula Evaluation = 120
Job ;2.host1;Formula Evaluation = 180
Job; 3.host1;Formula Evaluation = 300
```

The jobs are sorted in the following order:

Job 3

Job 2

Job 1

4.9.21.12 Examples of Using Resource Permissions in Job Sorting Formula

See section 5.14.2.3.vi, “Resource Permission Flags”, on page 262 for information on using resource permissions.

Example 4-15: You may want to create per-job coefficients in your job sorting formula which are set by system defaults and which cannot be viewed, requested or modified by the user. To do this, you create custom resources for the formula coefficients, and make them invisible to users. In this example, A, B, C and D are the coefficients. You then use them in your formula:

A *(Queue Priority) + B*(Job Class Priority) + C*(CPUs) + D*(Queue Wait Time)

Example 4-16: You may need to change the priority of a specific job, for example, have one job or a set of jobs run next. In this case, you can define a custom resource for a special job priority. If you do not want users to be able to change this priority, set the resource permission flag for the resource to *r*. If you do not want users to be able to see the priority, set its resource permission flag to *i*. For the job or jobs that you wish to give top priority, use `qalter` to set the special resource to a value much larger than any formula outcome.

Example 4-17: To use a special priority:

```
sched_priority = W_prio * wait_secs + P_prio * priority + ... +  special_priority
```

Here, special_priority is very large.

4.9.21.13 Caveats and Error Messages

- If the formula overflows or underflows the sorting behavior is undefined.
- If you set the formula to an invalid formula, `qmgr` will reject it, with one of the following error messages:

```
"Invalid Formula Format"
"Formula contains invalid keyword"
"Formula contains a resource of an invalid type"
```

- If an error is encountered while evaluating the formula, the formula evaluates to zero for that job, and the following message is logged at event class 0x0100:

```
"1234.mars;Formula evaluation for job had an error.  Zero value will be used"
```

- The job sorting formula must be set via `qmgr` at the server host.
- When a job is moved to a new server or queue, it inherits new default resources from that server or queue. If it is moved to a new server, it is prioritized according to the formula on that server, if one exists.
- If the job is moved to another server through peer scheduling and the pulling server uses queue priority in its job sorting formula, the queue priority used in the formula will be that of the queue to which the job is moved.
- If you are using FIFO scheduling, the job_sort_formula server attribute must be unset.
- If you are using eligible time in the formula, and eligible_time_enable is *False*, each job's eligible time evaluates to zero in the formula.
- If a job is requeued, and you are using the formula, the job may lose its place, because various factors may affect the job's priority. For example, a higher-priority job may be submitted between the time the job is requeued and the time it would have run, or another job's priority may be increased due to changes in which jobs are running or waiting.
- If the formula is configured, it is in force during both primetime and non-primetime.
- If an error is encountered while evaluating the formula, the formula evaluates to zero for that job, and the following message is logged at event class 0x0100:

```
"1234.mars;Formula evaluation for job had an error.  Zero value will be used"
```

- You may have to work around a Python bug by multiplying by 1.0, in order to prevent rounding to the nearest integer.

4.9.21.14 Logging

For each job, the evaluated formula answer is logged at the highest log level (0x0400):

```
"Formula  Evaluation = <answer>"
```

4.9.22 Gating Jobs at Server or Queue

You can set resource limits at the server and queues so that jobs must conform to the limits in order to be admitted. This way, you can reject jobs that request more of a resource than a scheduler's partition or a queue can supply.

You can also force jobs into specific queues where they will inherit the desired values for unrequested or custom resources. You can then use these resources to manage jobs, for example by using the resources in the job sorting formula or to route jobs to particular vnodes.

You can either force users to submit their jobs to specific queues, or you can have users submit jobs to routing queues, and then route the jobs to the desired queues.

For information on using resources for gating, see section 5.13, "Using Resources to Restrict Server or Queue Access", on page 256.

For a description of which resources can be used for gating, see section 2.3.6.4.iii, "Resources Used for Routing and Admittance", on page 29.

For how queue resource limits are applied to jobs, see section 2.3.6.4.i, "How Queue and Server Limits Are Applied, Except Running Time", on page 28.

For how routing queues work, see section 2.3.6, "Routing Queues", on page 27.

For how to route jobs to particular vnodes, see section 4.9.2, "Associating Vnodes with Queues", on page 105.

For how to use resources in the job sorting formula, see section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

4.9.22.1 Gating Caveats

- For most resources, if the job does not request the resource, and no server or queue defaults are set, the job inherits the maximum gating value for the resource. See section 5.9.3.6, "Using Gating Values As Defaults", on page 249.
- For shrink-to-fit jobs, if a walltime limit is specified:
    - Both min_walltime and max_walltime must be greater than or equal to resources_min.walltime.
    - Both min_walltime and max_walltime must be less than or equal to resources_max.walltime.

4.9.23 Managing Application Licenses

PBS does not check application licenses out from the license server. PBS has no direct control over application licenses. However, you can have a scheduler use a dynamic resource to track application license use. This way, a scheduler knows how many application licenses are available, and how many have been checked out. For how to configure dynamic resources to represent application licenses, see section 5.14.6, "Supplying Application Licenses", on page 277.

Unfortunately, some jobs or applications don't check out all of the application licenses they use until they have been running for some time. For example, job J1, which requests licenses, starts running, but doesn't check them out for a few minutes. Next, the scheduler considers job J2, which also requests licenses. The scheduler runs its query for the number of available licenses, and the query returns with a sufficient number of licenses to run J2, so the scheduler starts J2. Shortly afterward, J1 checks out licenses, leaving too few to run J2.

It might appear that you could track the number of application licenses being used with a static integer PBS resource, and force jobs requesting application licenses to request this resource as well, but there is a drawback: if a job that has requested this resource is suspended, its static resources are released, but its application licenses are not. In this case you could end up with a deceptively high number for available licenses.

You can limit the number of jobs that request application licenses, if you know how many jobs can run at one time:

- Create a custom server-level consumable integer resource to represent these jobs. See section 5.14.3, "Creating Server-level Custom Resources", on page 268.
- Use `qmgr` to set resources_available.<job limit> at the server to the number of jobs that can run at one time.
- Force all jobs requesting the application to request one of these. See section 14.3, "Allocating Resources to Jobs", on page 507.

4.9.24 Limits on Per-job Resource Usage

You can specify how much of each resource any job is allowed to request, at the server and queue level. The server and queues each have per-job limit attributes. The resources_min.<resource name> and resources_max.<resource name> server and queue attributes are limits on what each individual job may request.

You cannot set resources_min or resources_max limits on min_walltime or max_walltime.

See section 5.15.2, "Placing Resource Limits on Jobs", on page 307, and section 5.13, "Using Resources to Restrict Server or Queue Access", on page 256.

4.9.25 Limits on Project, User, and Group Jobs

You can manage the number of jobs being run by users or groups, and the number of jobs being run in projects, at the server or queue level. For example, you can limit the number of jobs enqueued in queue QueueA by any one group to *30*, and by any single user to *5*.

See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

4.9.26 Limits on Project, User, and Group Resource Usage

You can manage the total amount of each resource that is used by projects, users, or groups, at the server or queue level. For example, you can manage how much memory is being used by jobs in queue QueueA.

See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

4.9.27 Using Load Balancing

As of version 2020.1, the load_balancing scheduler parameter is **deprecated**. We recommend sorting vnodes according to load average, described in section 4.9.50.3, "Sorting Vnodes According to Load Average", on page 229.

PBS can use the load_balancing scheduler parameter to track the load on each execution host, running new jobs on the host according to the load on the host. You can specify that PBS does this for all machines in a scheduler's partition. This is somewhat different behavior from that used for managing the load on vnodes; when managing load levels on vnodes, a scheduler only pays attention to the state of the vnode, and does not calculate whether a job would put the vnode over its load limit. Managing load levels on vnodes does not require load balancing to be turned on. See section 9.6.5, "Managing Load Levels on Vnodes", on page 447. This load balancing tool does not work across vnodes on a multi-vnoded host.

You use the load_balancing scheduler parameter to control whether PBS tracks the load on each host.

The load_balancing parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

4.9.27.1 How Load Average is Computed

When load balancing is on, a scheduler queries each MoM once each scheduling cycle for the MoM's load. MoM checks the load average on her host every 10 seconds. The load used by MoM is the raw one-minute averaged "loadave" returned by the operating system.

When a new load is added to a vnode, the load average increases slowly over time, so that more jobs than you want may be started at first. Eventually, the load average matches the actual load. If this is above the limit, PBS won't start any more jobs on that vnode. As jobs terminate, the load average slowly moves down, and it takes time before the vnode is chosen for new jobs.

Consult your OS documentation to determine load values that make sense.

MoM sets the load only on the parent vnode, so it is the same for all vnodes on a multi-vnode machine.

4.9.27.2 How PBS Uses Load Information

When choosing vnodes for a job, a scheduler considers the load on the vnode in addition to whether the vnode can supply the resources specified in the job's Resource_List attribute.

PBS estimates that a 1-CPU job will produce one CPU's worth of load. This means that if you have a 2-CPU machine whose load is zero, PBS will put two 1-CPU jobs, or one 2-CPU job, on that machine.

When using load balancing, if a vnode has gone above $max_load, PBS does not run new jobs on the vnode until the load drops below $ideal_load.

MoM sets the vnode's state according to its load. When a vnode's load goes above $max_load, MoM marks the vnode *busy*. When the load drops below $ideal_load, MoM marks the vnode *free*. When a vnode's state changes, for example from *free* to *busy*, MoM informs the server.

When using load balancing, PBS does not run new jobs on vnodes under the following conditions:

- Vnodes that are marked *busy*
- Vnodes whose resources, such as ncpus, are already fully allocated
- Vnodes that are above $max_load
- Vnodes where running the job would cause the load to go above $max_load

4.9.27.3 When to Use Load Balancing

When using load balancing (meaning the load_balancing scheduler parameter is *True*), the only changes to behavior are the following:

- A scheduler won't place a job on a vnode whose load is above $max_load
- A scheduler won't place a job on a vnode where that job would put the load above $max_load

Load balancing is useful when you want to oversubscribe CPUs, managing job placement by load instead. This can help when you want to run lots of jobs where each job will need only some CPU time, and the average load on the machine will be reasonable.

4.9.27.4 Suspending Jobs on Overloaded Vnodes

You can specify that MoM should suspend jobs when the load goes above $max_load, by adding the suspend argument to the $max_load parameter. See section , “$max_load <load> [suspend]”, on page 161. In this case, MoM suspends all jobs on the vnode until the load drops below $ideal_load, then resumes them. This option is useful only when the source of the load is not strictly PBS jobs. This option is not recommended when the load is due solely to PBS jobs, because it can lead to the vnode cycling back and forth between becoming overloaded, being marked busy, suspending all jobs, being marked free, then starting all jobs, becoming overloaded, and so on.

4.9.27.5 Configuring Load Balancing

If you want to oversubscribe CPUs, set the value of ncpus on the vnode to the desired higher value.

We recommend setting the value of $max_load to a slightly higher value than the desired load, for example *.25 + ncpus*. Otherwise, a scheduler will not schedule jobs onto the last CPU, because it thinks a 1-CPU job will raise the load by 1, and the machine probably registers a load above zero.

To configure load balancing, perform the following steps:

1. Turn on load balancing by setting the load_balancing scheduler parameter to *True*:
   ```
   load_balancing: True ALL
   ```
2. Choose whether you want load balancing during primetime, non-primetime, or all. If you want separate behavior for primetime and non-primetime, specify each separately. The default is both. Example of separate behavior:
   ```
   load_balancing True prime
   load_balancing False non_prime
   ```
3. Set the ideal and maximum desired load for each execution host, by specifying values for $ideal_load and $max_load in each execution host's MoM configuration file:
   ```
   $ideal_load <value at which to start new jobs>
   $max_load   <value at which to cease starting jobs>
   ```
4. Set each host's resources_available.ncpus to the maximum number of CPUs you wish to allocate on that host. Follow the recommendations in section 3.4.5, “Configuring Vnode Resources”, on page 49.

4.9.27.6 Load Balancing Caveats and Recommendations

- When setting ncpus and $max_load, consider the ratio between the two. PBS won't allocate more than the value of resources_available.ncpus, so you can use this value to keep the load average from getting too high.
- Make sure that load balancing does not interfere with communications. Please read section 9.6.5, “Managing Load Levels on Vnodes”, on page 447.
- Load balancing is incompatible with sorting vnodes on a key (node_sort_key) when sorting on a resource using the "*unused*" or "*assigned*" parameters. Load balancing will be disabled. See section 4.9.50, “Sorting Vnodes on a Key”, on page 228.
- You can use load balancing with SMP cluster distribution, but smp_cluster_dist will behave as if it is set to *pack*. See section 4.9.43, “SMP Cluster Distribution”, on page 220.
- We recommend setting the value of $max_load to a slightly higher value than the desired load, for example *.25 + ncpus*. Otherwise, a scheduler will not schedule jobs onto the last CPU, because it thinks a 1-CPU job will raise the load by 1, and the machine probably registers a load above zero.
- If you are using cycle harvesting via load balancing, make sure your load balancing settings do not interfere with cycle harvesting. Be careful with the settings for $ideal_load and $max_load. You want to make sure that when the workstation owner is using the machine, the load on the machine triggers MoM to report being busy, and that PBS does not start any new jobs while the user is working. Please read section 4.9.9.6, “Cycle Harvesting Based on Load Average”, on page 123.
- Using load balancing with multi-vnoded machines is not supported. MoM sets the load average only on the parent vnode, so all vnodes on a multi-vnoded machine are given the same value regardless of their actual load.
- It is not recommended to specify that MoM should suspend jobs when the load goes above $max_load. See section 4.9.27.4, “Suspending Jobs on Overloaded Vnodes”, on page 159.
- If you configure both placement sets and load balancing, the net effect is that vnodes that are over their load limit will be removed from consideration.

4.9.27.7 Parameters Affecting Load Balancing

$ideal_load <load>

MoM parameter. Defines the load below which the vnode is not considered to be busy. Used with the $max_load parameter.

Example:

```
$ideal_load 1.8
```

Format: *Float*

No default

$max_load <load> [suspend]

MoM parameter. Defines the load above which the vnode is considered to be busy. Used with the $ideal_load parameter.

If the optional suspend argument is specified, PBS suspends jobs running on the vnode when the load average exceeds $max_load, regardless of the source of the load (PBS and/or logged-in users).

Example:

```
$max_load 3.5
```

Format: *Float*

Default: *number of CPUs*

load_balancing <T|F> [time slot specification]

Scheduler parameter. When set to *True*, this scheduler takes into account the load average on vnodes as well as the resources listed in the `resources:` line in `sched_config`. See “load_balancing” on page 255 of the PBS Professional Reference Guide.

Format: *Boolean*

Default: *False all*

4.9.28 Matching Jobs to Resources

A scheduler places each job where the resources requested by the job are available. A scheduler handles built-in and custom resources the same way. For a complete description of PBS resources, see Chapter 5, "Using PBS Resources", on page 231.

4.9.28.1 Scheduling on Consumable Resources

A scheduler constrains the use of a resource to the value that is set for that resource in resources_available.<resource name>. For a consumable resource, a scheduler won't place more demand on the resource than is available. For example, if a vnode has resources_available.ncpus set to *4*, a scheduler will place jobs requesting up to a total of 4 CPUs on that vnode, but no more.

A scheduler computes how much of a resource is available by subtracting the total of resources_assigned.<resource name> for all running jobs and started reservations from resources_available.<resource name>.

4.9.28.2 Scheduling on Non-Consumable Resources

For non-consumable resources such as arch or host, a scheduler matches the value requested by a job with the value at one or more vnodes. Matching a job this way does not change whether or not other jobs can be matched as well; non-consumable resources are not used up by jobs, and therefore have no limits.

4.9.28.3 Scheduling on Dynamic Resources

At each scheduling cycle, a scheduler queries each dynamic resource. If a dynamic resource is not under the control of PBS, jobs requesting it may run in an unpredictable fashion.

4.9.28.4 Scheduling on the walltime Resource

A scheduler looks at each job in priority order, and tries to run the job. A scheduler checks whether there is an open time slot on the requested resources that is at least as long as the job's walltime. If there is, the scheduler runs the job.

PBS examines each shrink-to-fit job when it gets to it, and looks for a time slot whose length is between the job's min_walltime and max_walltime. If the job can fit somewhere, PBS sets the job's walltime to a duration that fits the time slot, and runs the job. For more information about shrink-to-fit jobs, see section 4.9.42, “Using Shrink-to-fit Jobs”, on page 213.

4.9.28.4.i Caveats for Scheduling on walltime

Do not set values for resources such as walltime at the server or a queue, because a scheduler will not allocate more than the specified value. This means that if you set resources_available.walltime at the server to *10:00:00*, and one job requests 5 hours and one job requests 6 hours, only one job will be allowed to run at a time, regardless of other idle resources.

4.9.28.5 Unrequestable or Invisible Resources

You can define custom resources that are invisible to and unrequestable by users, or simply unrequestable by users. A scheduler treats these resources the same as visible, requestable resources. See section 5.14.2.3.vi, “Resource Permission Flags”, on page 262.

4.9.28.6 Enforcing Scheduling on Resources

A scheduler chooses which resources to schedule on according to the following rules:

- A scheduler always schedules jobs based on the availability of the following vnode-level resources:

  vnode

  host

  Any Boolean resource

- A scheduler will schedule jobs based on the availability of other resources only if those resources are listed in the "`resources:`" line in `<sched_priv directory>/sched_config`. Some resources are automatically added to this line. You can add resources to this line. The following resources are automatically added to this line:

  aoe

  arch

  eoe

  host

  mem

  ncpus

  vnode

4.9.28.7 Matching Unset Resources

When job resource requests are being matched with available resources, unset resources are treated as follows:

- A numerical resource that is unset on a host is treated as if it were *zero*
- An unset resource on the server or queue is treated as if it were infinite
- An unset string cannot be matched
- An unset Boolean resource is treated as if it were set to *False*.
- The resources ompthreads, mpiprocs, and nodes are ignored for unset resource matching.

The following table shows how a resource request will or won't match an unset resource at the host level.

Table 4-15: Matching Requests to Unset Host-level Resources

Resource Type	Unset Resource	Matching Request Value
Boolean	*False*	*False*
float	*0.0*	*0.0*
long	*0*	*0*
size	*0*	*0*
string	""	Never matches
string array	""	Never matches
time	*0, 0:0, 0:0.0, 0:0:0*	*0, 0:0, 0:0.0, 0:0:0*

4.9.28.7.i When Dynamic Resource Script Fails

If a server dynamic resource script fails, a scheduler uses the value of resources_available.<resource name>. If this was never set, it is treated as an unset resource, described above.

If a host-level dynamic resource script fails, a scheduler treats the resource as if its value is zero.

4.9.28.7.ii Backward Compatibility of Unset Resources

To preserve backward compatibility, you can set the server's resource_unset_infinite attribute with a list of host-level resources that will behave as if they are infinite when they are unset. See "resource_unset_infinite" on page 258 of the PBS Professional Reference Guide for information on resource_unset_infinite.

4.9.28.8 Resource Scheduling Caveats

- Do not set values for resources such as walltime at the server or a queue, because a scheduler will not allocate more than the specified value. This means that if you set resources_available.walltime at the server to *10:00:00*, and one job requests 5 hours and one job requests 6 hours, only one job will be allowed to run at a time, regardless of other idle resources.
- Jobs may be placed on different vnodes from those where they would have run in earlier versions of PBS. This is because a job's resource request will no longer match the same resources on the server, queues and vnodes.
- Beware of application license race conditions. If two jobs require the same application license, the first job may be started, but may not get around to using the license before the second job is started and uses the license. The first job must then wait until the license is available, taking up resources. A scheduler cannot avoid this problem.

4.9.29 Node Grouping

The term "*node grouping*" has been superseded by the term "*placement sets*". Vnodes were originally grouped according to the value of one resource, so for example all vnodes with a value of *linux* for arch were grouped together, and all vnodes with a value of *arch1* for arch were in a separate group. We use placement sets now because this means grouping vnodes according to the value of one *or more* resources. See section 4.9.32, "Placement Sets", on page 170.

4.9.29.1 Configuring Old-style Node Grouping

Configuring old-style node grouping means that you configure the simplest possible placement sets. In order to have the same behavior as in the old node grouping, group on a single resource. If this resource is a string array, it should only have one value on each vnode. This way, each vnode will be in only one node group.

You enable node grouping by setting the server's node_group_enable attribute to *True*.

You can configure one set of vnode groups for the entire complex by setting the server's node_group_key attribute to a resource name.

You can configure node grouping separately for each queue by setting that queue's node_group_key attribute to a resource name.

4.9.30 Overrides

You can use various overrides to change how one or more jobs run.

4.9.30.1 Run a Job Manually

You can tell PBS to run a job now, and you can optionally specify where to run it. You run a job manually using the `qrun` command.

The `-H` option to the `qrun` command makes an important difference:

`qrun`

When preemption is enabled, a scheduler preempts other jobs in order to run this job. Running a job via `qrun` gives the job higher preemption priority than any other class of job, except for reservation jobs.

When preemption is not enabled, a scheduler runs the job only if enough resources are available.

`qrun -H`

PBS runs the job regardless of scheduling policy and available resources.

The `qrun` command alone overrides the following:

- Limits on resource usage by users, groups, and projects
- Limits on the number of jobs that can be run at a vnode
- Boundaries between primetime and non-primetime, specified in backfill_prime
- Whether the job is in a primetime queue: you can run a job in a primetime queue even when it's not primetime, or vice versa. Primetime boundaries are not honored.
- Dedicated time: you can run a job in a dedicated time queue, even if it's not in a dedicated time queue, and vice versa. However, dedicated time boundaries are still honored.
- Top jobs
- The threshold set in the job_sort_formula_threshold scheduler attribute
- The limit on the number of simultaneously running subjobs for an array job set in the max_run_subjobs job attribute

The `qrun` command alone does not override the following:

- Server and queue resource usage limits

4.9.30.1.i Using `qrun` Without `-H` Option on Shrink-to-fit Jobs

When a shrink-to-fit job is run via `qrun`, and there is a hard deadline, e.g. reservation or dedicated time, that conflicts with the shrink-to-fit job's max_walltime but not its min_walltime, the following happens:

- If preemption is enabled and there is a preemptable job before the hard deadline that must be preempted in order to run the shrink-to-fit job, preemption behavior means that the shrink-to-fit job does not shrink to fit; instead, it conflicts with the deadline and does not run.
- If there is no preemptable job before the hard deadline, the shrink-to-fit job shrinks into the available time and runs.

4.9.30.1.ii Using `qrun` With `-H` Option on Shrink-to-fit Jobs

When a shrink-to-fit job is run via `qrun -H`, the shrink-to-fit job runs, regardless of reservations, dedicated time, other jobs, etc. When run via `qrun -H`, shrink-to-fit jobs do not shrink. If the shrink-to-fit job has a requested or inherited value for walltime, that value is used, instead of one set by PBS when the job runs. If no walltime is specified, the job runs without a walltime.

See "qrun" on page 183 of the PBS Professional Reference Guide, and section 4.9.33, "Using Preemption", on page 182.

4.9.30.1.iii `qrun` Caveats

- A job that has just been run via `qrun` has top priority only during the scheduling cycle where it was `qrun`. At the next scheduling cycle, that job is available for preemption just like any other job.
- Be careful when using `qrun -H` on jobs or vnodes involved in reservations.

4.9.30.2 Hold a Job Manually

You can use the qhold command to place a hold on a job. The effect of placing a hold depends on whether the job is running and whether you have checkpointing configured:

- If the job is queued, the job will not run.
- If the job is running and checkpoint-abort is configured, the job is checkpointed, requeued, and held.
- If the job is running and checkpoint-abort is not configured, the only change is that the job's Hold_Types attribute is set to User Hold. If the job is subsequently requeued, it will not run until the hold is released.

You can release the hold using the qrls command.

For information on checkpointing jobs, see section 9.3, "Checkpoint and Restart", on page 420.

See "qhold" on page 148 of the PBS Professional Reference Guide and "qrls" on page 181 of the PBS Professional Reference Guide.

4.9.30.3 Suspend a Job Manually

You can use the `qsig -s suspend` command to suspend a job so that it won't run. If you suspend a job, and then release it using the `qsig -s resume` command, the job remains in the suspended state until the required resources are available.

You can resume the job immediately by doing the following:

1. Resume the job:
   ```
   qsig -s resume <job ID>
   ```
2. Run the job manually:
   ```
   qrun <job ID>
   ```

See “qsig” on page 193 of the PBS Professional Reference Guide.

4.9.30.4 Set Special Resource Value Used in Formula

You can change the value of a resource used in the job sorting formula. For example, to give a particular job a higher priority by changing the value of a custom resource called "higher":

- Create a custom resource that is invisible to job submitters:
  ```
  Qmgr: create resource higher type=float, flag=i
  ```
- The formula expression includes "higher":
  ```
  Qmgr: s s job_sort_formula = "higher"
  ```
- Set the default for this resource at the server:
  ```
  Qmgr: set server resources_default.higher = 1
  ```
- These jobs are submitted:

  Job 1

  Job 2

  Job 3
- Change Job 2 so that its value for "higher" is 5:
  ```
  qalter -l higher = 5 job2
  ```
- The scheduler logs the following:
  ```
  Job;1.host1;Formula Evaluation = 1
  Job;2.host1;Formula Evaluation = 5
  Job;3.host1;Formula Evaluation = 1
  ```
- Jobs are sorted in this order:

  Job 2

  Job 1

  Job 3

4.9.30.5 Change Formula On the Fly

You can change the job sorting formula on the fly, so that the next scheduler iteration uses your new formula. This will change how job priorities are computed, and can rearrange the order in which jobs are run. See section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151.

4.9.30.6 Using Dedicated Time

You can set up blocks of dedicated time, where the only jobs eligible to be started or running are the ones in dedicated time queues. You can use dedicated time for upgrades. See section 4.9.10, “Dedicated Time”, on page 127, and section 2.3.5.2.i, “Dedicated Time Queues”, on page 26.

4.9.30.7 Using `cron` Jobs

You can use `cron` jobs to change PBS settings according to the needs of your time slots. See section 4.9.7, “cron Jobs”, on page 114.

4.9.30.8 Using Hooks

You can use hooks to examine jobs and alter their characteristics. See the *PBS Professional Hooks Guide*.

4.9.30.9 Preventing Jobs from Being Calendared

You can prevent a scheduler from calendaring a job by setting its topjob_ineligible attribute to *True*. See section 4.9.17, “Calendaring Jobs”, on page 139.

4.9.31 Peer Scheduling

Peer scheduling allows separate PBS partitions or complexes to automatically run jobs from each other's queues. This means that you can dynamically balance the workload across multiple, separate PBS partitions or complexes. These cooperating PBS partitions or complexes are referred to as "*Peers*".

4.9.31.1 How Peer Scheduling Works

In peer scheduling, a PBS server pulls jobs from one or more peer servers and runs them locally. When Partition or Complex A pulls a job from Partition or Complex B, Partition or Complex A is the "pulling" complex and Partition or Complex B is the "furnishing" partition or complex. When the pulling scheduler determines that another partition's or complex's job can immediately run locally, it moves the job to the specified queue on the pulling server and immediately run the job. The job is run as if it had been submitted to the pulling partition or complex.

You can set up peer scheduling so that A pulls from B and C, and so that B also pulls from A and C.

A job is pulled **only** when it can run immediately.

The pulling partition or complex must have all of the resources required by the job, including custom resources.

When a job is pulled from one partition or complex to another, the pulling partition or complex applies its policy to the job. The job's execution priority is determined by the policy of the pulling partition or complex. You can set special priority for pulled jobs; see section 4.9.31.4.ii, “Setting Priority for Pulled Jobs”, on page 169.

4.9.31.2 Prerequisites for Peer Scheduling

- You must create the pulling and furnishing queues before peer scheduling can be configured. See section 2.3.3, “Creating Queues”, on page 24 on how to create queues.
- When configuring peer scheduling, it is *strongly* recommended to use the same version of PBS Professional at all peer locations.
- Make sure that custom resources are consistent across peer locations. Jobs requesting custom resources at one location will not be able to run at another unless the same resources are available.

4.9.31.3 Configuring Peer Scheduling

The following sections give details on how to configure peer scheduling. Here is a brief outline:

- Define a flat user namespace on all complexes
- Map pulling queues to furnishing queues
- If necessary, specify port
- Grant manager access to each pulling server
- If possible, make user-to-group mappings be consistent across complexes
- If any of the peering sites is using failover, configure peering to work with failover

4.9.31.3.i Defining a Flat User Namespace

Peer scheduling requires a flat user namespace in all complexes involved. This means that user "joe" on the remote peer system(s) must be the same as user "joe" on the local system. Your site must have the same mapping of user to UID across all hosts, and a one-to-one mapping of UIDs to usernames. It means that PBS does not need to check whether X@hostA is the same as X@hostB; it can just assume that this is true. Set flatuid to *True*:

```
Qmgr: set server flatuid = True
```

For more on flatuid, see section 8.3.12, “Flatuid and Access”, on page 378.

4.9.31.3.ii Mapping Pulling Queues to Furnishing Queues

You configure peer scheduling by mapping a furnishing peer's queue to a pulling peer's queue. You can map each pulling queue to more than one furnishing queue, or more than one pulling queue to each furnishing queue.

The pulling and furnishing queues must be *execution* queues, not route queues. However, the queues can be either ordinary queues used for normal work, or special queues set up just for peer scheduling.

You map pulling queues to furnishing queues by setting the peer_queue scheduler configuration option in `<sched_priv directory>/sched_config`. The format is:

```
peer_queue: "<pulling queue> <furnishing queue>@<furnishing server>.domain"
```

For example, Complex A's queue "workq" is to pull from two queues: Complex B's queue "workq" and Complex C's queue "slowq". Complex B's server is ServerB and Complex C's server is ServerC. You would add this to Complex A's `<sched_priv directory>/sched_config`:

```
peer_queue: "workq workq@ServerB.domain.com"
peer_queue: "workq slowq@ServerC.domain.com"
```

Or if you wish to direct Complex B's jobs to queue Q1 on Complex A, and Complex C's jobs to Q2 on Complex A:

```
peer_queue: "Q1 workq@ServerB.domain.com"
peer_queue: "Q2 fastq@ServerC.domain.com"
```

In one partition or complex, you can create up to 50 mappings between queues. This means that you can have up to 50 lines in `<sched_priv directory>/sched_config` beginning with "`peer_queue`".

4.9.31.3.iii Specifying Ports

The default port for the server to listen on is 15001, and a scheduler uses any privileged port (1023 and lower). If the furnishing server is not using the default port, you must specify the port when you specify the queue. For example, if ServerB is using port 16001, and you wish to pull jobs from workq at ServerB to workq at ServerA, add this to `<sched_priv directory>/sched_config` at ServerA:

```
peer_queue: "workq workq@ServerB.domain.com:16001"
```

A scheduler and server communicate via TCP.

4.9.31.3.iv Granting Manager Access to Pulling Servers

Each furnishing server must grant manager access to each pulling server. If you wish jobs to move in both directions, where Complex A will both pull from and furnish jobs to Complex B, ServerA and ServerB must grant manager access to each other.

On the furnishing complex:

```
Qmgr: set server managers += root@pullingServer.domain.com
```

4.9.31.3.v Making User-to-group Mappings Consistent Across Complexes

If possible, ensure that for each user in a peer complex, that user is in the same group in all participating complexes. So if user "joe" is in groupX on Complex A, user "joe" should be in groupX on Complex B. This means that a job's `egroup` attribute will be the same on both complexes, and any group limit enforcement can be properly applied.

There is a condition when using peer scheduling in which group hard limits may not be applied correctly. This can occur when a job's effective group, which is its egroup attribute, i.e. the job's owner's group, is different on the furnishing and pulling systems. When the job is moved over to the pulling complex, it can evade group limit enforcement if the group under which it will run on the pulling system has not reached its hard limit. The reverse is also true; if the group under which it will run on the pulling system has already reached its hard limit, the job won't be pulled to run, although it should.

This situation can also occur if the user explicitly specifies a group via `qsub -W group_list`.

It is recommended to advise users to *not* use the `qsub` options "`-u user_list`" or "`-W group_list=groups`" in conjunction with peer scheduling.

4.9.31.3.vi Configuring Peer Scheduling with Failover

If you are configuring peer scheduling so that Complex A will pull from Complex B where Complex B is configured for failover, you must configure Complex A to pull from both of Complex B's servers. For these instructions, see section 9.2.6.2, "Configuring Failover to Work With Peer Scheduling", on page 417.

4.9.31.4 Peer Scheduling Advice

4.9.31.4.i Selective Peer Scheduling

You can choose the kinds of jobs that can be selected for peer scheduling to a different partition or complex. You can do the following:

- Set resource limits at the furnishing queue via the resources_min and resources_max queue attributes. See section 2.3.6.4, "Using Resources to Route Jobs Between Queues", on page 28.
- Route jobs into the furnishing queue via a hook. See "Routing Jobs" on page 7 in the PBS Professional Hooks Guide.
- Route jobs into the furnishing queue via a routing queue. See section 2.3.6, "Routing Queues", on page 27.

4.9.31.4.ii Setting Priority for Pulled Jobs

You can set a special priority for pulled jobs by creating a queue that is used only as a pulling queue, and setting the pulling queue's priority to the desired level. You can then use the queue's priority when setting job execution priority. See section 4.3.5.3.iv, "Using Queue Priority when Computing Job Priority", on page 67.

For example, if you give the pulling queue the lowest priority, the pulling partition or complex will pull a job only when there are no higher-priority jobs that can run.

You can also have pulled jobs land in a special queue where they inherit a custom resource that is used in the job sorting formula.

4.9.31.5 How Peer Scheduling Affects Jobs

4.9.31.5.i How Peer Scheduling Affects Inherited Resources

If the job is moved partition or complex to another via peer scheduling, any default resources in the job's resource list inherited from the furnishing queue or server are removed. This includes any select specification and place directive that may have been generated by the rules for conversion from the old syntax. If a job's resource is unset (undefined) and there exists a default value at the new queue or server, that default value is applied to the job's resource list. If either select or place is missing from the job's new resource list, it will be automatically generated, using any newly inherited default values.

When the pulling scheduler runs the job the first time, the job is run as if the job still had all of the resources it had at the furnishing partition or complex. If the job is requeued and restarted at the pulling partition or complex, the job picks up new default resources from the pulling partition or complex, and is scheduled according to the newly-inherited resources from the pulling partition or complex.

4.9.31.5.ii How Peer Scheduling Affects Policy Applied to Job

After a job is pulled from one partition or complex to another, the scheduling policy of the pulling partition or complex is applied to the job.

For example, if you use queue priority in the formula and the job is moved to another server through peer scheduling, the queue priority used in the formula will be that of the queue to which the job is moved.

When a job is pulled from one partition or complex to another, hooks are applied at the new partition or complex as if the job had been submitted locally. For example, if the pulling partition or complex has a *queuejob* hook, that hook runs when a job is pulled.

4.9.31.5.iii How Peer Scheduling Affects Job Eligible Time

The job's eligible_time is preserved when a job is moved due to peer scheduling.

4.9.31.5.iv Viewing Jobs That Have Been Moved to Another Server

If you are connected to ServerA and a job submitted to ServerA has been moved from ServerA to ServerB through peer scheduling, in order to display it via `qstat`, give the job ID as an argument to `qstat`. If you only give the `qstat` command, the job will not appear to exist. For example, the job `123.ServerA` is moved to ServerB. In this case, use

```
qstat 123
```

or

```
qstat 123.ServerA
```

To list all jobs at ServerB, you can use:

```
qstat @ServerB
```

4.9.31.5.v Peer Scheduling and Hooks

When a job is pulled from one complex to another, the following happens:

- Hooks are applied at the new complex as if the job had been submitted locally
- Any movejob hooks at the furnishing server are run

4.9.31.6 Peer Scheduling Caveats

- Each partition or complex can peer with at most 50 other partitions or complexes.
- When using peer scheduling, group hard limits may not be applied correctly. This can occur when the job owner's group is different on the furnishing and pulling systems. For help in avoiding this problem, see section 4.9.31.3.v, "Making User-to-group Mappings Consistent Across Complexes", on page 168.
- When the pulling scheduler runs the job the first time, the job is run as if the job still had all of the resources it had at the furnishing partition or complex. If the job is requeued and restarted at the pulling partition or complex, the job picks up new default resources from the pulling partition or complex, and is scheduled according to the newly-inherited resources from the pulling partition or complex.
- Peer scheduling is not supported for job arrays.

4.9.32 Placement Sets

Placement sets are the sets of vnodes within which PBS will try to place a job. PBS tries to group vnodes into the most useful sets, according to how well connected the vnodes are, or the values of resources available at the vnodes. Placement sets are used to improve task placement (optimizing to provide a "good fit") by exposing information on system configuration and topology. A scheduler tries to put a job in the smallest appropriate placement set.

4.9.32.1 Definitions

Task placement

The process of choosing a set of vnodes to allocate to a job that will satisfy both the job's resource request (select and place specifications) and the configured scheduling policy.

Placement Set

A set of vnodes. Placement sets are defined by the values of vnode-level string array resources. A placement set is all of the vnodes that have the same value for a specified defining resource substring. For example, if the defining resource is a vnode-level string array named "*switch*", which can have values "S1", "S2", or "S3": the set of vnodes which have a substring matching "switch=S2" is a placement set.

Placement sets can be specified at the server or queue level.

Placement Set Series

A set of placement sets; a set of sets of vnodes.

A placement set series is all of the placement sets that are defined by specifying one string array resource. Each placement set in the series is the set of vnodes that share one value for the resource. There is one placement set for each value of the resource. If the resource takes on N values at the vnodes, then there are N sets in the series. For example, if the defining resource is a string array named "*switch*", which can have values "S1", "S2", or "S3", there are three sets in the series. The first is defined by the value "S1", where all the vnodes in that set have the value "S1" for the resource switch. The second set is defined by "S2", and the third by "S3".

Each of the resources named in node_group_key specifies a placement series. For example, if the server's node_group_key attribute contains "router,switch", then the server has two placement set series.

Placement Pool

All of the placement sets that are defined; the server can have a placement pool, and each queue can have its own placement pool. If a queue has no placement pool, a scheduler uses the server's placement pool.

A placement pool is the set of placement set series that are defined by one or more string array resources named in node_group_key.

For example, if the server's node_group_key attribute contains "router,switch", and router can take the values "R1" and "R2" and switch can take the values "S1", "S2", and "S3", then there are five placement sets, in two placement series, in the server's placement pool.

Static Fit

A job statically fits into a placement set if the job could fit into the placement set if the set were empty. It might not fit right now with the currently available resources.

Dynamic Fit

A job dynamically fits into a placement set if it will fit with the currently available resources (i.e. the job can fit right now).

4.9.32.2 Requirements for Placement Sets

- Placement sets are enabled by setting the server's node_group_enable attribute to *True*
- Server-level placement sets are defined by setting the server's node_group_key attribute to a list of vnode-level string array resources.
- Queue-level placement sets are defined by setting a queue's node_group_key attribute to a list of vnode-level string array resources.
- At least one vnode-level string array resource must exist on vnodes and be set to values that can be used to assign the vnodes to placement sets.

4.9.32.3 Description of Placement Sets

4.9.32.3.i What Defines a Placement Set, Series, or Pool

Placement sets are defined by the values of vnode-level string array resources. You define placement sets by specifying the names of these resources in the node_group_key attribute for the server and/or queues. Each value of each resource defines a different placement set. A placement set is all of the vnodes that have the same value for a specified defining resource. For example, if the defining resource is a vnode-level string array named "*switch*", which has the values "S1", "S2", and "S3", the set of vnodes where switch has the value "S2" is a placement set. If some vnodes have more than one substring, and one of those substrings is the same in each vnode, those vnodes make up a placement set. For example, if the resource is "*router*", and vnode V0 has resources_available.router set to "r1i0,r1", and vnode V1 has resources_available.router set to "r1i1,r1", V0 and V1 are in the placement set defined by resources_available.router = "r1". If the resource has *N* distinct values across the vnodes, including the value zero and being unset, there can be *N-1* or *N* placement sets defined by that resource. If the only_explicit_psets scheduler attribute is *False*, there are *N* placement sets. If the only_explicit_psets scheduler attribute is *True*, there are *N-1* placement sets; see section 4.9.32.3.v, "Placement Sets Defined by Unset Resources", on page 173.

Each placement set can have a different number of vnodes; the number of vnodes is determined only by how many vnodes share that resource value.

Each placement set series is defined by the values of a single resource across all the vnodes. For example, if there are three switches, S1, S2 and S3, and there are vnodes with resources_available.switch that take on one or more of these three values, then there will be three placement sets in the series.

Whenever you define any placement sets, you are defining a placement pool. Placement pools can be defined for the server and for each queue. You define a server-level placement pool by setting the server's node_group_key to a list of one or more vnode-level string array resources. You define a queue-level placement pool by similarly setting the queue's node_group_key.

4.9.32.3.ii Vnode Participation in Placement Sets, Series, and Pools

Each vnode can be in multiple placement sets, placement set series, and placement pools.

A vnode can be in multiple placement sets in the same placement set series. For example, if the resource is called "*router*", and a vnode's router resource is set to "R1, R2", then the vnode will be in the placement set defined by router = R1 and the set defined by router = R2.

A vnode is in a placement series whenever the resource that defines the series is defined on the vnode. For example, if placement sets are defined by the values of the router and the switch resources, and a vnode has value *R1* for router, and *S1* for switch, then the vnode is in both placement series, because it is in the set that shares the *R1* value for router, and the set that shares the *S1* value for switch. Each of those sets is one of a different series.

The server has its own placement pool if the server's node_group_key attribute is set to at least one vnode-level string array resource. Similarly, each queue can have its own placement pool. A vnode can be in any placement pool that specifies a resource that is defined on the vnode.

4.9.32.3.iii Multihost Placement Sets

Placement sets, series, and pools can span hosts. Placement sets can be made up of vnodes from anywhere, regardless of whether the vnode is from a multi-vnode host.

To set up a multihost placement set, choose a string array resource for the purpose, and list it in the desired node_group_key attribute. For example, create a string_array resource called "span":

```
Qmgr: create resource span type=string_array, flag=h
```

Add the resource "span" to node_group_key on the server or queue. Use `qmgr` to give it the same value on all the desired vnodes. You can write a script that sets the same value on each vnode that you want in your placement set.

4.9.32.3.iv Machines with Multiple Vnodes

Machines with multiple vnodes are represented as a generic set of vnodes. Placement sets are used to allocate resources on a single machine to improve performance and satisfy scheduling policy and other constraints. Jobs are placed on vnodes using placement set information.

4.9.32.3.v Placement Sets Defined by Unset Resources

The only_explicit_psets scheduler attribute controls whether unset resources define placement sets.

- If the only_explicit_psets scheduler attribute is *False*, vnodes where a defining resource is unset are grouped into their own placement set, for each defining resource. For example, if you have ten vnodes, on which there is a string resource COLOR, where two have COLOR set to "red", two are set to "blue", two are set to "green" and the rest are unset, there will be four placement sets defined by the resource COLOR. This is because the fourth placement set consists of the four vnodes where COLOR is unset. This placement set will also be the largest. Every resource listed in node_group_key can potentially define such a placement set.
- If the only_explicit_psets scheduler attribute is *True*, vnodes where a resource is unset are not grouped into placement sets.

4.9.32.3.vi Placement Sets and Node Grouping

Node grouping is the same as one placement set series, where the placement sets are defined by a single resource. Node grouping has been superseded by placement sets.

In order to have the same behavior as in the old node grouping, group on a single resource. If this resource is a string array, it should only have one value on each vnode. This way, each vnode will only be in one node group.

4.9.32.4 How Placement Sets Are Used

You use placement sets to group vnodes according to the value of one or more resources. Placement sets allow you to group vnodes into useful sets.

You can run multi-vnode jobs in one placement set. For example, it makes the most sense to run a multi-vnode job on vnodes that are all connected to the same high-speed switch.

PBS will attempt to place each job in the smallest possible set that is appropriate for the job.

4.9.32.4.i Order of Placement Pool Selection

A scheduler chooses one placement pool from which to select a placement set.

Queue placement pools override the server's placement pool. If a queue has a placement pool, jobs from that queue are placed using the queue's placement pool. If a queue has no placement pool (the queue's node_group_key is not defined), jobs are placed using the server's placement pool, if it exists.

A per-job placement set is defined by the `-l place` statement in the job's resource request. Since the job can only request one value for the resource, it can only request one specific placement set. A job's `place=group` resource request overrides the sets defined by the queue's or server's node_group_key.

A scheduler chooses the most specific placement pool available, following this order of precedence:

1. A per-job placement set (job's `place=group=` request)
2. A placement set from the placement pool for the job's queue
3. A placement set from the placement pool in a scheduler's partition

4.9.32.4.ii Order of Placement Set Consideration Within Pool

A scheduler looks in the selected placement pool and chooses the smallest possible placement set that is appropriate for the job. A scheduler examines the placement sets in the pool and orders them, from smallest to largest, according to the following rules:

1. Static total ncpus of all vnodes in set
2. Static total mem of all vnodes in set
3. Dynamic free ncpus of all vnodes in set
4. Dynamic free mem of all vnodes in set

If a job can fit statically within any of the placement sets in the placement pool, then a scheduler places a job in the first placement set in which it fits dynamically. This ordering ensures a scheduler will use the smallest possible placement set in which the job will dynamically fit. If there are multiple placement sets where the job fits statically, but some are being used, a scheduler uses the first placement set where the job can run now. If the job fits statically into at least one placement set, but these placement sets are all busy, a scheduler waits until a placement set can fit the job dynamically.

For example, we have the following placement sets, and a job that requests 8 CPUs:

Set1 ncpus = 4

Set2 ncpus = 12; this placement set is full

Set3 ncpus = 16; this placement set is not being used

The scheduler looks at Set1; Set1 is statically too small, and the scheduler moves to the next placement set. Set2 is statically large enough, but the job does not fit dynamically. The scheduler looks at Set3; Set3 is large enough, and the job fits dynamically. The scheduler runs the job in Set3.

If the job requests 24 CPUs, the scheduler attempts to run the job in the set consisting of all vnodes that are associated with a specific queue, if do_not_span_psets is *False*.

4.9.32.4.iii Determining Whether Job Can Run

Whether the job can run in the selected placement pool is determined by the value of the do_not_span_psets attribute.

- If this attribute is *False*, and a job cannot statically fit into any placement set in the selected placement pool, a scheduler ignores defined placement sets and uses all vnodes that satisfy job restrictions as its placement set, and runs the job without regard to placement sets. For example, if the job's queue has access to a restricted set of vnodes, the job runs within that set of vnodes.
- If the attribute is *True*, a scheduler does not run the job.

4.9.32.4.iv Order of Vnode Selection Within Set

A scheduler orders the vnodes within the selected placement set using the following rules:

- If node_sort_key is set, vnodes are sorted by node_sort_key. See section 4.9.50, “Sorting Vnodes on a Key”, on page 228.
- If node_sort_key is not set, the order in which the vnodes are returned by `pbs_statnode()`. This is the default order the vnodes appear in the output of the `pbsnodes -a` command.

A scheduler places the job on the vnodes according to their ordering above.

4.9.32.5 Summary of Placement Set Requirements

The steps to configure placement sets are given in the next section. The requirements are summarized here for convenience:

- Definitions of the resources of interest
- Vnodes defining a value for each resource to be used for placement sets (e.g., rack)
    - If defined via vnode definition, you must HUP the MoMs involved
- The server's or queue's node_group_key attribute must be set to the resources to be used for placement sets. For example, if we have custom resources named "rack", "socket", "board", and "boardpair", which are to be used for placement sets:

  ```
  Qmgr: set server node_group_key = "rack,socket,board,boardpair"
  ```

    - No signals needed, takes effect immediately
- Placement sets must be enabled at the server by setting the server's node_group_enable attribute to *True*. For example:

  ```
  Qmgr: set server node_group_enable=True
  ```

    - No signals needed, takes effect immediately

Adding a resource to a scheduler's `resources`: line is required only if the resource is to be specifically requested by jobs. It is not required for `-lplace=group=<resource name>`.

4.9.32.6 How to Configure Placement Sets

The following steps show how to satisfy the requirements for placement sets:

1. If the vnodes that you will use in placement sets are not defined, define them. See section 3.3, “Creating Vnodes”, on page 40.
2. If the vnode-level string array resources that you will use to define placement sets do not exist, create them. See section 5.14.4, “Configuring Host-level Custom Resources”, on page 271.
3. If values for the vnode-level string array resources that you will use to define placement sets are not set at the vnodes you wish to use, set the values. See section 3.4, “Configuring Vnodes”, on page 43.
4. If you use vnode definition files to set values for vnode-level string array resources, HUP the MoMs involved.
5. To create queue placement pools, set the node_group_key attribute to the name(s) of one or more vnode-level string array resources. Do this for each queue for which you want a separate pool. For example:

   ```
   Qmgr: set queue workq node_group_key = <router,switch>
   ```

6. To create a server placement pool, set the node_group_key server attribute to the name(s) of one or more vnode-level string array resources. For example:

   ```
   Qmgr: set server node_group_key = <router,switch>
   ```

For example, to create a server-level placement pool for the resources host, L2 and L3:

```
Qmgr: set server node_group_key = "host,L2,L3"
```

7. Set the server's node_group_enable attribute to *True*

   ```
   Qmgr: set server node_group_enable = True
   ```

8. Set the do_not_span_psets scheduler attribute to *True* if you don't want jobs to span placement sets.

   ```
   Qmgr: set sched do_not_span_psets = True
   ```

9. Set the only_explicit_psets attribute to *True* if you don't want a scheduler to create placement sets from unset resources.

   ```
   Qmgr: set sched only_explicit_psets = True
   ```

10. For ease of reviewing placement set information, you can add the name of each resource used in each vnode's pnames attribute:

    ```
    Qmgr: active node <vnode name>,<vnode name>,...
    Qmgr: set node pnames += <resource name>
    ```

    or

    ```
    Qmgr: set node pnames = <resource list>
    ```

    For example:

    ```
    Qmgr: set node pnames = "board,boardpair,iruquadrant,iruhalf,iru,rack"
    ```

We recommend using the parent vnode for any placement set information that is invariant for a given host.

Resources used only for defining placement sets, and not for allocation to jobs, do not need to be listed in the `resources:` line in `<sched_priv directory>/sched_config`. So for example if you create a resource just for defining placement sets, and jobs will not be requesting this resource, you do not need to list it in the `resources:` line.

4.9.32.7 Examples of Creating Placement Sets

4.9.32.7.i Cluster with Four Switches

This cluster is arranged as shown with vnodes 1-4 on Switch1, vnodes 5-10 on Switch2, and vnodes 11-24 on Switch3. Switch1 and Switch2 are on Switch4.

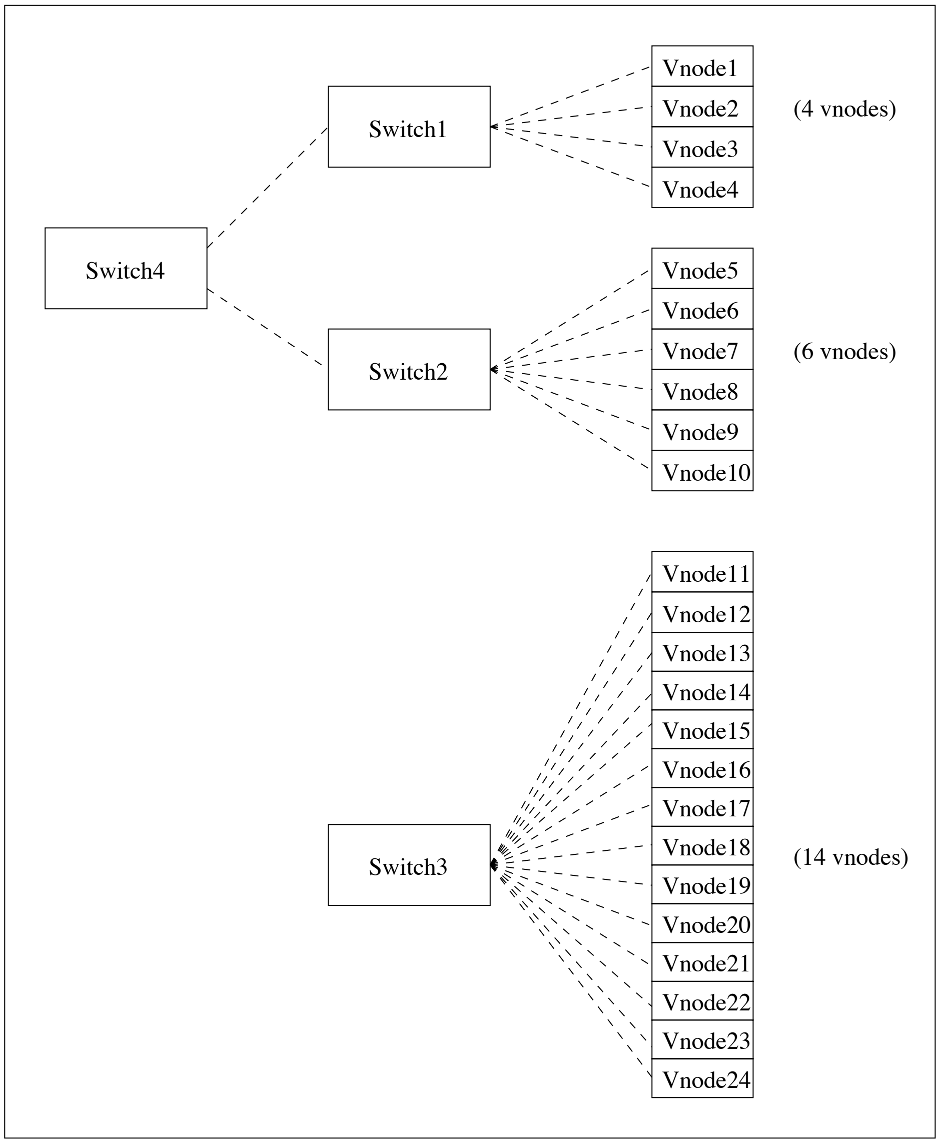


Figure 4-1:Cluster with Four Switches

To make the placement sets group the vnodes as they are grouped on the switches:

Create a custom resource called *switch*. The -h flag makes the resource requestable:

```
Qmgr: create resource switch  type=string_array, flag=h
```

On vnodes[1-4] set:

```
Qmgr: set node <vnode name> resources_available.switch="switch1,switch4"
```

On vnodes[5-10] set:

```
Qmgr: set node <vnode name> resources_available.switch="switch2,switch4"
```

On vnodes[11-24] set:

```
Qmgr: set node <vnode name> resources_available.switch="switch3"
```

On the server set:

```
Qmgr: set server node_group_enable=True
Qmgr: set server node_group_key=switch
```

So you have 4 placement sets:

The placement set "switch1" has 4 vnodes

The placement set "switch2" has 6 vnodes

The placement set "switch3" has 14 vnodes

The placement set "switch4" has 10 vnodes

PBS will try to place a job in the smallest available placement set. Does the job fit into the smallest set (switch1)? If not, does it fit into the next smallest set (switch2)? This continues until it finds one where the job will fit.

4.9.32.7.ii Example of Configuring Placement Sets on a Multi-vnode Machine

For information on how to configure vnodes via Version 2 configuration files, see section 3.4.3, “Version 2 Vnode Configuration Files”, on page 44.

In this example, we define a new placement set using the new resource "NewRes". We create a file called `SetDefs` that contains the changes we want.

1. Create the new resource:
   ```
   Qmgr: create resource NewRes type=string_array, flag=h
   ```
2. Add NewRes to the server's node_group_key
   ```
   Qmgr: set server node_group_key+="NewRes"
   ```
3. Add NewRes to the value of the pnames attribute for the parent vnode. This makes the name of the resource you used easily available. Add a line like this to `SetDefs`:
   ```
   host3:  resources_available.pnames =...,NewRes
   ```
4. For each vnode, V, that's a member of a new placement set you're defining, add a line of the form:
   ```
   V: resources_available.NewRes = <value1[,...]>
   ```
   All the vnodes in the new set should have lines of that form, with the same resource value, in the new configuration file.

   Here the value of the resource is "P" and/or "Q".

   We'll put vnodes A, B and C into one placement set, and vnodes B, C and D into another.
   ```
   A:  resources_available.NewRes2 = P
   B:  resources_available.NewRes2 = P,Q
   C:  resources_available.NewRes2 = P,Q
   D:  resources_available.NewRes2 = Q
   ```
   For each new placement set you define, use a different value for the resource.
5. Add `SetDefs` and tell MoM to read it, to make a Version 2 vnode configuration file `NewConfig`:
   ```
   pbs_mom -s insert NewConfig SetDefs
   ```
6. Stop and restart the MoM. For Linux, see “Restarting and Reinitializing MoM” on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see “Restarting MoMs” on page 173 in the PBS Professional Installation & Upgrade Guide.

4.9.32.7.iii Example of Placement Sets Using Colors

A placement pool is defined by two resources: `colorset1` and `colorset2`, by using "node_group_key=`colorset1,colorset2`".

If a vnode has the following values set:

```
resources_available.colorset1=blue, red
resources_available.colorset2=green
```

The placement pool contains at least three placement sets. These are:

{resources_available.colorset1=blue}

{resources_available.colorset1=red}

{resources_available.colorset2=green}

This means the vnode is in all three placement sets. The same result would be given by using one resource and setting it to all three values, e.g. `colorset=blue,red,green`.

Example: We have five vnodes `v1 - v5:`

```
v1 color=red host=mars
v2 color=red host=mars
v3 color=red host=venus
v4 color=blue host=mars
v5 color=blue host=mars
```

The placement sets are defined by

```
node_group_key=color
```

The resulting node groups would be: `{v1, v2, v3}, {v4, v5}`

4.9.32.7.iv Simple Switch Placement Set Example

Say you have a cluster with two high-performance switches each with half the vnodes connected to it. Now you want to set up placement sets so that jobs will be scheduled only onto the same switch.

First, create a new resource called "*switch*". See section 5.14.2, "Defining New Custom Resources", on page 259.

Next, we need to enable placement sets and specify the resource to use:

```
Qmgr: set server node_group_enable=True
Qmgr: set server node_group_key=switch
```

Now, set the value for switch on each vnode:

```
Qmgr: active node vnode1,vnode2,vnode3
Qmgr: set node resources_available.switch=A
Qmgr: active node vnode4,vnode5,vnode6
Qmgr: set node resources_available.switch=B
```

Now there are two placement sets:

switch=*A*: {vnode1, vnode2, vnode3}

switch=*B*: {vnode4, vnode5, vnode6}

4.9.32.8 Placement Sets and Reservations

When PBS chooses a placement set for a reservation, it makes the same choices as it would for a regular job. It fits the reservation into the smallest possible placement set. See section 4.9.32.4.ii, "Order of Placement Set Consideration Within Pool", on page 174.

When a reservation is created, it is created within a placement set, if possible. If no placement set will satisfy the reservation, placement sets are ignored. The vnodes allocated to a reservation are used as one single placement set for jobs in the reservation; they are not subdivided into smaller placement sets. A job within a reservation runs within the single placement set made up of the vnodes allocated to the reservation.

4.9.32.9 Placement Sets and Load Balancing

If you configure both placement sets and load balancing, the net effect is that vnodes that are over their load limit will be removed from consideration.

4.9.32.10 Viewing Placement Set Information

You can find information about placement sets in the following places:

- The server's node_group_enable attribute shows whether placement sets are enabled
- The server's node_group_key attribute contains the names of resources used for that queue's placement pool
- Each queue's node_group_key attribute contains the names of resources used for that queue's placement pool
- Each vnode's pnames attribute can contain the names of resources used for placement sets, if properly set
- A scheduler's do_not_span_psets attribute shows whether jobs are allowed to span placement sets
- A scheduler's only_explicit_psets attribute shows placement sets are created using unset resources
- PBS-generated MoM configuration files contain names and values of resources

4.9.32.11 Placement Set Caveats and Advice

- If there is a vnode-level platform-specific resource set on the vnodes on a multi-vnode machine, then node_group_key should probably include this resource, because this will enable PBS to run jobs in more logical sets of vnodes.
- If the user specifies a job-specific placement set, for example `-lplace=group=switch`, but the job cannot statically fit into any switch placement set, then the job will still run, but not in a switch placement set.
- The pnames vnode attribute is for displaying to the administrator the resources used for placement sets. This attribute is not used by PBS.

4.9.32.11.i Non-backward-compatible Change in Node Grouping

Given the following example configuration:

vnode1: switch=A

vnode2: switch=A

vnode3: switch=B

vnode4: switch=B

vnode5: switch unset

```
Qmgr: s s node_group_key=switch
```

There is no change in the behavior of jobs submitted with `qsub -l ncpus=1`

version 7.1: The job can run on any node: node1, ..., node5

version 8.0: The job can run on any node: node1, ..., node5

Example of 8.0 and later behavior: jobs submitted with `qsub -lnodes=1`

version 7.1: The job can only run on nodes: node1, node2, node3, node4. It will never use node5

version 8.0: The job can run on any node: node1, ..., node5

Overall, the change for version 8.0 was to include every vnode in placement sets (when enabled). In particular, if a resource is used in node_group_key, PBS will treat every vnode as having a value for that resource, hence every vnode will appear in at least one placement set for every resource. For vnodes where a string resource is "unset", PBS will behave as if the value is "".

4.9.32.12 Attributes and Parameters Affecting Placement Sets

do_not_span_psets

Scheduler attribute. Specifies whether or not this scheduler requires the job to fit within one of the existing placement sets. When do_not_span_psets is set to *True*, a scheduler will require the job to fit within a single existing placement set. A scheduler checks all placement sets, whether or not they are currently in use. If the job fits in a currently-used placement set, the job must wait for the placement set to be available. If the job cannot fit within a single placement set, it will not run.

When this attribute is set to *False*, a scheduler first attempts to place the job in a single placement set. All existing placement sets are checked. If the job fits in an occupied placement set, the job waits for the placement set to be available. If there is no existing placement set, occupied or empty, into which the job could fit, the job runs regardless of placement sets, running on whichever vnodes can satisfy the job's resource request.

Format: *Boolean*

Default value: *False* (This matches behavior of PBS 10.4 and earlier)

Example: To require jobs to fit within one placement set:

```
Qmgr: set sched do_not_span_psets=True
```

node_group_enable

Server attribute. Specifies whether placement sets are enabled.

Format: *Boolean*

Default: *False*

node_group_key

Server and queues have this attribute. Specifies resources to use for placement set definition. Queue's attribute overrides server's attribute.

Format: *string_array*

Default: Unset

only_explicit_psets

Scheduler attribute. Specifies whether placement sets are created using unset resources. If *False*, for each defining resource, if there are vnodes where the value of the resource is unset, PBS creates a placement set for the series defined by that resource. If *True*, PBS does not create placement sets for resources that are unset.

Format: *Boolean*

Default: *False*

4.9.32.13 Errors and Logging

If do_not_span_psets is set to *True*, and a job requests more resources than are available in one placement set, the following happens:

- The job's comment is set to the following:
  ```
  "Not Running: can't fit in the largest placement set, and can't span psets"
  ```
- The following message is printed to the scheduler's log:
  ```
  "Can't fit in the largest placement set, and can't span placement sets"
  ```

4.9.33 Using Preemption

PBS provides the ability to preempt currently running jobs in order to run higher-priority work. This is called *preemption* or *preemptive scheduling*. PBS has two different approaches to specifying preemption:

- You can define a set of preemption priorities for all jobs. Jobs that have high preemption priority preempt those with low preemption priority. Preemption priority is mostly independent of execution priority. See section 4.9.33.7, “Preemption Levels”, on page 186.
- You can specify a set of preemption targets for each job. You can also set defaults for these targets at the server and queues. Preemption targets are jobs in specific queues or that have requested specific resources. See section 4.9.33.4, “Using Preemption Targets”, on page 184.

Preemption is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

4.9.33.1 Glossary

Preempt

Stop one or more running jobs in order to start a higher-priority job

Preemption level

Job characteristic that determines preemption priority. Levels can be things like being in an express queue, starving, having an owner who is over a soft limit, being a normal job, or having an owner who is over a fair-share allotment

Preemption method

The method by which a job is preempted. This can be checkpointing, suspension, requeueing, or deletion

Preemption priority

How important this job is compared to other jobs, when considering whether to preempt

Preemption Target

A preemption target is a job in a specified queue or a job that has requested a specified resource. The queue and/or resource is specified in another job's Resource_List.preempt_targets.

4.9.33.2 Preemption Parameters and Attributes

The scheduler parameters that control preemption are defined in `<sched_priv directory>/sched_config`. A scheduler also has attributes that control preemption; they can be set via `qmgr`. Parameters and attributes that control preemption are listed here:

preemptive_sched

Parameter. Enables job preemption.

Format: *String*

Default: *True all*

preempt_order

Attribute. Defines the order of preemption methods which this scheduler will use on jobs. Can contain any of *S*, *C*, *R*, and *D*, in any order.

Format: *String*, as quoted list

Default: "*SCR*"

preempt_prio

Attribute. Specifies the ordering of priority of different preemption levels.

Format: *String*, as quoted list

Default: "*express_queue, normal_jobs*"

preempt_queue_prio

Attribute. Specifies the minimum queue priority required for a queue to be classified as an express queue.

Format: *Integer*

Default: *150*

preempt_sort

Attribute. Whether jobs most eligible for preemption will be sorted according to their start times. Allowable values: "*min_time_since_start*". The first job preempted will be that with most recent start time.

Format: *String*

Default: *min_time_since_start*

preempt_targets

Resource that a job can request or inherit from the server or a queue. The preempt_targets resource lists one or more queues and/or one or more resources. Jobs in those queues, and jobs that request those resources, are the jobs that can be preempted.

restrict_res_to_release_on_suspend

Server attribute. Comma-separated list of consumable resources to be released when jobs are suspended. If unset, all consumable resources are released on suspension. See section 5.9.6.2, "Job Suspension and Resource Usage", on page 252 and "Server Attributes" on page 283 of the PBS Professional Reference Guide.

Format: *string_array*

Default: *unset*

Python type: *list*

resources_released

Job attribute. Listed by vnode, consumable resources that were released when the job was suspended. Populated only when restrict_res_to_release_on_suspend server attribute is set. See section 5.9.6.2, "Job Suspension and Resource Usage", on page 252 and "Job Attributes" on page 330 of the PBS Professional Reference Guide.

Format: String of the form: *(<vnode>:<resource name>=<value>:<resource name>=<value>:...)+(<vnode>:<resource name>=<value>:...)*

Python type: *str*

resource_released_list

Job attribute. Sum of each consumable resource requested by the job that was released when the job was suspended. Populated only when restrict_res_to_release_on_suspend server attribute is set. See section 5.9.6.2, "Job Suspension and Resource Usage", on page 252 and "Job Attributes" on page 330 of the PBS Professional Reference Guide.

Format: String of the form: *resource_released_list.<resource name>=<value>,resource_released_list.<resource name>=<value>, ...*

sched_preempt_enforce_resumption

Scheduler attribute. Specifies whether this scheduler creates a special execution priority class for preempted jobs. If so, this scheduler runs these jobs just after any higher-priority jobs. See section 4.9.16, "Calculating Job Execution Priority", on page 136.

Format: *Boolean*

Default: *False*

Python type: *pbs.pbs_resource*

4.9.33.3 How Preemption Works

If preemption is enabled, a scheduler uses preemption as part of its normal pattern of examining each job and figuring out whether or not it can run now. If a job with high preemption priority cannot run immediately, a scheduler looks for jobs with lower preemption priority. A scheduler finds jobs in the lowest preemption level that have been started the most recently. A scheduler preempts these jobs and uses their resources for the higher-priority job. A scheduler tracks resources used by lower-priority jobs, looking for enough resources to run the higher-priority job. If a scheduler cannot find enough work to preempt in order to run a given job, it will not preempt any work.

A job running in a reservation cannot be preempted.

A job's preemption priority is determined by its preemption level.

4.9.33.4 Using Preemption Targets

You can restrict the set of jobs that can be preempted by an entity, by setting that entity's preempt_targets resource to a list of jobs and/or queues that can be preempted. This resource is a string array which can contain a list of queues and/or job resources. You specify job resources as *Resource_List.<resource>=<value>*.

Syntax:

preempt_targets="Queue=<queue name>[,Queue=<queue name>],Resource_List.<resource name>=<value>[,Resource_List.<resource name>=<value>]"

or

preempt_targets=None

The preempt_targets resource has the following keywords:

Queue=<queue name>

Jobs in the specified queue are eligible to be preempted. "Queue" is case-insensitive.

None

The job, or the jobs at the queue or server whose preempt_targets resource is set to *NONE* cannot preempt other jobs. "None" is case-insensitive.

In order for a job to preempt another job, the job to be preempted must have lower preemption priority than the preempting job.

4.9.33.4.i Setting Job Preemption Targets

Preemption targets work as a restriction on which jobs can be preempted by a particular job. If a job has requested preempt_targets, a scheduler searches for lower-priority jobs among only the jobs specified in that job's preempt_targets. If a job has not requested preempt_targets, the scheduler searches among all jobs. For example, if a scheduler is trying to run JobA, and JobA requests `preempt_targets="queue=Queue1,Resource_List.arch=linux"`, JobA is eligible to preempt only those jobs in Queue1 and/or that request `arch=linux`. In addition, JobA can only preempt jobs with lower preemption priority than JobA.

You can prevent a job from preempting any other job in the complex by setting its preemption_targets to the keyword "None" (case-insensitive).

You can set preempt_targets for a job during submission:

```
-l preempt_targets=...
```

You can set preempt_targets via `qalter`:

```
qalter -l preempt_targets=...
```

4.9.33.4.ii Setting Queue Preemption Targets

You can set the default preemption target for jobs in a queue. For example, you can specify that the jobs in a particular queue can preempt the jobs in one or more listed queues:

qmgr -c 'set queue <queue name> resources_default.preempt_targets="QUEUE=<queue name>,QUEUE=<queue name>"'

For example:

```
qmgr -c 'set queue high_prio_queue resources_default.preempt_targets="QUEUE=queueA,QUEUE=queueB"'
```

You can prevent the jobs in a queue which don't explicitly request preempt_targets from preempting other jobs by setting the queue's default preempt_targets to "NONE":

qmgr -c "set queue <queue name> resources_default.preempt_targets=NONE"

For example:

```
qmgr -c "set queue lowest_prio_queue resources_default.preempt_targets=NONE"
```

4.9.33.4.iii Setting Default Server Preemption Targets

You can set the default preemption target for jobs at a server. For example, you can specify that the jobs at a server can preempt the jobs in one or more listed queues:

qmgr -c 'set server resources_default.preempt_targets="QUEUE=<queue name>,QUEUE=<queue name>"'

For example:

```
qmgr -c 'set server resources_default.preempt_targets="QUEUE=queueA,QUEUE=queueB"'
```

You can prevent the jobs which don't explicitly request preempt_targets from preempting other jobs by setting the server's default preempt_targets to "NONE":

qmgr -c "set server resources_default.preempt_targets=NONE"

For example:

```
qmgr -c "set server resources_default.preempt_targets=NONE"
```

4.9.33.5 Preemption and Job Execution Priority

PBS has an execution class we call *Preempted* for jobs that have been preempted. A scheduler restarts preempted jobs as soon as the preemptor finishes and any other higher-priority jobs finish. See section 4.9.16, “Calculating Job Execution Priority”, on page 136.

4.9.33.6 Triggers for Preemption

If preemption is enabled, preemption is used during the following:

- The normal scheduling cycle
- When you run a job via `qrun`

4.9.33.7 Preemption Levels

A preemption level is a class of jobs, where all the jobs in the class share a characteristic. PBS provides built-in preemption levels, and you can combine them or ignore them as you need, except for the *normal_jobs* class, which is required. The built-in preemption levels are listed in the table below.

Table 4-16: Built-in Preemption Levels

Preemption Level	Description
express_queue	Jobs in express queues. See section 4.9.33.7.ii, "The Express Queues Preemption Level", on page 188
starving_jobs	A job that is starving. See section 4.9.33.7.iv, "The Starving Job Preemption Level", on page 188
normal_jobs	The preemption level into which a job falls if it does not fit into any other specified level. See section 4.9.33.7.v, "The Normal Jobs Preemption Level", on page 189
fairshare	When the entity owning a job exceeds its fairshare limit. See section 4.9.33.7.iii, "The Fairshare Preemption Level", on page 188
queue_softlimits	Jobs which are over their queue soft limits. See section 4.9.33.7.i, "The Soft Limits Preemption Level", on page 187
server_softlimits	Jobs which are over their server soft limits. See section 4.9.33.7.i, "The Soft Limits Preemption Level", on page 187

You can specify the relative priority of each preemption level, by listing the levels in the desired order in the preempt_prio scheduler attribute. Placing a level earlier in the list, meaning to the left, gives it higher priority. For example, if your list is `"express_queue", "normal_jobs", "server_softlimits"`, you are giving the highest priority to jobs in express queues, and the lowest priority to jobs that are over their server soft limits. You can list levels in any order, but be careful not to work at cross-purposes with your execution priority. See section 4.9.16, "Calculating Job Execution Priority", on page 136.

The default value for preempt_prio is the following:

```
preempt_prio: "express_queue, normal_jobs"
```

If you do not list a preemption level in the preempt_prio scheduler attribute, the jobs in that level are treated like normal jobs. For example, if you do not list server_softlimits, then jobs that are over their server soft limits are treated like jobs in the normal_jobs level.

You can create new levels that are combinations of the built-in levels. For example, you can define a level which is *"express_queue + server_softlimits"*. This level contains jobs that are in express queues and are over their server soft limits. You would probably want to place this level just to the right of the express_queue level, meaning that these jobs could be preempted by jobs that are in express queues but are not over their server soft limits.

You can give two or more levels the same priority. To do this, put a plus sign ("+") between them, and do not list either level separately in preempt_prio. You are creating a new level that includes all the built-in levels that should have the same priority. For example, to list express queue jobs as highest in priority, then fairshare and starving jobs at the next highest priority, then normal jobs last, create a new level that contains the fairshare and starving_jobs levels:

```
preempt_prio: "express_queue, fairshare+starving_jobs, normal_jobs"
```

You can be specific about dividing up jobs: if you want jobs in the express queue to preempt jobs that are also in the express queue but are over their server soft limits, list each level separately:

```
preempt_prio: "express_queue, express_queue+server_softlimits, normal_jobs"
```

However, be careful not to create a runaway effect by placing levels that are over limits before those that are not, for example, `express_queue+server_softlimits` to the left of `express_queue`.

You must list normal_jobs in the preempt_prio scheduler attribute.

4.9.33.7.i The Soft Limits Preemption Level

You can set a limit, called a *hard limit*, on the number of jobs that can be run or the amount of a resource that can be consumed by a person, a group, or by everyone, and this limit can be applied at the server and at each queue. If you set such a limit, that is the greatest number of jobs that will be run, or the largest amount of the resource that will be consumed.

You can also set a *soft limit* on the number of jobs that can be run or the amount of a resource that can be consumed. This soft limit should be lower than the hard limit, and should mark the point where usage changes from being normal to being "extra, but acceptable". Usage in this "extra, but acceptable" range can be treated by PBS as being lower priority than the normal usage. PBS can preempt jobs that are over their soft limits. The difference between the soft limit and the hard limit provides a way for users or groups to use resources as long as no higher-priority work is waiting.

Example 4-18: Using group soft limits

One group of users, group A, has submitted enough jobs that the group is over their soft limit. A second group, group B, submits a job and are under their soft limit. If preemption is enabled, jobs from group A are preempted until the job from group B can run.

Example 4-19: Using soft limits on number of running jobs

Given the following:

- You have three users, UserA, UserB, and UserC
- Each has a soft limit of 3 running jobs
- UserA runs 3 jobs
- UserB runs 4 jobs
- UserC submits a job to an express queue

This means:

- UserB has 1 job over the soft limit, so UserB's jobs are eligible for preemption by UserC's job

Example 4-20: Using soft limits on amount of resource being used

Given the following:

- Queue soft limit for ncpus is 8
- UserA's jobs use 6 CPUs
- UserB's jobs use 10 CPUs

This means:

- UserB is over their soft limit for CPU usage
- UserB's jobs are eligible for preemption

To use soft limits in preemption levels, you must define soft limits. Soft limits are specified by setting server and queue limit attributes. The attributes that control soft limits are:

max_run_soft

Sets the soft limit on the number of jobs that can be running

max_run_res_soft.<resource name>

Sets the soft limit on the amount of a resource that can be consumed by running jobs

Soft limits are enforced only when they are used as a preemption level.

To use soft limits as preemption levels, add their keywords to the preempt_prio attribute:

- To create a preemption level for those over their soft limits at the server level, add "`server_softlimits`" to the preempt_prio attribute.
- To create a preemption level for those over their soft limits at the queue level, add "`queue_softlimits`" to the preempt_prio attribute.
- To create a preemption level for those over their soft limits at both the queue and server, add "`server_softlimits+queue_softlimits`" to the preempt_prio attribute.

The jobs of a user or group are over their soft limit only as long as the number of running jobs or the amount of resources used by running jobs is over the soft limit. If some of these jobs are preempted or finish running, and the soft limit is no longer exceeded, the jobs of that user or group are no longer over their soft limit, and no longer in that preemption level. For example, if the soft limit is 3 running jobs, and UserA runs 4 jobs, as soon as one job is preempted and only 3 of UserA's jobs are running, UserA's jobs are no longer over their soft limit.

For a complete description of the use of these attributes, see section 5.15.1.4, "Hard and Soft Limits", on page 293.

4.9.33.7.ii The Express Queues Preemption Level

The express_queue preemption level applies to jobs residing in express queues. An express queue is an execution queue with priority at or above the value set in the preempt_queue_prio scheduler attribute. The default value for this parameter is *150*.

Express queues do not require the by_queue scheduler parameter to be *True*.

If you will use the express_queue preemption level, you probably want to configure at least one express queue, along with some method of moving jobs into it. See section 2.3, "Queues", on page 23.

If you have more than one express queue, and they have different priorities, you are effectively creating separate sub-levels for express queues. Jobs in a higher-priority express queue have greater preemption priority than jobs in lower-priority express queues.

See "preempt_queue_prio" on page 256 of the PBS Professional Reference Guide.

4.9.33.7.iii The Fairshare Preemption Level

The fairshare preemption level applies to jobs owned by entities who are over their fairshare allotment. For example, if each of five users has 20 percent of the fairshare tree, and UserA is using 25 percent of the resources being tracked for fairshare, UserA's jobs become eligible for preemption at the fairshare preemption level.

To use the fairshare preemption level, you must enable fairshare. See section 4.9.19, "Using Fairshare", on page 140.

4.9.33.7.iv The Starving Job Preemption Level

The starving_jobs preemption level applies to jobs that are starving. Starving jobs are jobs that have been waiting at least a specified amount of time to run.

To use the starving_jobs preemption level, you must enable starving:

- Set the `<sched_priv directory>/sched_config` help_starving_jobs parameter to *True*
- Set the amount of time that a job must wait before it is starving in the max_starve scheduler parameter
- Optionally, use eligible time for waiting time. See section 4.9.13, "Eligible Wait Time for Jobs", on page 128.

See section 4.9.48, "Starving Jobs", on page 225.

4.9.33.7.v The Normal Jobs Preemption Level

One special class, normal_jobs, is the default class for any job not otherwise specified. If a job does not fall into any of the specified levels, it is placed in normal_jobs.

Example 4-21: Starving jobs have the highest priority, then normal jobs, then jobs whose entities are over their fairshare limit:

```
preempt_prio: "starving_jobs, normal_jobs, fairshare"
```

Example 4-22: Starving jobs whose entities are also over their fairshare limit are lower priority than normal jobs:

```
preempt_prio: "normal_jobs, starving_jobs+fairshare"
```

4.9.33.8 Selecting Preemption Level

PBS places each job in the most exact preemption level, or the highest preemption level that fits the job.

Example 4-23: We have a job that is starving and over its server soft limits. The job is placed in the "starving_jobs" level:

```
preempt_prio: "starving_jobs, normal_jobs, server_softlimits"
```

Example 4-24: We have a job that is starving and over its server soft limits. The job is placed in the "starving_jobs+server_softlimits" level:

```
preempt_prio: "starving_jobs, starving_jobs+server_softlimits, normal_jobs, server_softlimits"
```

4.9.33.9 Sorting Within Preemption Level

If there is more than one job within the preemption level chosen for preemption, PBS chooses jobs within that level according to their start time. By default, PBS preempts the job which started running most recently. .

For example, if we have two jobs where job A started running at 10:00 a.m. and job B started running at 10:30 a.m:

- The default behavior preempts job B

The allowable value for the preempt_sort attribute is "*min_time_since_start*".

The default value for the preempt_sort attribute is "*min_time_since_start*".

4.9.33.10 Preemption Methods

A scheduler can preempt a job in one of the following ways:

- Suspend the job
- Checkpoint the job
- Requeue the job
- Delete the job

A scheduler tries to preempt a job using the methods listed in the order you specify. This means that if you specify that the order is "checkpoint, suspend, requeue, delete", the scheduler first tries to checkpoint the job, and if it cannot, it tries to suspend the job, and if it cannot do that, it tries to requeue the job, and if it cannot requeue the job, it tries to delete it.

You can specify the order of these attempts in the preempt_order scheduler attribute.

The preempt_order attribute defines the order of preemption methods which a scheduler uses on jobs. This order can change depending on the percentage of time remaining on the job. The ordering can be any combination of *S, C*, *R,* and *D* (for suspend, checkpoint, requeue, and delete).

The contents is an ordering, for example "SCRD" optionally followed by a percentage of time remaining and another ordering.

The format is a quoted list("").

Example 4-25: PBS should first attempt to use suspension to preempt a job, and if that is unsuccessful, then requeue the job:

```
preempt_order: "SR"
```

Example 4-26: If the job has between 100-81% of requested time remaining, first try to suspend the job, then try checkpoint, then requeue. If the job has between 80-51% of requested time remaining, then attempt suspend then checkpoint; and between 50% and 0% time remaining just attempt to suspend the job:

```
preempt_order: "SCR 80 SC 50 S"
```

The default value for preempt_order is "*SCR*".

You cannot repeat a method within a percentage specification. Note that in the example above, the *S* method appears only once per percentage.

4.9.33.10.i Preemption Via Checkpoint

When a job is preempted via checkpointing, MoM runs the checkpoint_abort script, and PBS kills and requeues the job. When a scheduler elects to run the job again, the scheduler runs the restart script to restart the job from where it was checkpointed.

To preempt via checkpointing, you must define both of the following:

- The checkpointing action in the MoM's checkpoint_abort $action parameter that is to take place when the job is preempted
- The restarting action in the MoM's restart $action parameter that is to take place when the job is restarted

To do this, you must supply checkpointing and restarting scripts or equivalents, and then configure the MoM's checkpoint_abort and restart $action parameters. Do not use the $action checkpoint MoM parameter; it is used when the job should keep running.

See section 9.3, "Checkpoint and Restart", on page 420.

4.9.33.10.ii Preemption Via Suspension

Jobs are normally suspended via the SIGSTOP signal and resumed via the SIGCONT signal. An alternate suspend or resume signal can be configured in MoM's $suspendsig configuration parameter. See "pbs_mom" on page 72 of the PBS Professional Reference Guide.

4.9.33.10.iii Suspended Jobs and Resources

Suspended jobs will hold onto some memory and disk space. Suspended jobs may hold application licenses if the application releases them only when it exits. See section 5.9.6.2.iv, "Suspension/resumption Resource Caveats", on page 253.

4.9.33.10.iv Preemption Via Requeue

When a job is preempted and requeued, the job stops execution and is requeued. A requeued job's eligible time is preserved. The amount of time allowed to requeue a job is controlled by the job_requeue_timeout server attribute. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

A job that is not eligible to be requeued, meaning a job that was submitted with "`-r n`", will not be selected to be preempted via requeue.

4.9.33.10.v Preemption via Deletion

When a job is preempted via deletion, the job is deleted. It is not requeued. Deletion is not in the default preemption order.

4.9.33.11 Enabling Preemption

Preemptive scheduling is enabled by setting parameters in a scheduler's configuration file `<sched_priv directory>/sched_config`.

To enable preemption, you must do the following:

1. Specify the preemption levels to be used by setting preempt_prio to desired preemption levels (the default is `"express_queue, normal_jobs"`)

   The preempt_prio attribute must contain an entry for normal_jobs.

2. Optional: specify preemption order by setting preempt_order
3. If you will use the fairshare preemption level, configure fairshare. See section 4.9.19, "Using Fairshare", on page 140.
4. If you will use the starving_jobs preemption level, configure starving. See section 4.9.33.7.iv, "The Starving Job Preemption Level", on page 188.
5. If you will use the server_softlimits and/or queue_softlimits preemption levels, configure server and/or queue soft limits. See section 4.9.33.7.i, "The Soft Limits Preemption Level", on page 187.
6. Enable preemption by setting preemptive_sched to *True* . It is *True* by default.
7. Choose whether to use preemption during primetime, non-primetime, or all of the time. The default is ALL. If you want separate behavior for primetime and non-primetime, specify each separately. For example:

   ```
   preemptive_sched: True prime
   preemptive_sched: False non_prime
   ```

4.9.33.12 Preemption Example

Below is an example of (part of) a scheduler's configuration file, showing an example configuration for preemptive scheduling.

```
# turn on preemptive scheduling
#
preemptive_sched:       TRUE ALL
#
# set the queue priority level for express queues
#
preempt_queue_prio:     150
#
# specify the priority of jobs as: express queue
# (highest) then starving jobs, then normal jobs,
# followed by jobs who are starving but the user/group
# is over a soft limit, followed by users/groups over
# their soft limit but not starving
#
preempt_prio: "express_queue, starving_jobs, normal_jobs, starving_jobs+server_softlimits,
    server_softlimits"
#
# specify when to use each preemption method.
# If the first method fails, try the next
# method. If a job has between 100-81% time
# remaining, try to suspend, then checkpoint
# then requeue. From 80-51% suspend and then
# checkpoint, but don't requeue.
# If between 50-0% time remaining, then just
# suspend it.
#
preempt_order: "SCR 80 SC 50 S"
```

4.9.33.13 Preemption Caveats and Recommendations

- Do not use preemption via deletion along with a runjob hook that can reject the job often. In this case jobs are deleted and the preempting job is rejected.
- When using any of the fairshare, soft limits, express queue, or starving jobs preemption levels, be sure to enable the corresponding PBS feature. For example, when using preemption with the fairshare preemption level, be sure to turn fairshare on. Otherwise, you will be using stale fairshare data to preempt jobs.
- It's important to be careful about the order of the preemption levels and the sizes of the limits at queue and server. For example, if you make users who are over their server soft limits have higher priority than users who are over their queue soft limits, and you set the soft limit higher at the server than at the queue, you can end up with users who have more jobs running preempting users who have fewer jobs running.

  In this example, a user with more jobs preempts a user with fewer jobs.
- If a subjob is not running because its array job has hit the limit in max_run_subjobs, the subjob is not eligible to start and PBS does not try to use preemption to start the subjob.

Given the following:

- preempt_prio attribute contains "`server_softlimits, queue_softlimits`"
- Server soft limit is 5
- Queue soft limit is 3
- User1 has 6 jobs running
- User2 has 4 jobs running

This means:

- User1 has higher priority, because User1 is over the server soft limit
- User1's jobs can preempt User2's jobs

To avoid this scenario, you could set the preempt_prio attribute to contain "`server_softlimits, queue_softlimits, server_softlimits+queue_softlimits`". In this case User1 would have lower priority, because User1 is over both soft limits.

- Preemption priority is mostly independent of execution priority. You can list preemption levels in any order in preempt_prio, but be careful not to work at cross-purposes with your execution priority. Be sure that you are not preempting jobs that have higher execution priority. See section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- Using preemption with strict ordering and backfilling may change which job is being backfilled around.
- When a job is suspended via checkpoint or requeue, it loses it queue wait time. This does not apply to preemption via suspension.
- If a high-priority job has been selected to preempt lower-priority jobs, but is rejected by a runjob hook, a scheduler undoes the preemption of the low-priority jobs. Suspended jobs are resumed, and checkpointed jobs are restarted.
- A job that has requested an AOE will not preempt another job, regardless of whether the job's requested AOE matches an instantiated AOE. Running jobs are not preempted by jobs requesting AOEs.
- If a job is checkpointed by a scheduler because it was preempted, a scheduler briefly applies a hold, but releases the hold immediately after checkpointing the job, and runs the restart script when the job is scheduled to run.
- When jobs are preempted via requeueing, the requeue can fail if the job being preempted takes longer than the allowed timeout. See section 9.6.3, “Setting Job Requeue Timeout”, on page 447.
- When you issue "`qrun <job ID>`", without the `-H` option, the selected job has preemption priority between Reservation and Express, for that scheduling cycle. However, at the following scheduling cycle, the preemption priority of the selected job returns to whatever it would be without `qrun`.
- When sched_preempt_enforce_resumption is set to *True*, all suspended jobs become top jobs, regardless of their setting for topjob_ineligible.
- PBS will not use suspension or checkpointing to preempt a job that requests a value for eoe.
- Do not use suspend/resume and the cgroups hook on the same hosts. Doing so may result in jobs being rejected.

4.9.34 Using Primetime and Holidays

Often it is useful to run different scheduling policies for specific intervals during the day or work week. PBS provides a way to specify two types of interval, called *primetime* and *non-primetime*.

Between them, primetime and non-primetime cover all time. There is no time slot that is neither primetime nor non-primetime. This includes dedicated time. Primetime and/or non-primetime overlap dedicated time.

You can use non-primetime for such tasks as running jobs on desktop clusters at night.

4.9.34.1 How Primetime and Holidays Work

By default, primetime is 24/7. A scheduler looks in the `<sched_priv directory>/holidays` file for definitions of primetime, non-primetime, and holidays. You can edit this file to define your holidays and primetime.

Many PBS scheduling parameters can be specified separately for primetime, non-primetime, or all of the time. This means that you can use, for example, fairshare during primetime and no fairshare during non-primetime. These parameters have a time slot default of all, meaning that if enabled, they are in force all of the time.

A scheduler applies the parameters defined for primetime during the primetime time slots, and applies parameters defined for non-primetime during the non-primetime time slots. Any scheduler parameters defined for all time are run whether it is primetime or not.

Any holidays listed in the holidays file are treated as non-primetime. To have a holiday treated like a normal workday or weekend, do not list it in the holidays file.

There are default behaviors for primetime and non-primetime, but you can set up the behavior you want for each type. The names "primetime" and "non-primetime" are meant to be informative, but they are arbitrary. The default for primetime is 24/7, meaning that primetime is all of the time by default. Example holidays are provided, but commented out, in the `holidays` file.

You can define primetime and non-primetime queues. Jobs in these queues can run only during the designated time. Queues that are not defined specifically as primetime or non-primetime queues are called "anytime queues".

4.9.34.2 Configuring Primetime and Non-primetime

In order to use primetime and non-primetime, you must have a `holidays` file with the current year in it.

You can specify primetime and non-primetime time slots by specifying them in the `<sched_priv directory>/holidays` file.

The format of the primetime and non-primetime section of the `holidays` file is the following:

YEAR YYYY

<day> <prime> <nonprime>

<day> <prime> <nonprime>

In *YEAR YYYY, YYYY* is the current year.

Day can be *weekday, monday, tuesday, wednesday, thursday, friday, saturday,* or *sunday.*

Each day line must have all three fields.

Any line that begins with a "*" or a "#" is a comment.

Weekday names must be lowercase.

The ordering of elements in this file is important. The ordering of <day> lines in the holidays file controls how primetime is determined. A later line takes precedence over an earlier line.

For example:

```
weekday        0630    1730
friday         0715    1600
```

means the same as

```
monday         0630    1730
tuesday        0630    1730
wednesday      0630    1730
thursday       0630    1730
friday         0715    1600
```

However, if a specific day is followed by "weekday",

```
friday        0700   1600
weekday       0630   1730
```

the "weekday" line takes precedence, so Friday will have the same primetime as the other weekdays.

Times can be expressed as one of the following:

- *HHMM* with no colons(:)
- The word "`all`"
- The word "`none`"

4.9.34.3 Configuring Holidays

You can specify primetime and non-primetime time slots by specifying them in the `<sched_priv directory>/holidays` file.

You must specify the year, otherwise primetime is in force at all times, and PBS will not recognize any holidays. Specify the year here, where YYYY is the current year:

YEAR YYYY

Holidays are specified in lines of this form:

<day of year> <month day-of-month> <holiday name>

PBS uses the <day of year> field and ignores the <date> string.

Day of year is the julian day of the year between 1 and 365 (e.g. "1").

Month day-of-month is the calendar date, for example "Jan 1".

Holiday name is the name of the holiday, for example "New Year's Day".

4.9.34.4 Example of `holidays` File

```
YEAR    2020
*            Prime   Non-Prime
* Day        Start   Start
*
  weekday    0600    1730
  saturday   none    all
  sunday     none    all
*
* Day of    Calendar      Company Holiday
* Year       Date         Holiday
     1       Jan 1        New Year's Day
    20       Jan 20       Martin Luther King Day
    48       Feb 17       Presidents Day
   146       May 25       Memorial Day
   186       Jul 4        Independence Day
   251       Sep 7        Labor Day
   286       Oct 12       Columbus Day
   316       Nov 11       Veterans Day
   331       Nov 26       Thanksgiving
   360       Dec 25       Christmas Day
```

4.9.34.5 Reference Copy of `holidays` File

A reference copy of the holidays file contains example holidays that are commented out. It is provided in `PBS_EXEC/etc/pbs_holidays.` The file looks like this:

```
* UNCOMMENT AND CHANGE THIS TO THE CURRENT YEAR
*YEAR 1970
*
* Prime/Nonprime Table
*
* Prime Non-Prime
* Day Start Start
*
* UNCOMMENT AND SET THE REQUIRED PRIME/NON-PRIME START TIMES
* weekday 0600 1730
* saturday none all
* sunday none all
*
* Day of Calendar Company
* Year Date Holiday
*

* UNCOMMENT AND ADD CALENDAR HOLIDAYS TO BE CONSIDERED AS NON-PRIME DAYS
* 1 Jan 1 New Year's Day
* 359 Dec 25 Christmas Day
```

4.9.34.6 Defining Primetime and Non-primetime Queues

Jobs in a primetime queue can start only during primetime. Jobs in a non-primetime queue can start only during non-primetime. Jobs in an anytime queue can start at any time.

You define a primetime queue by naming it using the primetime prefix. The prefix is defined in the primetime_prefix scheduler parameter. The default is "*p_*". For example, you could name a primetime queue "*p_queueA*", using the default.

Similarly, you define a non-primetime queue by prefixing the name. The prefix is defined in the nonprimetime_prefix scheduler parameter, and defaults to "*np_*".

4.9.34.7 Controlling Whether Jobs Cross Primetime Boundaries

You can control whether jobs are allowed to start running in one time slot and finish in another, for example when job A starts during primetime and finishes a few minutes into non-primetime. When a job runs past the boundary, it delays the start of a job that is constrained to run only in the later time slot. For example, if job B can run only during non-prime-time, it may have to wait while job A uses up non-primetime before it can start. You can control this behavior for all queues, or you can exempt anytime queues, controlling only primetime and non-primetime queues. You can also specify how much time past the boundary a job is allowed to run.

To prevent a scheduler from starting any jobs which would run past a primetime/non-primetime boundary, set the backfill_prime scheduler parameter to *True.* You can specify this separately for primetime and non-primetime. If you specify it for one type of time slot, it prevents those jobs from crossing the next boundary. For example, if you set the following:

```
backfill_prime True prime
```

jobs in primetime slots are not allowed to cross into non-primetime slots.

If you set the following:

```
backfill_prime True non_prime
```

jobs in non-primetime slots are not allowed to cross into primetime slots.

To exempt jobs in anytime queues from the control of backfill_prime, set the prime_exempt_anytime_queues scheduler parameter to *True*. This means that jobs in an anytime queue are not prevented from running across a primetime/nonprimetime or non-primetime/primetime boundary.

To allow jobs to spill over a certain amount of time past primetime/non-primetime boundaries, but no more, specify this amount of time in the prime_spill scheduler parameter. You can specify separate behavior for primetime and non-primetime jobs. For example, to allow primetime jobs to spill by 20 minutes, but only allow non-primetime jobs to spill by 1minute:

```
prime_spill 00:20:00 prime
prime_spill 00:01:00 non_prime
```

The prime_spill scheduler parameter applies only when backfill_prime is *True*.

4.9.34.8 Logging

A scheduler logs a message at the beginning of each scheduling cycle indicating whether it is primetime or not, and when this period of primetime or non-primetime will end. The message is at log level 0x0100. The message is of this form:

```
"It is primetime and it will end in NN seconds at MM/DD/YYYY HH:MM:SS"
```

or

```
"It is non-primetime and it will end in NN seconds at MM/DD/YYYY HH:MM:SS"
```

4.9.34.9 Scheduling Parameters Affecting Primetime

backfill_prime

This scheduler will not run jobs which would overlap the boundary between primetime and non-primetime.

Format: *Boolean*

Default: *False all*

nonprimetime_prefix

Queue names which start with this prefix will be treated as non-primetime queues. Jobs within these queues will only run during non-primetime.

Format: *String*

Default: *np_*

primetime_prefix

Queue names starting with this prefix are treated as primetime queues. Jobs will only run in these queues during primetime.

Format: *String*

Default: *p_*

prime_exempt_anytime_queues

Determines whether anytime queues are controlled by backfill_prime.

If set to *True*, jobs in an anytime queue will not be prevented from running across a primetime/non-primetime or non-primetime/primetime boundary.

If set to *False*, the jobs in an anytime queue may not cross this boundary, except for the amount specified by their prime_spill setting.

Format: *Boolean*

Default: *False*

prime_spill

Specifies the amount of time a job can spill over from non-primetime into primetime or from primetime into non-primetime. This option can be separately specified for prime- and non-primetime. This option is only meaningful if backfill_prime is *True*.

Format: *Duration*

Default: *00:00:00*

4.9.34.10 Caveats for Primetime and Holidays

- In order to use primetime and non-primetime, you must have a `holidays` file with the current year in it. If there is no `holidays` file with a year in it, primetime is in force all of the time.
- You cannot combine `holidays` files.
- If you use the formula, it is in force all of the time.
- If there is no *YEAR* line in the holidays file, primetime is in force at all times. If there is more than one *YEAR* line, the last one is used.
- If the information for any day is missing or incorrect, primetime is in force for all of that day.

4.9.35 Provisioning

PBS provides automatic provisioning of an OS or application, on vnodes that are configured to be provisioned. When a job requires an OS that is available but not running, or an application that is not installed, PBS provisions the vnode with that OS or application.

You can configure vnodes so that PBS will automatically install the OS or application that jobs need in order to run on those vnodes. For example, you can configure a vnode that is usually running RHEL to run SLES instead whenever the Physics group runs a job requiring SLES. If a job requires an application that is not usually installed, PBS can install the application in order for the job to run.

You can use provisioning for booting multi-boot systems into the desired OS, downloading an OS to and rebooting a diskless system, downloading an OS to and rebooting from disk, instantiating a virtual machine, etc. You can also use provisioning to run a configuration script or install an application.

For a complete description of how provisioning works and how to configure it, see Chapter 7, "Provisioning", on page 329.

4.9.36 Queue Priority

Queues and queue priority play several different roles in scheduling, so this section contains pointers to other sections.

Each queue can have a different priority. A higher value for priority means the queue has greater priority. By default, queues are sorted from highest to lowest priority. Jobs in the highest priority queue will be considered for execution before jobs from the next highest priority queue. If queues don't have different priority, queue order is undefined.

Each queue's priority is specified in its priority attribute By default, the queue priority attribute is unset. There is no limit to the priority that you can assign to a queue, however it must fit within integer size. See “Queue Attributes” on page 313 of the PBS Professional Reference Guide.

4.9.36.1 Configuring Queue Priority

You can specify the priority of each queue by setting a value for its priority attribute:

```
Qmgr: set queue <queue name> priority = <value>
```

4.9.36.2 Using Queue Priority

You can configure a scheduler so that job execution or preemption priority is partly or entirely determined by the priority of the queue in which the job resides. Queue priority can be used for the following purposes:

- Queue priority can be used as a term in the job sorting formula. See section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151
- Queue priority can be used to specify the order in which queues are examined when scheduling jobs. If you want jobs to be examined queue by queue, in order of queue priority, you must specify a different priority for each queue. A queue with a higher value is examined before a queue with a lower value. See section 4.3.5.3.i, “Using Queue Order to Affect Order of Consideration”, on page 67
- You can set up execution priority levels that include jobs in express queues. For information on configuring job priorities in a scheduler, see section 4.9.16, “Calculating Job Execution Priority”, on page 136.
- You can set up preemption levels that include jobs in express queues. For information on preemption, see section 4.9.33, “Using Preemption”, on page 182.

A queue is an express queue if its priority is greater than or equal to the value that defines an express queue. For more about using express queues, see section 4.9.18, “Express Queues”, on page 139.

4.9.36.3 Queue Priority Caveats

- If you use queue priority in the formula and the job is moved to another server through peer scheduling, the queue priority used in the formula will be that of the new queue to which the job is moved.

4.9.37 Reservations

PBS provides a way to reserve specific resources for a defined time period. If you want reservations in which to run jobs, you can make one-time reservations (called *advance reservations*), or you can make a series of reservations (called *standing reservations*), where each one is for the same resources, but for a different time period. Or, if you want to secure resources for a specific (perhaps troublesome) job, you can create a *job-specific reservation* for that job at submission time, while the job is queued, or later while the job is running.

If you want to sequester hosts for maintenance, you can create a *maintenance reservation*. Maintenance reservations block out time on specified machines, preventing jobs from being started where you need to perform maintenance tasks.

Advance, standing, and job-specific reservations are "job reservations", to distinguish them from maintenance reservations.

Reservations are useful for accomplishing the following job-related tasks:

- To get a time slot on a specific host
- To run a job in a specific time slot, meaning at or by a specific time
- To be sure a job will run
- To have a high-priority job run soon
- To make sure that a job doesn't lose access to resources when needs to be re-run

4.9.37.1 Definitions

Advance reservation

A reservation for a set of resources for a specified time. The reservation is available only to the creator of the reservation and any users or groups specified by the creator.

Degraded reservation

A job-specific or advance reservation for which one or more associated vnodes are unavailable.

A standing reservation for which one or more vnodes associated with the soonest occurrence are unavailable.

Job-specific reservation

A reservation created for a specific job, for the same resources that the job requested.

Job-specific ASAP reservation

Reservation created for a specific queued job, for the same resources the job requests. PBS schedules the reservation to run as soon as possible, and PBS moves the job into the reservation. Created when you use `pbs_rsub -Wqmove=<job ID>` on a queued job.

Job-specific now reservation

Reservation created for a specific running job. PBS immediately creates a job-specific now reservation on the same resources as the job is using, and moves the job into the reservation. The reservation is created and starts running immediately when you use `pbs_rsub --job <job ID>` on a running job.

Job-specific start reservation

Reservation created for a specific job, for the same resources the job requests. PBS starts the job according to scheduling policy. When the job starts, PBS creates and starts the reservation, and PBS moves the job into the reservation. Created when you use `qsub -Wcreate_resv_from_job=true` to submit a job or when you `qalter` a job to set the job's create_resv_from_job attribute to *True*.

Maintenance reservation

A reservation designed for performing maintenance on the specified hosts for the specified time. Created using `pbs_rsub --hosts <host list>`.

Occurrence of a standing reservation

An occurrence of a standing reservation behaves like an advance reservation, with the following exceptions:

- While a job can be submitted to a specific advance reservation, it can only be submitted to the standing reservation as a whole, not to a specific occurrence. You can only specify *when* the job is eligible to run. See "qsub" on page 214 of the PBS Professional Reference Guide.
- When an advance reservation ends, it and all of its jobs, running or queued, are deleted, but when an occurrence ends, only its running jobs are deleted.

Each occurrence of a standing reservation has reserved resources which satisfy the resource request, but each occurrence may have its resources drawn from a different source. A query for the resources assigned to a standing reservation will return the resources assigned to the soonest occurrence, shown in the resv_nodes attribute reported by `pbs_rstat`.

Also called an *instance* of a standing reservation.

Soonest occurrence of a standing reservation

The occurrence which is currently active, or if none is active, then it is the next occurrence.

Standing reservation

An advance reservation which recurs at specified times. For example, the user can reserve 8 CPUs and 10GB every Wednesday and Thursday from 5pm to 8pm, for the next three months.

4.9.37.2 Job Reservations

4.9.37.2.i Creating Advance and Standing Reservations

Any PBS user can create both advance and standing reservations for jobs using the `pbs_rsub` command. PBS either confirms that the reservation can be made, or rejects the request. Once the reservation is confirmed, PBS creates a queue for the reservation's jobs. Jobs are then submitted to this queue.

When a reservation is confirmed, it means that the reservation will not conflict with currently running jobs, other confirmed reservations, or dedicated time, and that the requested resources are available for the reservation. A reservation request that fails these tests is rejected. All occurrences of a standing reservation must be acceptable in order for the standing reservation to be confirmed.

The `pbs_rsub` command returns a *reservation ID*, which is the reservation name. For an advance reservation, this reservation ID has the format:

R<sequence number>.<server name>

For a standing reservation, this reservation ID refers to the entire series, and has the format:

S<sequence number>.<server name>

The user specifies the resources for a reservation using the same syntax as for a job.

See "Reserving Resources", on page 135 of the PBS Professional User's Guide, for detailed information on creation and use of reservations.

The time for which a reservation is requested is in the time zone at the submission host.

4.9.37.2.ii Job-Specific Reservations

A job-specific reservation is for the same resources that the job requested. Job-specific reservations are intended to preserve access to the job's resources in the case where a job may need to be modified and then re-run, so that the job does not need to wait to be re-scheduled.

Any PBS user can create a job-specific reservation.

A job-specific reservation ID has the format:

R<sequence number>.<server name>

Job-specific reservations cannot be used with job arrays.

4.9.37.2.iii Creating Job-specific Start Reservations

Job submitters can create a job-specific start reservation at submission time. The job is scheduled normally, and when it starts, PBS creates and starts a reservation on the same resources, and puts the job into the reservation. To create a job-specific reservation at submission time, set the job's create_resv_from_job attribute to *True*:

qsub ... -Wcreate_resv_from_job=1

To create a job-specific start reservation from a queued job, use `qalter` to set the create_resv_from_job attribute to *True*.

4.9.37.2.iv Creating Job-specific ASAP Reservations

Job submitters can create a job-specific ASAP from a queued job. PBS creates the reservation for the same resources the job requests, moves the job into the reservation, and schedules the reservation to start as soon as possible.

To create a job-specific ASAP reservation:

pbs_rsub -Wqmove=<job ID>

Note that job-specific ASAP reservations, once created, do not adjust themselves to a change in resource availability. An ASAP reservation can cause resources to go idle while waiting for the reservation to start. For example, if a job scheduled to finish before an ASAP reservation finishes early, and no jobs can be backfilled into the new open slot, resources will sit idle until the reservation runs. In addition, if a high-priority job comes in after an ASAP reservation has been created for a lower-priority job, the high-priority job must wait until after the reservation finishes.

To get the equivalent of flexible ASAP reservations that don't cause idle resources, use a job sort formula with a custom priority term, for example "cust_high_pri", and set this term to a high value, for example 10, for the desired job. Then you can alter the job: `qalter -l cust_high_pri=10 -Wcreate_resv_from_job=true`. Make sure that cust_high_pri has a large enough coefficient in the formula to change the job priority.

4.9.37.2.v Creating Job-specific Now Reservations

Job submitters can create a job-specific now from a running job. PBS creates the reservation for the same resources the job is using, starts the reservation, and moves the job into the reservation.

To create a job-specific now reservation:

pbs_rsub --job <job ID>

4.9.37.2.vi Job Reservations and Placement Sets

When PBS chooses a placement set for a reservation, it makes the same choices as it would for a regular job. It fits the reservation into the smallest possible placement set. See section 4.9.32.4.ii, "Order of Placement Set Consideration Within Pool", on page 174.

When a reservation is created, it is created within a placement set, if possible. If no placement set will satisfy the reservation, placement sets are ignored, if the scheduler's do_not_span_psets attribute is *False*. If no placement set will satisfy the reservation, and the scheduler's do_not_span_psets attribute is *True*, the reservation is not created.

The vnodes allocated to a reservation are used as one single placement set for jobs in the reservation; they are not subdivided into smaller placement sets. A job within a reservation runs within the single placement set made up of the vnodes allocated to the reservation.

4.9.37.2.vii Requesting Resources for Job Reservations

Reservations request resources using the same mechanism that jobs use. If a resource is unrequestable, users cannot request it for a reservation. If a resource is invisible, users cannot view it or request it for a reservation.

4.9.37.2.viii Job Reservations and Provisioning

Users can create reservations that request AOEs. Each reservation can have at most one AOE specified for it. Any jobs that run in that reservation must not request a different AOE. See section 7.4.3, "Provisioning And Reservations", on page 333.

The vnodes allocated to a reservation that requests an AOE are put in the *resv-exclusive* state when the reservation runs. These vnodes are not shared with other reservations or with jobs outside the reservation.

For information on restrictions applying to reservations used with provisioning, see section 7.7.2.3, "Vnode Reservation Restrictions", on page 346.

For how to avoid problems with provisioning and reservations, see section 7.10.1, "Using Provisioning Wisely", on page 355.

4.9.37.2.ix Job Reservation Priority

A job running in a reservation cannot be preempted.

A job running in a reservation has the highest execution priority.

4.9.37.2.x Querying Reservations

To query a reservation, use the `pbs_rstat` command. See "Viewing the Status of a Reservation", on page 143 of the PBS Professional User's Guide. To delete a reservation, use the `pbs_rdel` command, not the `qmgr` command.

4.9.37.2.xi Controlling Access to Job Reservations

You can specify which projects, users, and groups can and cannot submit jobs to reservations. Use the `pbs_rsub -U/-G` command to set the reservation's acl_users and/or acl_groups attributes, and `pbs_ralter -U/-G` to change them. See section 8.3.8, "Reservation Access", on page 373.

4.9.37.2.xii Job Reservation Fault Tolerance

PBS automatically keeps track of the vnodes assigned to reservations, and tries to find replacement vnodes for those that become unavailable. See section 9.4, "Reservation Fault Tolerance", on page 434.

4.9.37.2.xiii Logging Standing Reservation Information

The start and end of each occurrence of a standing reservation is logged as if each occurrence were a single advance reservation.

Reservation-related messages are logged at level PBSEVENT_RESV, which is 0x0200 (512).

4.9.37.2.xiv Accounting

Resources requested for a reservation are recorded in the reservation's Resource_List attribute, and reported in the accounting log B and Y records for the reservation. See section 19.5.3, "Timeline for Reservation Accounting Messages", on page 655.

4.9.37.3 Maintenance Reservations

You can create maintenance reservations using `pbs_rsub --hosts <host list>`. Maintenance reservations are designed to make the specified hosts available for the specified amount of time, regardless of what else is happening:

- You can create a maintenance reservation that includes or is made up of vnodes that are down or offline.
- Maintenance reservations ignore the value of a vnode's resv_enable attribute.
- PBS immediately confirms any maintenance reservation.
- Maintenance reservations take precedence over other reservations; if you create a maintenance reservation that overlaps an advance or standing job reservation, the overlapping vnodes become unavailable to the job reservation, and the job reservation is in conflict with the maintenance reservation. PBS looks for replacement vnodes; see "Reservation Fault Tolerance" on page 434 in the PBS Professional Administrator's Guide.

PBS will not start any new jobs on vnodes overlapping or in a maintenance reservation. However, jobs that were already running on overlapping vnodes continue to run; you can let them run or requeue them.

You cannot specify place or select for a maintenance reservation; these are created by PBS:

- PBS creates the reservation's placement specification so that hosts are assigned exclusively to the reservation. The placement specification is always the following:

  -lplace=exclhost
- PBS sets the reservation's resv_nodes attribute value so that all CPUs on the reserved hosts are assigned to the maintenance reservation. The select specification is always the following:

  -lselect=host=<host1>:ncpus=<number of CPUs at host1>+host=<host2>:ncpus=<number of CPUs at host2>+...

Maintenance reservations are prefixed with *M*. A maintenance reservation ID has the format:

M<sequence number>.<server name>

You cannot create a recurring maintenance reservation.

Creating a maintenance reservation does not trigger a scheduling cycle.

You must have manager or operator privilege to create a maintenance reservation.

4.9.37.4 Modifying Reservations

You can use the pbs_ralter command to alter an existing reservation, whether it is an individual job-specific, advance, or maintenance reservation, or the next or current instance of a standing reservation. Syntax:

pbs_ralter [-D <duration>] [-E <end time>] [-G <auth group list>] [-I <block time>] [-l select=<select spec>] [-m <mail points>] [-M <mail list>] [-N <reservation name>] [-R <start time>] [-U <auth user list>] <reservation ID>

To force a change to the start time, end time, or duration of a reservation, you can use the `-Wforce` option:

pbs_ralter -Wforce [-D <duration>] [-E <end time>] [-R <start time>] <reservation ID>

Note that with the `-Wforce` option you can force PBS to oversubscribe resources, in which case you (the administrator) may need to manage them yourself.

You cannot change the start time of a reservation in which jobs are running.

When changing the select specification, the new specification must be a subset of the same chunks requested by the original reservation. If the reservation has started, you cannot release chunks where reservation jobs are running. To find unused chunks in a running reservation, you can compare the reservation's resv_nodes attribute to the exec_vnodes attribute of the jobs running in the reservation.

If the reservation has started and and is degraded, you must release all unavailable chunks in order to alter the reservation select specification.

If the reservation has not started, modifying the select specification may result in moving the reservation to different vnodes.

After the change is requested, the change is either confirmed or denied. On denial of the change, the reservation is not deleted and is left as is, and the following message appears in the server's log:

```
Unable to alter reservation <reservation ID>
```

When a reservation is confirmed, the following message appears in the server's log:

```
Reservation alter successful for <reservation ID>
```

To find out whether or not the change was allowed:

- Use the `pbs_rstat` command: see whether you altered reservation attribute(s)
- Use the interactive option: check for confirmation after the blocking time has run out

If the reservation has not started and it cannot be confirmed on the same vnodes, PBS searches for another set of vnodes. See section 9.4, "Reservation Fault Tolerance", on page 434.

You must be the reservation owner or the PBS Administrator to run this command.

For details, see "pbs_ralter" on page 87 of the PBS Professional Reference Guide.

4.9.37.5 Attributes Affecting Reservations

We list the server, vnode, and job attributes affecting reservations here. See the full list of reservation attributes in "Reservation Attributes" on page 305 in the PBS Professional Administrator's Guide. See "Server Attributes" on page 283 of the PBS Professional Reference Guide and "Vnode Attributes" on page 322 of the PBS Professional Reference Guide.

Table 4-17: Attributes Affecting Reservations

Entity	Attribute	Effect
Server	acl_resv_host_enable	Controls whether or not the server uses the acl_resv_hosts access control lists.
Server	acl_resv_hosts	List of hosts from which reservations may and may not be created at this server.
Server	acl_resv_group_enable	Controls whether or not the server uses the acl_resv_groups access control lists.
Server	acl_resv_groups	List of groups who may and may not create reservations at this server.
Server	acl_resv_user_enable	Controls whether or not the server uses the acl_resv_users access control lists.
Server	acl_resv_users	List of users who may and may not create reservations at this server.
Server	resv_enable	Controls whether or not reservations can be created at this server.
Server	reserve_retry_time	Length of time to wait between when a reservation becomes degraded and when PBS tries to reconfirm the reservation, as well as interval between attempts to reconfirm a degraded reservation. Default: 600 (10 minutes)
Vnode	queue **deprecated**	Associates the vnode with an execution queue. If this attribute is set, this vnode cannot be used for reservations.
Vnode	resv_enable	Controls whether the vnode can be used for reservations. Default is *True*, but set to *False* for a vnode used for cycle harvesting.
Job	create_resv_from_job	Controls whether PBS creates a job-specific reservation for this job.

4.9.37.6 Reservation Advice and Caveats

- Do not delete a reservation's queue.
- Do not start a reservation's queue (do not set the reservation's started attribute to *True*). Jobs will run prematurely.
- Do not try to set attribute values for a reservation queue directly; instead, operate on the reservation.
- Reservations are incompatible with cycle harvesting. Do not allow reservations on machines used for cycle harvesting. The user may begin using the machine, which will suspend any PBS jobs, possibly preventing them from finishing before the reservation runs out. Set each cycle harvesting vnode's resv_enable attribute to *False*, to prevent the vnode from being used for reservations.
- You can write hooks that execute, modifying a reservation's attributes, when a reservation is created. See the PBS Professional Hooks Guide.
- Allow enough time in reservations. If a job is submitted to a reservation with a duration close to the walltime of the job, provisioning could cause the job to be terminated before it finishes running, or to be prevented from starting. If a reservation is designed to take jobs requesting an AOE, leave enough extra time in the reservation for provisioning.
- Hosts or vnodes that have been configured to accept jobs only from a specific queue (vnode-queue restrictions) cannot be used for advance reservations. Hosts or vnodes that are being used for cycle harvesting should not be used for reservations.
- Hosts with $max_load and $ideal_load configured should not be used for reservations. Set the resv_enable vnode attribute on these hosts to *False*.
- For troubleshooting problems with reservations, see "Reservation Caveats and Errors", on page 147 of the PBS Professional User's Guide.
- Be careful when using `qrun -H` on jobs or vnodes involved in reservations. Make sure that you don't oversubscribe reserved resources.
- In order to create reservations, the submission host must have its timezone set to a value that is understood by the PBS server. See section 21.9.5, "Unrecognized Timezone Variable", on page 682.
- Avoid making reservations for resources that are out of the control of PBS. Resources that are managed through a server_dyn_res script may not be available when jobs need them.
- If you create a maintenance reservation that overlaps an advance or standing job reservation, the maintenance reservation takes precedence, the overlapping vnodes become unavailable to the job reservation, and the job reservation becomes degraded. PBS looks for replacement vnodes; see section 9.4, "Reservation Fault Tolerance", on page 434. Any job reservation overlapping a maintenance reservation goes into the *RESV_IN_CONFLICT* substate (*12*).
- Note that job-specific ASAP reservations, once created, do not adjust themselves to a change in resource availability. An ASAP reservation can cause resources to go idle while waiting for the reservation to start. For example, if a job scheduled to finish before an ASAP reservation finishes early, and no jobs can be backfilled into the new open slot, resources will sit idle until the reservation runs.
- To get the equivalent of flexible ASAP reservations that don't cause idle resources, use a job sort formula with a custom priority term, for example "cust_high_pri", and set this term to a high value, for example 10, for the desired job. Then you can alter the job: `qalter -l cust_high_pri=10 -Wcreate_resv_from_job=true`.
- Beware of oversubscribing resources when using the `-Wforce` option to `pbs_ralter`.

4.9.38 Round Robin Queue Selection

PBS can select jobs from execution queues by examining the queues in round-robin fashion. The behavior is round-robin only when you have groups of queues where all queues in each group have the same priority.

The order in which queues are selected is determined by each queue's priority. You can set each queue's priority; see section 2.3.5.3, "Prioritizing Execution Queues", on page 26. If queue priorities are not set, they are undefined. If you do not prioritize the queues, their order is undefined.

When you have multiple queues with the same priority, a scheduler round-robins through all of the queues with the same priority as a group. So if you have Q1, Q2, and Q3 at a priority of 100, Q4 and Q5 at a priority of 50, and Q6 at a priority of 10, a scheduler will round-robin through Q1, Q2, and Q3 until all of those jobs are out of the way, then the scheduler will round-robin through Q4 and Q5 until there are no more jobs in them, and finally the scheduler will go through Q6.

When using the round-robin method with queues that have unique priorities, a scheduler runs all jobs from the first queue, then runs all the jobs in the next queue, and so on.

To specify that PBS should use the round-robin method to select jobs, set the value of the round_robin scheduler parameter to *True*.

The round_robin parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

You can use the round-robin method as a resource allocation tool. For example, if you need to run the same number of jobs from each group, you can put each group's jobs in a different queue, and then use round-robin to run jobs, one from each queue.

The round-robin method is also used in PBS for a feature that is not controlled by the round_robin scheduler attribute. The SMP cluster distribution parameter, smp_cluster_dist, can use a round-robin method to place jobs. See section 4.9.43, “SMP Cluster Distribution”, on page 220.

See “round_robin” on page 258 of the PBS Professional Reference Guide.

4.9.38.1 Round-robin Caveats

- Each scheduling cycle starts with the highest-priority queue. Therefore, when using round-robin, this queue gets preferential treatment.
- When set to *True*, the round_robin parameter overrides the by_queue parameter.
- If round robin and strict ordering are *True*, and backfilling is not being used, and the top job cannot run, whether because of resources or rejection by MoM, no job runs. However, if round robin is *True* and strict ordering is *False*, and the top job in the current queue cannot run, the next top job is considered instead. For example, we have 3 queues, each with 3 jobs, and with the same priority:

  Q1: J1 J2 J3

  Q2: J4 J5 J6

  Q3: J7 J8 J9

  If round_robin and strict_ordering are *True*, and J1 cannot run, no job runs.

  If round_robin is *True* and strict_ordering is *False*, and J1 cannot run, job order is J4, J7, J2, J5, J8, J3, etc.
- With round_robin and strict_ordering set to *True*, a job continually rejected by a runjob hook may prevent other jobs from being run. A well-written hook would put the job on hold or requeue the job with a start time at some later time to allow other jobs in the same queue to be run.

4.9.39 Routing Jobs

Before reading this section, please read about the mechanics of configuring and using routing queues, in section 2.3.6, “Routing Queues”, on page 27.

In this section, we use the term "routing" to mean the general process of moving a job somewhere, whether it is from one queue to another, from one partition or complex to another, or from a queue to particular vnodes.

Routing jobs can involve collecting jobs so they don't stray into the wrong queues, moving those jobs to the correct queues, and filtering which jobs are allowed into queues.

You may need to collect jobs into a routing queue, before moving them to the correct destination queue. If you use a routing queue, you can force users to submit jobs to the routing queue only, you can grab jobs as they are submitted and put them in the routing queue, and you can set a routing queue as the default. The mechanisms to collect jobs are described below, and listed here:

- Setting default queue; see section 4.9.39.1.i, "Default Queue as Mechanism to Collect Jobs", on page 208
- Grabbing jobs upon submission; see section 4.9.39.1.ii, "Grabbing Jobs Upon Submission", on page 209
- Disallowing direct submission to execution queues; see section 4.9.39.1.iii, "Disallowing Direct Submission as Mechanism to Collect Jobs", on page 209
- Disallowing submission using access controls; see section 4.9.39.3.ii, "Access Controls as Filtering Mechanism", on page 210

There is also a one-step process, but depending on the number of jobs being submitted, it may be too slow. You can also simply examine them upon submission and send them where you want. The method is listed here:

- Examining jobs upon submission and routing them using a hook; see section 4.9.39.1.iv, "Examining Jobs Upon Submission", on page 209.

You can use any of several mechanisms for moving jobs. Each is described in subsections below. The mechanisms for moving jobs are the following:

- Routing queues; see section 4.9.39.2.i, "Routing Queues as Mechanism to Move Jobs", on page 209
- Hooks; see section 4.9.39.2.ii, "Hooks as Mechanism to Move Jobs", on page 209
- Peer scheduling; see section 4.9.39.2.iii, "Peer Scheduling as Mechanism to Move Jobs", on page 209
- The `qmove` command; see section 4.9.39.2.iv, "The qmove Command as Mechanism to Move Jobs", on page 210

You can use filtering methods to control which jobs are allowed into destination queues. We describe filtering methods in subsections below. The filtering mechanisms are the following:

- Resource limits; jobs are filtered by resource request. See section 4.9.39.3.i, "Resource Limits as Filtering Mechanism", on page 210
- Access control limits; jobs are filtered by owner. See section 4.9.39.3.ii, "Access Controls as Filtering Mechanism", on page 210

You can use a combination of moving a job and "tagging" it, that is, including a special custom resource in the job's resource request, to route the job. If you set the resource using a hook, you can route the job either to a queue or to vnodes. If you make the job inherit the resource from a queue, you can route it only to vnodes. You can set resource limits for the special custom resource at the receiving queue, allowing in only jobs with the special resource. You can set the special custom resource at vnodes, so that the job must run there. Mechanisms for tagging jobs are listed here:

- Using a hook to assign a resource; see section 4.9.39.4.i, "Using Hooks to Tag Jobs", on page 210
- Associating vnodes with queues; see section 4.9.2, "Associating Vnodes with Queues", on page 105
- Changing the job's resource request using the `qalter` command; see section 4.9.39.4.ii, "Using the qalter Command to Tag Jobs", on page 211

4.9.39.1 Mechanisms for Collecting Jobs

4.9.39.1.i Default Queue as Mechanism to Collect Jobs

To make it easy on your users, have their jobs land in your routing queue by default. You probably don't want frustrated users trying to submit jobs without specifying a queue, only to have the jobs be rejected if you have set access controls on, or only allowed routing to, the default queue. The server's default_queue attribute specifies the name of the default queue. To make things easy, make the default queue be the routing queue:

```
Qmgr: set server default_queue = <queue name>
```

4.9.39.1.ii Grabbing Jobs Upon Submission

You can allow users to submit jobs to any queue, and then scoop up the newly-submitted jobs and put them in the desired queue. To do this, you write a hook. See the *PBS Professional Hooks Guide*.

4.9.39.1.iii Disallowing Direct Submission as Mechanism to Collect Jobs

If you are using a routing queue, you can disallow job submission to all other queues. This forces users to submit jobs to the routing queue. You should probably make the routing queue be the default queue in this case, to avoid irritating users. Whether or not a queue allows direct job submission is controlled by its from_route_only attribute. To disallow job submission to a queue:

```
Qmgr: set queue <queue name> from_route_only = True
```

4.9.39.1.iv Examining Jobs Upon Submission

You can use a job submission hook to examine each job as it is submitted, and then route it to the desired queue. For example, you can route jobs directly according to resource request, project, owner, etc. See the *PBS Professional Hooks Guide*.

4.9.39.2 Mechanisms for Moving Jobs

4.9.39.2.i Routing Queues as Mechanism to Move Jobs

Routing queues are a mechanism supplied by PBS that automatically move jobs from a routing queue to another queue. You can direct which destination queues accept a job using these filters at each destination queue:

- Resource limits: you can set up execution queues designed for specific kinds of jobs, and then route each kind of job separately. For example, you can create two execution queues, and one routing queue, and route all jobs requesting large amounts of memory to one of the execution queues, and the rest of the jobs to the other queue. See section 2.3.6.4, “Using Resources to Route Jobs Between Queues”, on page 28.
- Access control limits: you can set up destination queues that are designed for specific groups of users. Each queue accepts jobs only from a designated set of users or groups. For example, if you have three departments, Math, Physics, and Chemistry, the queue belonging to Math accepts only users from the Math department. See section 2.3.6.5, “Using Access Control to Route Jobs”, on page 31.

When routing a job between complexes, the job's owner must be able to submit a job to the destination complex.

For how to configure and use routing queues, see section 2.3.6, “Routing Queues”, on page 27.

4.9.39.2.ii Hooks as Mechanism to Move Jobs

You can use a submission hook to move jobs into queues such as dedicated time queues, queues with special priority, or reservation queues. You write the hook so that it identifies the jobs that should go into a particular queue, and then moves them there. For example, your hook can move all jobs from ProjectA to a specific queue. This is a snippet, where you would replace <destination queue> with the queue name.

```
import pbs
e = pbs.event()
e.job.queue = pbs.server().queue("<destination queue>")
```

For complete information on hooks, see the PBS Professional Hooks Guide.

4.9.39.2.iii Peer Scheduling as Mechanism to Move Jobs

To send jobs from one partition or complex to another, you use peer scheduling. In peer scheduling, the partition or complex that supplies the jobs (the "furnishing" partition or complex) contains at least one special queue (the "furnishing queue"), whose jobs can be pulled over to another partition or complex, to be run at the other partition or complex. The partition or complex that pulls jobs contains a special queue (the "pulling queue"), where those pulled jobs land.

You can use any of the job routing methods, such as routing queues, tagging, or hooks, to control which jobs land in the furnishing queue.

You can use any of the job filtering methods, such as resource limits or access controls, to control which jobs land in the furnishing queue.

You can use job submission hooks on the jobs that land in the pulling queue.

See section 4.9.31, "Peer Scheduling", on page 167.

4.9.39.2.iv The `qmove` Command as Mechanism to Move Jobs

You can use the `qmove` command, either manually or via a `cron` job, to move jobs into the desired queues. See "qmove" on page 173 of the PBS Professional Reference Guide.

4.9.39.3 Mechanisms for Filtering Jobs

4.9.39.3.i Resource Limits as Filtering Mechanism

You can filter whether each job is accepted at the server or a queue based on the job's resource request. For example, you can control which jobs are allowed to be submitted to the server, by limiting the amount of memory a job is allowed to request. You can do the same at execution queues. These limits apply regardless of the routing mechanism being used, and apply to jobs being submitted directly to the queue. See section 5.13, "Using Resources to Restrict Server or Queue Access", on page 256.

4.9.39.3.ii Access Controls as Filtering Mechanism

You can filter jobs whether each job is accepted at the server or a queue based on the job's owner, or the job owner's group. At each queue and at the server, you can create a different list of the users who can submit jobs and the users who cannot submit jobs. You can do the same for groups.

For example, you can set up a routing queue and several execution queues, where each execution queue has access controls allowing only certain users and groups. When PBS routes the jobs from the routing queue, it will route them into the execution queues that accept owners of the jobs. See section 2.3.6.5, "Using Access Control to Route Jobs", on page 31.

4.9.39.3.iii Hooks as Filtering Mechanism

You can filter which jobs are accepted at the server or queues according to any criterion, using a hook. For example, you can write a hook that disallows jobs that request certain combinations of resources. See the PBS Professional Hooks Guide.

4.9.39.4 Mechanisms for Tagging Jobs

4.9.39.4.i Using Hooks to Tag Jobs

You can use a hook to force certain jobs to run on particular hardware, by having the hook set the value of a host-level custom resource in a job's resource request. The hook sets this resource to match the value at the selected vnodes, so that the job must run on one or more of those vnodes. You can use the job's project to determine how the job is tagged. Note that the value at other vnodes should be different, otherwise the job could end up on vnodes you don't want.

- Define a host-level custom resource; see section 5.14.4, "Configuring Host-level Custom Resources", on page 271.
- Set this resource to a special value on the special vnodes only. See section 5.7.2, "Setting Values for Global Static Resources", on page 243.
- Create a hook that filters jobs by size, project, or other characteristic, and sets the value of the custom resource to the special value, in the job's resource request. See the PBS Professional Hooks Guide

If you must use a routing queue, and you need to route on host-level resources (resources in the job's select specification), you can use a hook to tag jobs so that they are routed correctly. The hook reads the job's host-level resource request, and sets the job's server-level resource request accordingly. This server-level resource is used for routing:

- Create a custom server-level resource that you use exclusively for routing; set it to appropriate values on the destination queues; see section 5.14.3, "Creating Server-level Custom Resources", on page 268
- Create a submit hook to extract the host-level resource value and use it to populate the custom resource that you use exclusively for routing; see the PBS Professional Hooks Guide

4.9.39.4.ii Using the `qalter` Command to Tag Jobs

You can change a job's resource request using the qalter command. This way you can override normal behavior. See "qalter" on page 128 of the PBS Professional Reference Guide.

4.9.40 Scheduler Cycle Speedup

4.9.40.1 Top Job Calculation Speedup

When you are using backfilling, you can choose whether and how much you want to speed up the scheduling cycle (within limits). You can get shorter scheduling cycle duration with coarser granularity in estimating start times for jobs. When you are using backfilling, a scheduler calculates estimated start times for jobs. You can choose not to make this trade-off (keeping fine granularity in start time estimation), or you can choose low, medium, or high speedup. See section 4.9.3, "Using Backfilling", on page 107.

4.9.40.1.i Configuring Top Job Calculation Speedup

You configure top job calculation speedup by using `qmgr` to set the opt_backfill_fuzzy scheduler attribute:

```
Qmgr: set sched opt_backfill_fuzzy [off | low | medium | high]
```

where each option has the following effect:

off

This scheduler uses its normal, finest granularity. No speedup.

low

This scheduler uses fairly fine granularity, not as fine as normal. Some speedup.

medium

This scheduler uses medium granularity. Medium speedup.

high

This scheduler uses the coarsest granularity. Greatest speedup.

The options *off*, *low*, *medium*, and *high* are not case-sensitive. You can use only one option at a time. Since this is an attribute and not a scheduler parameter, it is not a primetime option.

4.9.40.1.ii What Changing Calculation Speed Affects

Changing this attribute takes effect on the next scheduling cycle. If you change this attribute, top jobs are recalculated in the next scheduling cycle.

Once an ASAP reservation is made, it is fixed. If you change opt_backfill_fuzzy later, the reservation start time does not change, even if it becomes degraded. PBS finds new vnodes for degraded reservations, but does not change the start times.

4.9.40.1.iii Caveats and Restrictions for Top Job Calculation Speedup

This option is effective only when you are using backfilling.

4.9.41 Shared vs. Exclusive Use of Resources by Jobs

When PBS places a job, it can do so on hardware that is either already in use or has no jobs running on it. PBS can make the choice at the vnode level or at the host level. How this choice is made is controlled by a combination of the value of each vnode's sharing attribute and the placement requested by a job.

You can set each vnode's sharing attribute so that the vnode or host is always shared, is always exclusive, or so that it honors the job's placement request. If the vnode attribute is set to *force_shared* or *force_excl*, the value of a vnode's sharing attribute takes precedence over a job's placement request. If the vnode attribute is set to *default_*, the job request overrides the vnode attribute.

Each vnode can be allocated exclusively to one job (each job gets its own vnodes), or its resources can be shared among jobs (PBS puts as many jobs as possible on a vnode). If a vnode is allocated exclusively to a job, all of its resources are assigned to the job. The state of the vnode becomes *job-exclusive*. No other job can use the vnode.

Hosts can also be allocated exclusively to one job, or shared among jobs. If a host is to be allocated exclusively to one job, all of the host must be used: if any vnode from a host has its sharing attribute set to either *default_exclhost* or *force_exclhost*, all vnodes on that host must have the same value for the sharing attribute.

For a complete description of the sharing attribute, and a table showing the interaction between the value of the sharing attribute and the job's placement request, see "sharing" on page 326 of the PBS Professional Reference Guide.

4.9.41.1 Sharing on a Multi-vnode Machine

On a multi-vnode shared-memory machine, a scheduler will share memory from a chunk even if all the CPUs are used by other jobs. It will first try to put a chunk entirely on one vnode. If it can, it will run it there. If not, it will break the chunk up across any vnode it can get resources from, even for small amounts of unused memory.

To keep a job in a single vnode, use `-lplace=group=vnode`; if you want to restrict it to larger sets of vnodes, identify those sets using a custom string or string_array resource and use it in `-lplace=group=<resource>`. If you already have resources used in node_group_key you can usually use these.

4.9.41.2 Setting the sharing Vnode Attribute

To set the sharing attribute for a vnode, use either:

- An exechost_startup hook; see "Setting and Unsetting Vnode Resources and Attributes" on page 48 in the PBS Professional Hooks Guide
- A Version 2 configuration file; see section 3.4.4, "Configuring the Vnode Sharing Attribute", on page 48

4.9.41.3 Viewing Sharing Information

You can use the `qmgr` or `pbsnodes` commands to view sharing information. See "qmgr" on page 150 of the PBS Professional Reference Guide and "pbsnodes" on page 36 of the PBS Professional Reference Guide.

4.9.41.4 Sharing Caveats

- On the Cray XC, on *cray_compute* vnodes, the sharing attribute is set to *force_exclhost* by default. Do not change this setting, because ALPS does not support sharing a compute vnode with more than one job.
- The term "sharing" is also used to describe the case where MoM manages a resource that is shared among her vnodes, for example an application license shared by the vnodes of a multi-vnode machine.
- The term "sharing" is also used to mean oversubscribing CPUs, where more than one job is run on one CPU; the jobs are "sharing" a CPU. See section 9.6.5, “Managing Load Levels on Vnodes”, on page 447
- If a host is to be allocated exclusively to one job, all of the host must be used: if any vnode from a host has its sharing attribute set to either *default_exclhost* or *force_exclhost*, all vnodes on that host must have the same value for the sharing attribute.
- For vnodes with sharing=*default_shared*, jobs can share a vnode, so that unused memory on partially-allocated vnodes is allocated to a job. The exec_vnode attribute will show this allocation.

4.9.42 Using Shrink-to-fit Jobs

4.9.42.1 Shrink-to-fit Jobs

PBS allows you or the job submitter to adjust the running time of a job to fit into an available scheduling slot. The job's minimum and maximum running time are specified in the min_walltime and max_walltime resources. PBS chooses the actual walltime. Any job that requests min_walltime is a **shrink-to-fit** job.

4.9.42.1.i Requirements for a Shrink-to-fit Job

A job must have a value for min_walltime to be a shrink-to-fit job. Shrink-to-fit jobs are not required to request max_walltime, but it is an error to request max_walltime and not min_walltime.

Jobs that do not have values for min_walltime are not shrink-to-fit jobs, and their walltime can be specified by the user, inherited through defaults, or set in a hook.

4.9.42.1.ii Comparison Between Shrink-to-fit and Non-shrink-to-fit Jobs

Shrink-to-fit jobs are treated the same as non-shrink-to-fit jobs unless explicitly stated. For example, job priority is not affected by being shrink-to-fit. The only difference between a shrink-to-fit and a non-shrink-to-fit job is how the job's walltime is treated. PBS sets the walltime at the time the job is run; any walltime settings not computed by PBS are ignored.

4.9.42.2 Where to Use Shrink-to-fit Jobs

If you have jobs that can run for less than the expected time to completion and still make useful progress, you can use them as shrink-to-fit jobs in order to maximize utilization.

You can use shrink-to-fit jobs for the following:

- Jobs that are internally checkpointed. This includes jobs which are part of a larger effort, where a job does as much work as it can before it is killed, and the next job in that effort takes up where the previous job left off.
- Jobs using periodic PBS checkpointing
- Jobs whose real running time might be much less than the expected time
- When you have set up dedicated time for system maintenance, and you want to keep machines well-utilized right up until shutdown, submitters who want to risk having a job killed before it finishes can run speculative shrink-to-fit jobs. Similarly, speculative jobs can take advantage of the time just before a reservation starts
- Any job where the submitter does not mind running the job as a speculative attempt to finish some work

4.9.42.3 Running Time of a Shrink-to-fit Job

4.9.42.3.i Setting Running Time Range for Shrink-to-fit Jobs

It is only required that the job request min_walltime to be a shrink-to-fit job. If a job requests min_walltime but does not request max_walltime, you may want to use a hook or defaults to set a reasonable value for max_walltime. If you use defaults, you may want to route shrink-to-fit jobs to a special queue where they inherit a value for max_walltime if they haven't got one already. See section 4.9.39, "Routing Jobs", on page 207.

Requesting max_walltime without requesting min_walltime is an error.

A job can end up with a value for min_walltime and max_walltime when the user specifies them, when it inherits them from server or queue defaults, or when they are set in a hook.

Job submitters can set the job's running time range by requesting min_walltime and max_walltime, for example:

qsub -l min_walltime=<min walltime>, max_walltime=<max walltime> <job script>

You can set min_walltime or max_walltime using a hook, whether or not the job requests it. You can set up defaults so that the job inherits these resources if they are not explicitly requested or set in a hook.

4.9.42.3.ii Inheriting Values for min_walltime and max_walltime

The min_walltime and max_walltime resources inherit values differently. A job can inherit a value for max_walltime from resources_max.walltime; the same is not true for min_walltime. This is because once a job is shrink-to-fit, PBS can use a walltime limit for max_walltime.

If a job is submitted without a value for min_walltime, the value for min_walltime for the job becomes the first of the following that exists:

- Server's default `qsub` arguments
- Queue's resources_default.min_walltime
- Server's resources_default.min_walltime

If a shrink-to-fit job is submitted without a value for max_walltime, the value for max_walltime for the job becomes the first of the following that exists:

- Server's default `qsub` arguments
- Queue's resources_default.max_walltime
- Server's resources_default.max_walltime
- Queue's resources_max.walltime
- Server's resources_max.walltime

4.9.42.3.iii Setting walltime for Shrink-to-fit Jobs

For a shrink-to-fit job, PBS sets the walltime resource based on the values of min_walltime and max_walltime, regardless of whether walltime is specified for the job. You cannot use a hook to set the job's walltime, and any queue or server defaults for walltime are ignored, except for the case where the job is run via `qrun -H`; see section 4.9.42.8.ii, "Using qrun With -H Option", on page 216.

PBS examines each shrink-to-fit job when it gets to it, and looks for a time slot whose length is between the job's min_walltime and max_walltime. If the job can fit somewhere, PBS sets the job's walltime to a duration that fits the time slot, and runs the job. The chosen value for walltime is visible in the job's Resource_List.walltime attribute. Any existing walltime value, regardless of where it comes from (user, queue default, hook, previous execution), is reset to the new calculated running time.

If a shrink-to-fit job is run more than once, PBS recalculates the job's running time to fit an available time slot that is between min_walltime and max_walltime, and resets the job's walltime, each time the job is run.

4.9.42.4 How PBS Places Shrink-to-fit Jobs

A PBS scheduler treats shrink-to-fit jobs the same way as it treats non-shrink-to-fit jobs when it schedules them to run. A scheduler looks at each job in order of priority, and tries to run it on available resources. If a shrink-to-fit job can be shrunk to fit in an available slot, a scheduler runs it in its turn. A scheduler chooses a time slot that is at least as long as the job's min_walltime value. A shrink-to-fit job may be placed in a time slot that is shorter than its max_walltime value, even if a longer time slot is available.

For a multi-vnode job, PBS chooses a walltime that works for all of the chunks required by the job, and places job chunks according to the placement specification.

4.9.42.5 Shrink-to-fit Jobs and Time Boundaries

The time boundaries that constrain job running time are the following:

- Reservations
- Dedicated time
- Primetime
- Start time for a top job

Time boundaries are not affected by shrink-to-fit jobs.

A shrink-to-fit job can shrink to avoid time boundaries, as long as the available time slot before the time boundary is greater than min_walltime.

If any job is already running, whether or not it is shrink-to-fit, and you introduce a new period of dedicated time that would impinge on the job's running time, PBS does not kill or otherwise take any action to prevent the job from hitting the new boundary.

4.9.42.5.i Shrink-to-fit Jobs and Prime Time

If you have enabled prime time by setting backfill_prime to *True*, shrink-to-fit jobs will honor the boundary between primetime and non-primetime. If prime_spill is *True*, shrink-to-fit jobs are scheduled so that they cross the prime-non-prime boundary by up to prime_spill duration only. If prime_exempt_anytime_queues is set to *True*, a job submitted in an anytime queue is not affected by primetime boundaries.

4.9.42.6 Shrink-to-fit Jobs and Resource Limits

4.9.42.6.i Shrink-to-fit Jobs and Gating at Server or Queue

Shrink-to-fit jobs must honor any resource limits at the server or queues. If a walltime limit is specified:

- Both min_walltime and max_walltime must be greater than or equal to resources_min.walltime.
- Both min_walltime and max_walltime must be less than or equal to resources_max.walltime.

If resource limits are not met, a job submission or modification request will fail with the following error:

```
"Job exceeds queue and/or server resource limits"
```

4.9.42.6.ii Gating Restrictions

You cannot set resources_min or resources_max for min_walltime or max_walltime. If you try, you will see the following error message, for example for min_walltime:

```
"Resource limits can not be set for min_walltime"
```

4.9.42.7 Shrink-to-fit Jobs and Preemption

When preempting other jobs, shrink-to-fit jobs do not shrink. Their walltime is set to their max_walltime.

4.9.42.8 Using `qrun` on Shrink-to-fit Jobs

If you use `qrun` on a shrink-to-fit job, its behavior depends on whether you use the `-H` option to `qrun`.

4.9.42.8.i Using `qrun` Without `-H` Option

When a shrink-to-fit job is run via `qrun`, it can shrink into available space to run. However, if preemption is enabled and there is a preemptable job that must be preempted in order to run the shrink-to-fit job, the preemptable job is preempted and the shrink-to-fit job shrinks and runs.

When a shrink-to-fit job is run via `qrun`, and there is a hard deadline, e.g. reservation or dedicated time, that conflicts with the shrink-to-fit job's max_walltime but not its min_walltime, the following happens:

- If preemption is enabled and there is a preemptable job before the hard deadline that must be preempted in order to run the shrink-to-fit job, preemption behavior means that the shrink-to-fit job does not shrink to fit; instead, it conflicts with the deadline and does not run.
- If preemption is enabled and there is no preemptable job before the hard deadline, the shrink-to-fit job shrinks into the available time and runs.

4.9.42.8.ii Using `qrun` With `-H` Option

When a shrink-to-fit job is run via `qrun -H`, the shrink-to-fit job runs, regardless of reservations, dedicated time, other jobs, etc. When run via `qrun -H`, shrink-to-fit jobs do not shrink. If the shrink-to-fit job has a requested or inherited value for walltime, that value is used, instead of one set by PBS when the job runs. If no walltime is specified, the job runs without a walltime.

4.9.42.9 Modifying Shrink-to-fit and Non-shrink-to-fit Jobs

4.9.42.9.i Modifying min_walltime and max_walltime

You can change min_walltime and/or max_walltime for a shrink-to-fit job using modifyjob or queuejob hooks, or by using the `qalter` command. Any changes take effect after the current scheduling cycle. Changes affect only queued jobs; running jobs are unaffected unless they are rerun.

4.9.42.9.ii Making Non-shrink-to-fit Jobs into Shrink-to-fit Jobs

You can convert a normal non-shrink-to-fit job into a shrink-to-fit job using the following methods:

- Use a hook that does the following:
  - Sets max_walltime to the job's walltime
  - Sets min_walltime to a useful value
- Use resources_default at the server or a queue. For a queue, you might want to set that queue's from_route_only attribute to True.
- Route to a queue that has resources_default.min_walltime set.
- Use the `qalter` command to set values for min_walltime and max_walltime.

Any changes take effect after the current scheduling cycle. Changes affect only queued jobs; running jobs are unaffected unless they are rerun.

4.9.42.9.iii Making Shrink-to-fit Jobs into Non-shrink-to-fit Jobs

To make a shrink-to-fit job into a normal, non-shrink-to-fit job, use either a hook or the `qalter` command to do the following:

- Set the job's walltime to the value for max_walltime (beware of allowing the job to run into existing reservations etc.)
- Unset min_walltime
- Unset max_walltime

4.9.42.9.iv Hooks for Running Time Limits

If you want to set a new running time limit for shrink-to-fit jobs, you can use a hook. However, this hook must set the value of max_walltime, rather than walltime, since hook settings for walltime for a shrink-to-fit job are ignored.

4.9.42.10 Viewing Running Time for a Shrink-to-fit Job

4.9.42.10.i Viewing min_walltime and max_walltime

You can use `qstat -f` to view the values of the min_walltime and max_walltime. For example:

```
% qsub -lmin_walltime=01:00:15, max_walltime=03:30:00 job.sh
<job-id>
% qstat -f <job-id>
...
resource_list.min_walltime=01:00:15
resource_list.max_walltime=03:30:00
```

You can use tracejob to display max_walltime and min_walltime as part of the job's resource list. For example:

```
12/16/2011 14:28:55  A    user=pbsadmin group=Users project=_pbs_project_default
…
    Resource_List.max_walltime=10:00:00
    Resource_List.min_walltime=00:00:10
```

4.9.42.10.ii Viewing walltime for a Shrink-to-fit Job

PBS sets a job's walltime only when the job runs. While the job is running, you can see its walltime via `qstat -f`. While the job is not running, you cannot see its real walltime; it may have a value set for walltime, but this value is ignored.

You can see the walltime value for a finished shrink-to-fit job if you are preserving job history. See section 14.15, "Managing Job History", on page 531.

You can see the walltime value for a finished shrink-to-fit job in the scheduler log.

4.9.42.11 Lifecycle of a Shrink-to-fit Job

4.9.42.11.i Execution of Shrink-to-fit Jobs

Shrink-to-fit jobs are started just like non-shrink-to-fit jobs.

4.9.42.11.ii Termination of Shrink-to-fit Jobs

When a shrink-to-fit job exceeds the walltime PBS has set for it, it is killed by PBS exactly as a non-shrink-to-fit job is killed when it exceeds its walltime.

4.9.42.12 The min_walltime and max_walltime Resources

max_walltime

Maximum walltime allowed for a shrink-to-fit job. Job's actual walltime is between max_walltime and min_walltime. PBS sets walltime for a shrink-to-fit job. If this resource is specified, min_walltime must also be specified. Must be greater than or equal to min_walltime. Cannot be used for resources_min or resources_max. Cannot be set on job arrays or reservations. If not specified, PBS uses an eternal time slot. Can be requested only outside of a select statement. Non-consumable. Default: None. Type: duration. Python type: pbs.duration

min_walltime

Minimum walltime allowed for a shrink-to-fit job. When this resource is specified, job is a shrink-to-fit job. If this attribute is set, PBS sets the job's walltime. Job's actual walltime is between max_walltime and min_walltime. Must be less than or equal to max_walltime. Cannot be used for resources_min or resources_max. Cannot be set on job arrays or reservations. Can be requested only outside of a select statement. Non-consumable. Default: None. Type: duration. Python type: pbs.duration

4.9.42.13 Accounting and Logging for Shrink-to-fit Jobs

4.9.42.13.i Accounting Log Entries for min_walltime and max_walltime

The accounting log will contain values for min_walltime and max_walltime, as part of the job's Resource_List attribute. This attribute is recorded in the S, E, and R records in the accounting log. For example, if the following job is submitted:

```
qsub -l min_walltime="00:01:00",max_walltime="05:00:00" -l select=2:ncpus=1 job.sh
```

This is the resulting accounting record:

```
…S…….. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18 resources_assigned.ncpus=2

…R…….. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18

…E……. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18…….
```

4.9.42.13.ii Logging

- When a scheduler finds a primetime/dedicated time conflict with a shrink-to-fit job, and the job can be shrunk, the following message is logged in the scheduler logs, with log level PBSEVENT_DEBUG2:

  ```
  "Considering shrinking job to duration=<duration>, due to prime/dedicated time conflict"
  ```

  Sample message from the scheduler log:

  ```
  "03/26/2012 11:53:55;0040;pbs_sched;Job;98.host3;Considering shrinking job to duration=1:06:05,
      due to a prime/dedicated time conflict"
  ```

  This message doesn't indicate or guarantee that the job will eventually be shrunk and run. This message shows that the job's maximum running time conflicted with primetime and the job can still be run by shrinking its running time.
- When a scheduler finds a reservation/top job conflict with a shrink-to-fit job, and the job can be shrunk, the following message is logged in the scheduler logs, with log level PBSEVENT_DEBUG2:

  ```
  "Considering shrinking job to duration=<duration>", due to reservation/top job conflict"
  ```

Sample log message from the scheduler log:

```
"03/26/2012 11:53:55;0040;pbs_sched;Job;98.host3;   Considering shrinking job to
   duration=1:06:05, due to  reservation/top job conflict"
```

This message doesn't indicate or guarantee that the job will eventually be shrunk and run. This message shows that the job's maximum running time conflicted with a reservation or top job and the job can still be run by shrinking its running time.

- When a scheduler runs the shrink-to-fit job, the following message is logged in the scheduler logs with log level PBSEVENT_DEBUG2:

  ```
  "Job will run for duration=<duration>"
  ```

  Sample scheduler log message:

  ```
  "03/26/2012 11:53:55;0040;pbs_sched;Job;98.host3;Job will  run for duration=1:06:05"
  ```

4.9.42.14 Caveats and Restrictions for Shrink-to-fit Jobs

- It is erroneous to specify max_walltime for a job without specifying min_walltime. If a queuejob or modifyjob hook attempts this, the following error appears in the server logs. If attempted via `qsub` or `qalter`, the following error appears in the server log and is printed as well:

  ```
  'Can not have "max_walltime" without "min_walltime"'
  ```

- It is erroneous to specify a min_walltime that is greater than max_walltime. If a queuejob or modifyjob hook attempts this, the following error appears in the server logs. If attempted via `qsub` or `qalter`, the following error appears in the server log and is printed as well:

  ```
  '"min_walltime" can not be greater than "max_walltime"'
  ```

- Job arrays cannot be shrink-to-fit. You cannot have a shrink-to-fit job array. It is erroneous to specify a min_walltime or max_walltime for a job array. If a queuejob or modifyjob hook attempts this, the following error appears in the server logs. If attempted via `qsub` or `qalter`, the following error appears in the server log and is printed as well:

  ```
  '"min_walltime" and "max_walltime" are not valid resources for a job array'
  ```

- Reservations cannot be shrink-to-fit. You cannot have a shrink-to-fit reservation. It is erroneous to set min_walltime or max_walltime for a reservation. If attempted via `pbs_rsub`, the following error is printed:

  ```
  '"min_walltime" and "max_walltime" are not valid resources for reservation.'
  ```

- It is erroneous to set resources_max or resources_min for min_walltime and max_walltime. If attempted, the following error message is displayed, whichever is appropriate:

  ```
  "Resource limits can not be set for min_walltime"
  "Resource limits can not be set for max_walltime"
  ```

4.9.43 SMP Cluster Distribution

This tool is **deprecated**. PBS provides a method for distributing single-chunk jobs to a cluster of single-vnode machines according to a simple set of rules. The method is called *SMP cluster distribution*. It takes into account the resources specified on the `resources:` line in `<sched_priv directory>/sched_config`. The SMP cluster distribution method allows you to choose one of three job distribution systems:

Table 4-18: SMP Cluster Distribution Options

Option	Meaning
pack	Pack all jobs onto one vnode, until that vnode is full, then move to the next vnode
round_robin	Place one job on each vnode in turn, before cycling back to the first vnode
lowest_load	Place the job on the host with the lowest load average

4.9.43.1 How to Use SMP Cluster Distribution

To use SMP cluster distribution, do the following:

- Set the smp_cluster_dist scheduler parameter to the desired value. For example, to enable SMP cluster distribution using the round robin algorithm during primetime, and the pack algorithm during non-primetime, set the following in the scheduler's configuration file:

  ```
  smp_cluster_dist: round_robin prime
  smp_cluster_dist: pack non_prime
  ```

- Set resources_available.<resource name> to the desired limit on each vnode. You do not need to set any of the resources that are automatically set by PBS. For a list of these, see section 5.7.1.1, “How Vnode Available Resource Values are Set”, on page 241.
- Specify the resources to use during scheduling, in `<sched_priv directory>/sched_config`:

  ```
  resources: "ncpus, mem, arch, host, ..."
  ```

The smp_cluster_dist parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

4.9.43.2 How To Disable SMP Cluster Distribution

To ensure that SMP cluster distribution does not interfere with your scheduling policy, leave the smp_cluster_dist parameter set to its default value:

```
smp_cluster_dist   pack   all
```

4.9.43.3 SMP Cluster Distribution Caveats and Advice

- This feature was intended for early implementations of complexes, and probably is not useful for you.
- If you use this feature, you are committed to using it for the entire partition or complex; you cannot designate some machines where it will be used and others where it will not be used.
- If smp_cluster_dist with either *round_robin* or *lowest_load* is used with node_sort_key set to *unused* or *assigned*, smp_cluster_dist is set to *pack*.
- The avoid_provision provisioning policy is incompatible with the smp_cluster_dist scheduler configuration parameter. If a job requests an AOE, the avoid_provision policy overrides the behavior of smp_cluster_dist.
- This feature is applied only to single-chunk jobs that specify an arrangement of pack. Multi-chunk jobs are ignored.
- This feature is useful only for single-vnode machines. On a multi-vnoded machine, this feature distributes jobs across vnodes, but those jobs can end up all stuck on a single host.
- The choice of smp_cluster_dist with round_robin can be replaced by sorting vnodes according to unused CPUs, which does a better job:
  ```
  node_sort_key: "ncpus HIGH unused"
  ```

4.9.44 Using Soft Walltime

A scheduler requires walltime to do backfilling. Job submitters want to avoid having their jobs killed if they run over their walltimes, so they may overestimate job walltimes. You can give a scheduler tighter time slots by giving jobs soft walltimes. Jobs are not killed if they go over their soft walltimes. If a job has both a walltime and a soft walltime, a scheduler uses the soft walltime.

When a job exceeds its soft walltime, PBS estimates a new soft walltime, and records the estimate in the job's estimated.soft_walltime attribute. The estimated.soft_walltime job attribute is readable by all, but writable only by PBS.

4.9.44.1 Assigning Soft Walltime to Jobs

You can set a soft walltime for a job by having it request the soft_walltime resource. You can set it in a server hook, or by using `qalter` or resources_default.

The soft_walltime resource can be requested for a job only by PBS Managers. The soft_walltime resource cannot be set at job submission time, except by a queuejob hook, because job submission uses user permissions. Soft walltime cannot be set in MoM hooks.

You can create a custom resource and allow users to request it, and then set the value of soft_walltime to that resource. See an example in section 4.9.44.4, “Allowing Job Submitters to Set Soft Walltime”, on page 222.

4.9.44.2 How Soft and Hard Walltimes Are Used

When a job is queued:

- If the job is a top job, its soft_walltime is used in determining where the job fits into the calendar
- If the job is a filler job, its soft_walltime is used in determining whether the job conflicts with top jobs
- If the job is a filler job, its hard walltime is used in determining whether the job conflicts with confirmed reservations
- If dedicated time is used, soft_walltime is used in determining whether the job will finish before dedicated time starts
- If backfill_prime is set, soft_walltime is used in determining whether the job will finish before the next prime boundary + prime_spill

When a job is running:

- If resources_used.walltime <= soft_walltime, the job continues to run
- If resources_used.walltime > soft_walltime, the job has exceeded its soft_walltime. The job is not killed; the job's soft_walltime is extended:
  - Every time the job exceeds its soft_walltime, it is extended by 100% of its original soft_walltime
  - If both a soft_walltime and a hard walltime are set, the soft_walltime is never extended past the job's hard walltime
  - If a job exceeds its soft_walltime and crosses over into dedicated_time, PBS does not kill the job
  - The value of Resource_List.soft_walltime does not change. A scheduler sets the estimated.soft_walltime job attribute to the new soft_walltime estimate
- If a job is a preemption candidate, and preempt_order is based on the percentage the job has completed (e.g., `preempt_order SCR 20 S`), the initial soft_walltime request is used to determine the percentage of completion
  - If the job runs past its initial soft_walltime request, preempt_order behaves as if the job is 100% complete. It remains at 100% complete for the remainder of the job regardless of how many times the soft_walltime is extended. For example, if a job has soft_walltime=1:00:00, at 59m, the job is at 99% complete. At 1:00:00, the soft_walltime is extended to 2:00:00. At 1:30:00 the job remains at 100% complete since it has reached its original soft_walltime request

When confirming reservations:

- Only a job's hard walltime is used in determining when jobs end
- A job's soft_walltime is not used when confirming reservations

4.9.44.3 Examples of Using Soft Walltime

Example 4-27: Job J has a soft_walltime=1:00:00 but no hard walltime

J exceeds its soft_walltime. J is extended by its original soft_walltime to 2:00:00.

If J exceeds its soft_walltime again, J is extended again by its original soft_walltime to 3:00:00

Example 4-28: Job K has a soft_walltime=1:00:00 and a hard walltime=1:30:00

K exceeds its soft_walltime. Because 2:00:00 is past its hard walltime, K is extended to its limit of 1:30:00 instead.

4.9.44.4 Allowing Job Submitters to Set Soft Walltime

Example of hook to allow users to directly set soft_walltime:

```
import pbs
e = pbs.event()
j = e.job

j.Resource_List["soft_walltime"] = pbs.duration(j.Resource_List["set_soft_walltime"])
```

Job submitters request the new resource:

```
% qsub -l set_soft_walltime=1:00:00 -l select=1:ncpus=1
```

4.9.44.5 Caveats and Restrictions for Soft Walltime

- The soft_walltime resource is not sent to the MoM when the job is started.
- A shrink-to-fit job requesting soft_walltime is rejected, because a job's min_walltime is the minimum amount of time a job needs to get any real work done. A job's hard walltime can be set to its min_walltime. A job's soft_walltime has to be shorter than its hard walltime. This means that the soft_walltime would have to be shorter than the job's minimum amount of time to get any real work done. The two features do not make sense together.

4.9.45 Sorting Jobs on a Key

PBS allows you to sort jobs on a key that you specify. This can be used when setting both execution and preemption priority. Sorting jobs comes into play after jobs have been divided into classes, because each class may contain more than one job. You can sort on one or more of several different keys, and for each key, you can sort either from low to high or from high to low.

You configure sorting jobs on a key by setting values for the job_sort_key scheduler parameter. When preemption is enabled, jobs are automatically sorted by preemption priority. Table 4-8, “Job Execution Classes,” on page 137 shows where this step takes place.

You can create an invisible, unrequestable custom resource, and use a hook to set the value of this resource for each job. The hook modifies the job's resource request to include the new resource, and sets the value to whatever the hook computes. Then you can sort jobs according to the value of this resource.

The job_sort_key parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

4.9.45.1 job_sort_key Syntax

job_sort_key: "<sort key> HIGH | LOW <primetime option>"

You can use the following keys for sorting jobs:

Table 4-19: Keys for Sorting Jobs

Sort Key	Allowed Order	Description
<PBS resource>	HIGH | LOW	Sorts jobs according to how much of the specified resource they request.
fairshare_perc	HIGH | LOW	Sorts according to fairshare percentage allotted to entity that owns job. This percentage is defined in the `resource_group` file. If user A has more priority than user B, all of user A's jobs are always run first. Past history is not used.
job_priority	*HIGH | LOW*	Sorts jobs by the value of each job's priority attribute.
sort_priority	*HIGH | LOW*	**Deprecated**. Replaced by job_priority option.

You can sort on up to 20 keys.

The argument to the job_sort_key parameter is a quoted string. The default for job_sort_key is that it is not in force.

See “job_sort_key” on page 254 of the PBS Professional Reference Guide.

4.9.45.2 Configuring Sorting Jobs on a Key

You can specify more than one sort key, where you want a primary sort key, a secondary sort key, etc.

If you specify more than one entry for job_sort_key, the first entry is the primary sort key, the second entry is the secondary sort key, which is used to sort equal-valued entries from the first sort, and so on.

Each entry is specified one to a line.

To sort jobs on a key, set the job_sort_key scheduler parameter:

- Set the desired key
- Specify whether high or low results should come first
- Specify the primetime behavior

A scheduler's configuration file is read on startup and HUP.

4.9.45.3 Examples of Sorting Jobs on Key

Example 4-29: Sort jobs so that those with long walltime come first:

```
job_sort_key: "walltime HIGH"
```

Example 4-30: For example, if you want big jobs to run first, where "big" means more CPUs, and if the CPUs are the same, more memory, sort on the number of CPUs requested, then the amount of memory requested:

```
job_sort_key: "ncpus HIGH" all
job_sort_key: "mem HIGH" all
```

Example 4-31: Sort jobs so that those with lower memory come first:

```
job_sort_key: "mem LOW" prime
```

Example 4-32: Sort jobs according to the value of an invisible custom resource called *JobOrder*:

```
job_sort_key: "JobOrder LOW" all
```

4.9.45.4 Caveats and Advice for Sorting Jobs on Key

- Do not use fairshare_perc as the sort key when using fairshare, meaning the fair_share scheduler parameter is enabled. If you do this, a scheduler will attempt to sort a set of jobs where each job has the same sort key value. This will not sort the jobs.
- Use the fairshare_perc option only when ordering jobs by entity shares. See section 4.9.14, “Sorting Jobs by Entity Shares (Was Strict Priority)”, on page 133.
- To run big jobs first, use ncpus as the primary sort key for job_sort_key:
  ```
  job_sort_key: "ncpus HIGH"
  ```
- The job_sort_key parameter is overridden by the job sorting formula and by fairshare. It is invalid to set both job_sort_formula and job_sort_key at the same time. If they are both set, job_sort_key is ignored and the following error message is logged:
  ```
  "Job sorting formula and job_sort_key are incompatible.  The job sorting formula will be used."
  ```
- A scheduler's configuration file contains an example line for job_sort_key. This line is commented out, but shows an example of job_sort_key with "*cput*" as the sorting key.
- The preempt_priority argument to the job_sort_key parameter is **deprecated**. Jobs are now automatically sorted by preemption priority when preemption is enabled.

4.9.46 Sorting Jobs by Requested Priority

You can sort jobs according to the priority that was requested for the job. This value is found in the job's Priority attribute. You can use this value in the following ways:

- The term job_priority represents the value of the job's priority attribute in the job sorting formula. See section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.
- The job_sort_key scheduler parameter can take the term job_priority as an argument. The term *job_priority* represents the value of the job's Priority attribute. See section 4.9.45, "Sorting Jobs on a Key", on page 223.

You can use a hook to set or change the value of a job's Priority attribute. See the PBS Professional Hooks Guide.

4.9.47 Sorting Queues into Priority Order

PBS always sorts all the execution queues in your partition or complex according to their priority, and uses that ordering when examining queues individually. Queues are ordered with the highest-priority queue first.

If you want queues to be considered in a specific order, you must assign a different priority to each queue. Give the queue you want considered first the highest priority, then the next queue the next highest priority, and so on. To set a queue's priority, use the `qmgr` command to assign a value to the priority queue attribute.

```
Qmgr: set queue <queue name> priority = <value>
```

Sorting queues into priority order is useful for the following:

- Examining queues one at a time. See section 4.9.4, "Examining Jobs Queue by Queue", on page 112.
- Selecting jobs from queues in a round-robin fashion. See section 4.9.38, "Round Robin Queue Selection", on page 206.

4.9.47.1 Caveats and Advice when Sorting Queues

- If you do not set queue priorities, queue ordering is undefined.
- The sort_queues parameter is **obsolete** (version 20).

4.9.48 Starving Jobs

PBS can keep track of the amount of time a job has been waiting to run, and then mark the job as *starving* if this time has passed a specified limit. You can use this starving status in calculating both execution and preemption priority.

4.9.48.1 Enabling Starving

You enable tracking whether jobs are starving by setting the help_starving_jobs scheduler parameter to *True*.

You specify the amount of time required for a job to be considered starving in the max_starve scheduler parameter. The default for this parameter is 24 hours.

The help_starving_jobs parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time. See "help_starving_jobs" on page 253 of the PBS Professional Reference Guide.

4.9.48.2 Time Used for Starving

PBS can use one of the following kinds of time to determine whether a job is starving:

- The job's eligible wait time, described in section 4.9.13, "Eligible Wait Time for Jobs", on page 128
- The amount of time the job has been queued

You specify which to use in the server's eligible_time_enable attribute. When eligible_time_enable is set to *True*, each job's eligible_time value is used as its wait time for starving. If eligible_time_enable is set to *False*, the amount of time the job has been queued is used as its wait time for starving. The default for eligible_time_enable is *False*.

If the server's eligible_time_enable attribute is set to *False*, the following rules apply:

- The amount of time the job has been queued is used as its wait time for starving.
- Jobs lose their queue wait time whenever they are requeued, as with the `qrerun` command. This includes when they are checkpointed or requeued (but not suspended) during preemption.
- Suspended jobs do not lose their queue wait time. However, when they become suspended, the amount of time since they were submitted is counted towards their queue wait time. For example, if a job was submitted, then remained queued for 1 hour, then ran for 26 hours, then was suspended, if max_starve is 24 hours, then the job will become starving.

If the server's eligible_time_enable attribute is set to *True*, the following rules apply:

- The job's eligible_time value is used as its wait time for starving.
- Jobs do not lose their eligible_time when they are requeued.
- Jobs do not lose their eligible_time when they are suspended.

4.9.48.3 Starving and Job Priority

Starving is one of the job classes used by PBS to calculate job execution priority. If you enable starving jobs, PBS will classify starving jobs in the Starving class, which gives them greater than ordinary priority. See section 4.9.16, “Calculating Job Execution Priority”, on page 136. Each job's eligible wait time can also be used in the job sorting formula used to calculate job execution priority. See section 4.9.21, “Using a Formula for Computing Job Execution Priority”, on page 151.

Starving is one of the job classes that you can use when specifying how preemption should work. You can choose how much preemption priority is given to starving jobs when you set preemption levels. See section 4.9.33, “Using Preemption”, on page 182.

4.9.48.4 Parameters and Attributes Affecting Starving

The following table lists the parameters and attributes that affect starving:

Table 4-20: Parameters and Attributes Affecting Starving

Parameter or Attribute	Location	Effect
help_starving_jobs	`<sched_priv directory>/sched_config`	Controls whether long-waiting jobs are considered starving. When set to *True*, jobs can be starving. Default: *True all*
max_starve	`<sched_priv directory>/sched_config`	Amount of wait time for job to be considered starving. Default: 24 hours.
eligible_time_enable	Server attribute	Controls whether a job's wait time is taken from its eligible_time or from its queued time. When set to *True*, a job's eligible_time is used as its wait time. Default: *False*.
eligible_time	Job attribute	The amount of time a job has been blocked from running due to lack of resources.

4.9.48.5 Starving and Queued or Running Jobs

A job can only accumulate starving time while it waits to run, not while it runs. When a job is running, it keeps the starving status it had when it was started. While a job is running, if it wasn't starving before, it can't become starving. However, it keeps its starving status if it became starving while queued.

4.9.48.6 Starving and Subjobs

Subjobs that are queued can become starving. Starving status is applied to individual subjobs in the same way it is applied to jobs. The queued subjobs of a job array can become starving while others are running. If a job array has starving subjobs, then the job array is starving.

4.9.48.7 Starving and Backfilling

Because a starving job can become a top job, but can continue to be unable to run due to a lack of resources, you may find it useful to use backfilling around starving jobs. See section 4.9.3, “Using Backfilling”, on page 107.

4.9.48.8 Starving Caveats

Do not enable starving with fairshare, meaning do not set both the fair_share and help_starving_jobs scheduler parameters to *True*.

4.9.49 Using Strict Ordering

By default, when scheduling jobs, PBS orders jobs according to execution priority, then considers each job, highest-priority first, and runs the next job that can run now. Using strict ordering means that you tell PBS that it must not skip a job when choosing which job to run. If the top job cannot run, no job runs.

Strict ordering does not change how execution priority is calculated.

4.9.49.1 Configuring Strict Ordering

To configure strict ordering, set the strict_ordering scheduler parameter to *True*.

The strict_ordering parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time. See “strict_ordering” on page 259 of the PBS Professional Reference Guide.

4.9.49.2 How Strict Ordering Works

When strict_ordering is *True*, a scheduler runs jobs in exactly the order of their priority.

Strict ordering does not affect how job priority is calculated, but it does change which execution priority classes a scheduler uses; see section 4.9.16, “Calculating Job Execution Priority”, on page 136.

4.9.49.3 Combining Strict Ordering and Backfilling

Strict ordering alone may cause some resources to stand idle while the top job waits for resources to become available. If you want to prevent this, you can use backfilling with strict ordering. Using backfilling, if the top job cannot run, filler jobs can be squeezed in around the job that cannot run. See section 4.9.3, “Using Backfilling”, on page 107.

4.9.49.4 Strict Ordering and Calendaring

If you mark a job's topjob_ineligible attribute *True*, PBS does not put that job in the calendar if it cannot run right now. See section 4.9.17, "Calendaring Jobs", on page 139.

4.9.49.5 Strict Ordering Caveats

- It is inadvisable to use strict ordering and backfilling with fairshare. The results may be non-intuitive. Fairshare will cause relative job priorities to change with each scheduling cycle. It is possible that a job from the same entity or group as the desired large job will be chosen as the filler job. The usage from these filler jobs will lower the priority of the top job.

  For example, if a user has a large job that is the top job, and that job cannot run, smaller jobs owned by that user will chew up the user's usage, and prevent the large job from being likely to ever run. Also, if the small jobs are owned by a user in one area of the fairshare tree, no large jobs owned by anyone else in that section of the fairshare tree are likely to be able to run.
- Using dynamic resources with strict ordering and backfilling may result in unpredictable scheduling. See section 4.9.3.11, "Backfilling Recommendations and Caveats", on page 111.
- Using preemption with strict ordering and backfilling may change which job is the top job.
- With both round robin and strict ordering, a job continually rejected by a runjob hook may prevent other jobs from being run. A well-written hook would put the job on hold or requeue the job at some later time to allow other jobs in the same queue to be run.

4.9.50 Sorting Vnodes on a Key

PBS can sort vnodes according to a key that you specify. This can be used when deciding which vnodes to use for jobs. Sorting vnodes comes into play after a placement set has been selected, or when a job will run on vnodes associated with a queue, or when placement sets are not used, because in those cases there may be more vnodes available than are needed. You can sort vnodes on one or more different keys, and for each key, you can sort from high to low, or the reverse.

You can sort on the last_used_time and Priority vnode attributes, and vnode resources.

The default way to sort vnodes is according to the value of the vnode priority attribute, from higher to lower.

When you sort vnodes according to the assigned or unused amount of a resource, the vnode list is re-sorted after every job is run. This is because each job may change the usage for that resource.

You configure sorting vnodes on a key by setting values for the node_sort_key scheduler parameter.

The node_sort_key parameter is a primetime option, meaning that you can configure it separately for primetime and non-primetime, or you can specify it for all of the time.

When vnodes are not sorted on a key, their order is undefined.

4.9.50.1 node_sort_key Syntax

node_sort_key: "sort_priority HIGH | LOW" <prime option>

node_sort_key: "<resource name> HIGH | LOW' <prime option>

node_sort_key: "<resource name> HIGH | LOW total | assigned | unused" <prime option>

where

total

Use the resources_available value

assigned

Use the resources_assigned value

unused

Use the value given by resources_available - resources_assigned

Specifying a resource such as mem or ncpus sorts vnodes by the resource specified. Note that a scheduler rounds all resources of type size, including mem , up to the nearest kb.

Specifying the sort_priority keyword sorts vnodes on the vnode priority attribute.

The default third argument for a resource is *total*. If the third argument, *total* | *assigned* | *unused*, is not specified with a resource, *total* is used. This provides backwards compatibility with previous releases.

The values used for sorting must be numerical.

4.9.50.2 Configuring Sorting Vnodes on a Key

You can specify up to 20 sort keys, where you want a primary sort key, a secondary sort key, etc.

If you specify more than one entry for node_sort_key, the first entry is the primary sort key, the second entry is the secondary sort key, which is used to sort equal-valued entries from the first sort, and so on.

Each entry is specified one to a line.

To sort jobs on a key, set the node_sort_key scheduler parameter:

- Set the desired key
- Specify whether high or low results should come first
- For sorting on a resource, optionally specify total, assigned, or unused
- Specify the primetime behavior

A scheduler's configuration file is read on startup and HUP.

The argument to the node_sort_key parameter is a quoted string. The default for node_sort_key is the following:

```
node_sort_key: "sort_priority HIGH" all
```

See "node_sort_key" on page 255 of the PBS Professional Reference Guide.

4.9.50.3 Sorting Vnodes According to Load Average

To place jobs on the vnodes with the lowest load:

- Create a custom host-level resource to reflect current load, named for example "r5m":
  ```
  qmgr -c "create resource aveload type=long,flag=h"
  ```
- Write an exechost_periodic hook to set the resource to the value of the load average; see "Log loads on vnodes" on page 284 in the PBS Professional Installation & Upgrade Guide for an example of an exechost_periodic hook that reads the load on the host.
- Use the aveload resource as your node_sort_key:
  ```
  node_sort_key: "r5m LOW" all
  ```

4.9.50.4 Examples of Sorting Vnodes

Example 4-33: This sorts vnodes by the highest number of unused CPUs:

```
node_sort_key: "ncpus HIGH unused" all
```

Example 4-34: This sorts vnodes by the highest amount of memory assigned to vnodes, but only during primetime:

```
node_sort_key: "mem HIGH assigned" prime
```

Example 4-35: This sorts vnodes according to speed. You want to run jobs on the fastest host available. You have 3 machines, where HostA is fast, HostB is medium speed, and HostC is slow.

Set node priorities so that faster machines have higher priority:

```
Qmgr: set node HostA priority = 200
Qmgr: set node HostB priority = 150
Qmgr: set node HostC priority = 100
```

Specify that vnodes are sorted according to priority, with highest priority first:

```
node_sort_key: "sort_priority HIGH" ALL
```

Example 4-36: The old "nodepack" behavior can be achieved by this:

```
node_sort_key: "ncpus low unused"
```

Example 4-37: In this example of the interactions between placement sets and node_sort_key, we have 8 vnodes numbered 1-8. The vnode priorities are the same as their numbers. However, in this example, when unsorted, the vnodes are selected in the order 4, 1, 3, 2, 8, 7, 5, 6. This is to illustrate the change in behavior due to node_sort_key.

We use:

```
node_sort_key: "sort_priority LOW"
```

Using node_sort_key, the vnodes are sorted in order, 1 to 8. We have three placement sets:

A: 1, 2, 3, 4 when sorted by node_sort_key; 4, 1, 3, 2 when no node_sort_key is used

B: 5, 6, 7, 8 when sorted by node_sort_key; 8, 7, 5, 6 when no node_sort_key is used

C: 1-8 when sorted, 4, 1, 3, 2, 8, 7, 5, 6 when not sorted.

A 6-vnode job will not fit in either A or B, but will fit in C. Without the use of node_sort_key, it would get vnodes 4, 1, 3, 2, 8, 7. With node_sort_key, it would get vnodes 1 - 6, still in placement set C.

4.9.50.5 Caveats for Sorting Vnodes

- Sorting on a resource with node_sort_key and using "unused" or "assigned" cannot be used with load_balancing. If both are used, load balancing will be disabled.
- Sorting on a resource and using "unused" or "assigned" cannot be used with smp_cluster_dist when it is set to anything but "pack". If both are used, smp_cluster_dist will be set to "pack".
- A scheduler rounds all resources of type size, including mem, up to the nearest kb. This can affect how vnodes are sorted when you are sorting on mem.

5 Using PBS Resources

This chapter covers PBS resources, including providing resources for user jobs, setting up resources such as application licenses and scratch space, how to make objects inherit resources, and how to use, define, and view resources.

For a list of built-in and custom Cray XC resources automatically created by PBS, see “List of Built-in Resources” on page 261 of the PBS Professional Reference Guide.

5.1 Chapter Contents

5.2 Introduction to PBS Resources

PBS resources represent things such as CPUs, memory, application licenses, switches, scratch space, and time. They can also represent whether or not something is true, for example, whether a machine is dedicated to a particular project. PBS provides a set of built-in resources, and allows you to define additional custom resources. For some systems, PBS creates specific custom resources. The scheduler matches requested resources with available resources, according to rules defined by the administrator. PBS can enforce limits on resource usage by jobs. The administrator can specify which resources are available at the server, each queue, and each vnode.

5.3 Glossary

Reservation

A reservation for a specific set of resources for a specified start time and duration in the future. See section 4.9.37, “Reservations”, on page 199.

Borrowing vnode

A shared vnode resource is available for use by jobs at more than one vnode, but is managed at just one vnode. A *borrowing vnode* is a vnode where a shared vnode resource is available, but not managed.

Built-in resource

A resource that is defined in PBS Professional as shipped. Examples of built-in resources are ncpus, which tracks the number of CPUs, and mem, which tracks memory. See section 5.4.1, “Built-in vs. Custom Resources”, on page 235.

Chunk

A set of resources allocated as a unit to a job. Specified inside a selection directive. All parts of a chunk come from the same host. In a typical MPI (Message-Passing Interface) job, there is one chunk per MPI process.

Consumable resource

A consumable resource is a resource that is reduced or taken up by being used. Examples of consumable resources are memory or CPUs. See section 5.4.3, “Consumable vs. Non-consumable Resources”, on page 236.

CPU

Has two meanings, one from a hardware viewpoint, and one from a software viewpoint:

1. A core. The part of a processor that carries out computational tasks. Some systems present virtual cores, for example in hyperthreading.
2. Resource required to execute a program thread. PBS schedules jobs according, in part, to the number of threads, giving each thread a core on which to execute. The resource used by PBS to track CPUs is called "*ncpus*". The number of CPUs available for use defaults to the number of cores reported by the OS. When a job requests one CPU, it is requesting one core on which to run.

Custom resource

A resource that is not defined in PBS as shipped. Custom resources are created by the PBS administrator or by PBS for some systems. See section 5.4.1, “Built-in vs. Custom Resources”, on page 235 and section 5.14, “Custom Resources”, on page 257.

Floating license

A unit of license dynamically allocated (checked out) when a user begins using an application on some host (when the job starts), and deallocated (checked in) when a user finishes using the application (when the job ends).

Generic group limit

A limit that applies separately to groups at the server or a queue. This is the limit for groups which have no individual limit specified. A limit for generic groups is applied to the usage across the entire group. A separate limit can be specified at the server and each queue.

Generic user limit

A limit that applies separately to users at the server or a queue. This is the limit for users who have no individual limit specified. A separate limit for generic users can be specified at the server and at each queue.

Global resource

A global resource is defined in a resources_available attribute, at the server, a queue, or a host. Global resources can be operated on via the `qmgr` command and are visible via the `qstat` and `pbsnodes` commands. See section 5.4.5, “Global vs. Local Resources”, on page 237.

Group limit

Refers to configurable limits on resources and jobs. This is a limit applied to the total used by a group, whether the limit is a generic group limit or an individual group limit.

Indirect resource

A shared vnode resource at vnode(s) where the resource is not defined, but which share the resource.

Individual group limit

Applies separately to groups at the server or a queue. This is the limit for a group which has its own individual limit specified. An individual group limit overrides the generic group limit, but only in the same context, for example, at a particular queue. The limit is applied to the usage across the entire group. A separate limit can be specified at the server and each queue.

Individual user limit

Applies separately to users at the server or a queue. This is the limit for users who have their own individual limit specified. A limit for an individual user overrides the generic user limit, but only in the same context, for example, at a particular queue. A separate limit can be specified at the server and each queue.

Limit

A maximum that can be applied in various situations:

- The maximum number of jobs that can be queued
- The maximum number of jobs that can be running
- The maximum number of jobs that can be queued and running
- The maximum amount of a resource that can be allocated to queued jobs
- The maximum amount of a resource that can be consumed at any time by running jobs
- The maximum amount of a resource that can be allocated to queued and running jobs

Local resource

A local resource is defined in a Version 1 MoM configuration file. Local resources cannot be operated on via the `qmgr` command and are not visible via the `qstat` and `pbsnodes` commands. Local resources can be used by the scheduler. See section 5.4.5, "Global vs. Local Resources", on page 237.

Managing vnode

The vnode where a shared vnode resource is defined, and which manages the resource.

Memory-only vnode

Represents a node board that has only memory resources (no CPUs).

Non-consumable resource

A non-consumable resource is a resource that is not reduced or taken up by being used. Examples of non-consumable resources are Boolean resources and walltime. See section 5.4.3, "Consumable vs. Non-consumable Resources", on page 236.

Overall limit

Limit on the total usage. In the context of server limits, this is the limit for usage at the PBS complex. In the context of queue limits, this is the limit for usage at the queue. An overall limit is applied to the total usage at the specified location. Separate overall limits can be specified at the server and each queue.

Resource

A *resource* can be something used by a job, such as CPUs, memory, high-speed switches, scratch space, licenses, or time, or it can be an arbitrary item defined for another purpose. PBS provides built-in resources, and allows custom-defined resources.

Shared resource

A vnode resource defined and managed at one vnode, but available for use at other vnodes.

User limit

Refers to configurable limits on resources and jobs. A user's limit, whether generic or individual.

5.4 Categories of Resources

A PBS resource has several defining characteristics describing where and how it is used, how it was defined, etc. Each characteristic puts it in one of a set of categories. A resource inhabits several categories at once; for example, a resource can be a custom global static consumable server resource. We describe the sets of categories below.

5.4.1 Built-in vs. Custom Resources

Built-in resources are the resources that are already defined for you in PBS. PBS supplies built-in resources including number of CPUs, CPU time, and memory. For a list of built-in resources, see "Resources Built Into PBS" on page 267 of the PBS Professional Reference Guide. Custom resources are those that you define, or that PBS creates for some systems. For example, if you wanted a resource to represent scratch space, you could define a resource called *Scratch*, and specify a script which queries for the amount of available scratch space. See section 5.14, "Custom Resources", on page 257.

5.4.2 Server vs. Queue vs. Vnode Resources

PBS resources can be available at the server, queues, both the server and queues, or at vnodes. Any of these resources can be static or dynamic, built-in or custom, and consumable or non-consumable. Vnode resources can additionally be global or local.

5.4.2.1 Server Resources

A server resource, also called a server-level resource, is a resource that is available at the server. A server resource is available to be consumed or matched at the server if you set the server's resources_available.<resource name> attribute to the available or matching value. For example, you can define a custom resource called *FloatingLicenses* and set the server's resources_available.FloatingLicenses attribute to the number of available floating licenses.

A server resource is a job-wide resource. This means that a job can request this resource for the entire job, but not for individual chunks.

An example of a job-wide resource is shared scratch space, or any custom resource that is defined at the server and queue level.

5.4.2.2 Queue Resources

A queue resource, also called a queue-level resource, is available to be consumed or matched by jobs in the queue if you set the queue's resources_available.<resource name> attribute to the available or matching value.

A queue resource is a job-wide resource. A job can request a queue resource for the entire job, but not for individual chunks.

An example of a job-wide resource is floating licenses, or any custom resource that is defined at both server and queue level.

5.4.2.3 Resources Defined at Both Server and Queue

Custom resources can be defined to be available either at vnodes or at both the server and queues. Consumable custom resources that are defined at the server and queue level have their consumption monitored at the server and queue level. In our example, if a job requests one FloatingLicenses, then the value of the resources_assigned.FloatingLicenses attribute is incremented by one at both the server and the queue in which the job resides.

5.4.2.4 Vnode Resources

A vnode resource, also called a vnode-level or host-level resource, is available only at vnodes. A vnode resource is a chunk-level resource, meaning that it can be requested for a job only inside of a chunk.

5.4.3 Consumable vs. Non-consumable Resources

A *consumable* resource is one that is reduced by being used. Consumable resources include ncpus, mem and vmem by default, and any custom resource defined with the -n or -f flags.

A *non-consumable* resource is not reduced through use, meaning that allocation to one job does not affect allocation to other jobs. The scheduler matches jobs to non-consumable resources. Examples of non-consumable resources are walltime, file, cput, pcput, pmem, pvmem, nice, or Boolean resources.

The following table shows which resource types are consumable:

Table 5-1: Consumable and Non-consumable Resources

Resource Type	Consumable vs. Non-consumable
Boolean	Non-consumable
duration	Non-consumable
float	Consumable
long	Consumable
Size	Consumable
string	Non-consumable
string_array	Non-consumable

5.4.4 Static vs. Dynamic Resources

Static resources are managed by PBS and have values that are fixed until you change them or until you change the hardware and MoM reports a new value for memory or number of CPUs.

Dynamic resources are not under the control of PBS, meaning that they can change independently of PBS. Dynamic resources are reported via a script; PBS runs a query to discover the available amount. Server dynamic resources use a script that runs at the server host. Host-level (MoM) dynamic resources use a script that runs at the execution host.

Static and dynamic resources can be available at the server or host level.

The default timeout for a server dynamic resource script is 30 seconds. You can specify a timeout for server dynamic resources in each scheduler's server_dyn_res_alarm attribute. If the script does not finish before the timeout, the scheduler uses a value of zero for the dynamic server resource. If you set the timeout to zero, the scheduler does not place a time limit on the script.

5.4.4.1 Dynamic Resource Caveats

- Dynamic resource values are displayed in `qstat`, but the value displayed is the last value retrieved, not the current value. Dynamic resources have no resources_available.<resource name> representation anywhere in PBS.
- Dynamic resources can take longer to discover because PBS runs a script to determine each one.

5.4.5 Global vs. Local Resources

5.4.5.1 Global Static Resources

Global static resources are defined in resources_available attributes at the server, queue, or vnode, and are available at the server, queue, or vnode level. Global static resources can be operated on via the `qmgr` command and viewed via the `qstat` command. Values for built-in global static resources are set via the `qmgr` command. The walltime and aoe resources are examples of global static resources. For custom global static resources, see section 5.14.2.8, "Example of Defining Each Type of Custom Resource", on page 267.

5.4.5.2 Global Dynamic Resources

Global dynamic resources can be used at the server, queue, or vnode level. Global host-level dynamic resources can be viewed via the `qstat` command. Server dynamic resource values have no resources_available.<resource name> representation anywhere in PBS. See section 5.14.3.1, "Creating Server Dynamic Resource Scripts", on page 268.

The value displayed via `qstat` for a dynamic resource is the most recently retrieved, not the current value.

5.4.5.3 Local Static Resources

It is not recommended to use local static resources. Local static resources are defined in the MoM Version 1 configuration file. These resources cannot be operated on via the `qmgr` command or viewed via the `qstat` command. They have no entry in the vnode's resources_available.<resource name> resources. They can be used by the scheduler.

5.4.5.4 Local Dynamic Resources

Dynamic local resources are defined in the MoM Version 1 configuration file. These are scripts that run on the execution host where they are defined and return a value. These resources can be used by the scheduler. Host dynamic resource values have no resources_available.<resource name> representation anywhere in PBS. See section 5.14.4.1, "Dynamic Host-level Resources", on page 271.

The value displayed via `qstat` for a dynamic resource is the most recently retrieved, not the current value.

5.4.6 Requested vs. Default Resources

A job's requested resources are the resources explicitly requested by the job. Default resources are resources that you specify that each job should have if not requested. For example, you can specify that any job that does not request walltime gets 12 hours of walltime. For jobs that do request walltime, the default of 12 hours is not applied.

For information on default resources, see section 5.9.3, "Specifying Job Default Resources", on page 247 and section 5.9.4, "Allocating Default Resources to Jobs", on page 249.

5.4.7 Shared vs. Non-shared Vnode Resources

5.4.7.1 Non-shared Vnode Resources

Most vnode resources are not shared. When a resource is defined at one vnode for use by jobs only at that vnode, the resource is not shared. For example, when resources_available.ncpus is set to *4* on a single-vnode machine, and no other vnodes have resources_available.ncpus defined as a pointer to this resource, this resource is not shared.

5.4.7.2 Shared Vnode Resources

When more than one vnode needs access to the same actual resource, that resource can be shared among those vnodes. The resource is defined at one vnode, and the other vnodes that supply the resource contain a pointer to that vnode. Any of the vnodes can supply that resource to a job, but only up to the amount where the total being used by jobs is less than or equal to the total available at the vnode where the resource is defined. For example, if you had a 4-vnode machine which had 8GB of memory, and wanted any single vnode to be able to supply up to 8GB to jobs, you would make the memory a shared resource. See section 5.14.4.3, "Shared Host-level Resources", on page 273.

5.4.8 Platform-specific vs. Generally Available Resources

Most PBS built-in resources are available on, and apply to, all supported platforms. However, PBS provides some resources specifically designed for a given platform. These platform-specific resources are not applicable to any other platform, and cannot be used on platforms other than the one(s) for which they are designed. For example, PBS creates custom resources that represent Cray XC elements, such as the Cray XC nid and the Cray XC label.

5.4.9 Job-wide vs. Chunk Resources

5.4.9.1 Job-wide Resources

A job-wide resource applies to the entire job, and is available at the server or queue, but not at the host level. Job-wide resources are requested outside of a select statement, using this form:

-l <resource name>=<value>

For example, to request one hour of walltime for a job:

-l walltime=1:00:00

Examples of job-wide resources are walltime, scratch space, and licenses.

5.4.9.2 Chunk Resources

A chunk resource applies to the part of the job running on that chunk, and is available at the host level. Chunk resources are requested inside a select statement. A single chunk is requested using this form:

-l select=<resource name>=<value>:<resource name>=<value>

For example, one chunk might have 2 CPUs and 4GB of memory:

```
    -l select=ncpus=2:mem=4gb
```

To request multiples of a chunk, prefix the chunk specification by the number of chunks:

-l select=[number of chunks]<chunk specification>

For example, to request six of the previous chunk:

```
    -l select=6:ncpus=2:mem=4gb
```

To request different chunks, concatenate the chunks using the plus sign ("+"):

-l select=[number of chunks]<chunk specification>+[number of chunks]<chunk specification>

For example, to request two kinds of chunks, one with 2 CPUs per chunk, and one with 8 CPUs per chunk, both kinds with 4GB of memory:

```
    -l select=6:ncpus=2:mem=4gb+3:ncpus=8:mem=4GB
```

5.5 Resource Types

PBS supplies the following types of resources:

- Boolean
- Duration
- Float
- Long
- Size
- String
- String Array

5.6 Resource Formats

Custom resources follow the same rules as built-in resources: custom resource names must be PBS NAMEs, allowable values for float and long resources are the same as for built-in resources, and custom Boolean, time, size, string or string array resources must have the same format as built-in resources.

Boolean

Name of Boolean resource is a string.

Values:

TRUE, True, true, T, t, Y, y, 1

FALSE, False, false, F, f, N, n, 0

Duration

A period of time, expressed either as

An integer whose units are seconds

or

[[hours:]minutes:]seconds[.milliseconds]

in the form:

[[HH:]MM:]SS[.milliseconds]

Milliseconds are rounded to the nearest second.

Float

Floating point. Allowable values: [+-] 0-9 [[0-9] ...][.][[0-9] ...]

Long

Long integer. Allowable values: 0-9 [[0-9] ...], and + and -

<queue name>@<server name>

Size

Number of bytes or words. The size of a word is 64 bits.

Format: *<integer>[<suffix>]*

where *suffix* can be one of the following:

Table 5-2: Size in Bytes

Suffix	Meaning	Size
b or w	Bytes or words	1
kb or kw	Kilobytes or kilowords	2 to the 10th, or 1024
mb or mw	Megabytes or megawords	2 to the 20th, or 1,048,576
gb or gw	Gigabytes or gigawords	2 to the 30th, or 1,073,741,824
tb or tw	Terabytes or terawords	2 to the 40th, or 1024 gigabytes
pb or pw	Petabytes or petawords	2 to the 50th, or 1,048,576 gigabytes

Default: *bytes*

Note that a scheduler rounds all resources of type size up to the nearest kb.

String

Any character, including the space character.

Only one of the two types of quote characters, " or ', may appear in any given value.

Values:[_a-zA-Z0-9][[-_a-zA-Z0-9 ! " # $ % ´ ( ) * + , - . / : ; < = > ? @ [\ ] ^ _ ' { | } ~] ...]

String resource values are case-sensitive. No limit on length.

String Array

Comma-separated list of strings.

Strings in string_array may not contain commas. No limit on length.

Python type is *str*.

A string array resource with one value works exactly like a string resource.

5.6.1 Resource Names

Resource names are case-insensitive PBS NAMEs. Resource names can be 64 characters in length.

This is a generic term, used to describe various PBS entities. For example, attribute names are PBS NAMEs.

Must start with an alphabetic character, and may contain only the following: alpha-numeric, underscore ("_"), or dash ("-").

Do not use PBS keywords as PBS NAMEs.

5.7 Setting Values for Resources

5.7.1 How Resource Values are Set

PBS automatically collects information about some resources such as ncpus and mem and sets their initial values accordingly. If you explicitly set the value for a resource, that value is carried forth across server restarts.

Since the value for each dynamic resource is set by PBS to the value returned by a script or command, it makes sense set values for static resources only.

Resources that are not explicitly set can inherit their values from defaults. Jobs can inherit default resources; see section 5.9.4, "Allocating Default Resources to Jobs", on page 249.

You set values for custom and built-in resources using the same methods. You can set resource values using the following methods:

- Using `qmgr`:

  To set the available amount of a non-string_array resource, use the `qmgr` command, either from the command line or within `qmgr`:

  ```
  qmgr -c "set <object> ressources_available.<resource name> = <value>"
  Qmgr: set <object> resources_available.<resource name> = <value>
  ```

  To set or change the available amount of a string_array resource, use the `qmgr` command, either from the command line or within `qmgr`:

  ```
  qmgr -c "set <object> resources_available.<resource name> = <value>"
  qmgr -c 'set <object> resources_available.<resource name> = "<value,value>"'
  qmgr -c 'set <object> resources_available.<resource name> += <value>'
  qmgr -c 'set <object> resources_available.<resource name> -= <value>'
  Qmgr: set <object> resources_available.<resource name> = <value>
  Qmgr: set <object> resources_available.<resource name> = '<value,value>'
  Qmgr: set <object> resources_available.<resource name> += <value>
  Qmgr: set <object> resources_available.<resource name> -= <value>
  ```

  To unset the value of an attribute:

  ```
  qmgr -c "unset <object> resources_available.<resource name>"
  Qmgr: unset <object> resources_available.<resource name>
  ```

  where *<object>* is one of *server*, *queue*, *hook*, *node*, or *sched*.

  For example, to set resources_max.walltime at the server to be 24 hours:

  ```
  Qmgr: set server resources_max.walltime = 24:00:00
  ```

  See "qmgr" on page 150.
- Using a Version 2 configuration file; see section 3.4.3, "Version 2 Vnode Configuration Files", on page 44.
- Setting the value in a hook; see "Using Attributes and Resources in Hooks" on page 44 in the PBS Professional Hooks Guide.

5.7.1.1 How Vnode Available Resource Values are Set

PBS stores values for the global resources available at a vnode in that vnode's resources_available.<resource name> attribute.

5.7.1.1.i Vnode Resources Set by PBS

PBS automatically sets the value for certain resources available at each vnode, meaning that PBS sets the value for the vnode's resources_available.<resource name> attribute. For example, PBS automatically sets the value of resources_available.ncpus at each vnode. The following table lists the vnode resources that are set automatically by PBS.

Table 5-3: Resources Set by PBS

Resource Name	Initial Value	Notes
arch	*Value reported by OS*	Settable. If you unset the value, it remains unset until MoM is restarted.
host	*Short form of hostname in Mom vnode attribute*	Settable. If you unset the value, it remains unset until MoM is restarted.
mem	*Amount reported by OS*	Settable. If you unset the value, it remains unset until MoM is restarted.
ncpus	*Number of CPUs reported by OS*	Settable. If you unset this value, the MoM will reset it to the value reported by the OS.
PBScrayhost	*On CLE 3.0 and higher, set to value of mpp_host for this system*	Do not set.
PBScraylabel_<label name>	*Concatenation of PBScraylabel_ and label name. Set to True on all of node's vnodes .*	Do not set.
PBScraynid	*Value of node_id for this compute node*	Do not set.
PBScrayorder	Value starts at 1 and increments by 1 for each node in inventory	Do not set
router	*Name of router, from topology file*	Applies to vnodes on certain HPE systems only
vnode	*Name of the vnode*	Vnode name must be specified via the `qmgr create node` command.

5.7.1.1.ii Setting Vnode Resources Manually

You can set values for available vnode resources:

- You can set values for a vnode's resources_available in a hook. See "Setting and Unsetting Vnode Resources and Attributes" on page 48 in the PBS Professional Hooks Guide. If you set a vnode resource in a hook, MoM will no longer update the resource.
- You can set values for a vnode's resources_available attribute in a Version 2 configuration file; see section 3.4.3, "Version 2 Vnode Configuration Files", on page 44.
- You can set most values for a vnode's resources_available attribute using `qmgr`, but not for resources_available.host; see "Operating on Attributes and Resources" on page 159 of the PBS Professional Reference Guide.

5.7.1.2 Setting Server and Queue Resource Values

You can set resources, such as default and available resources, for queues and for the server, using `qmgr`:

```
Qmgr: set queue <queue name> resources_default<resource name> = <value>
Qmgr: set queue <queue name> resources_available.<resource name> = <value>
Qmgr: set server resources_available.<resource name> = <value>
```

5.7.1.3 Setting Job Resources

5.7.1.3.i Setting Requested Resource Values

Job resources, stored in the Resource_List job attribute, can be set initially at submission in the job request. You can augment or change these values. You can set values for a job's Resource_List attribute using hooks. See "Setting Job Resources in Hooks" on page 49 in the PBS Professional Hooks Guide.

5.7.1.3.ii Setting Used Resource Values

The resources used by a job are set in the job's resources_used attribute

You can set values for a job's resources_used attribute using hooks. These values will appear in the accounting log and in `qstat -f` output. See "Setting Job Resources in Hooks" on page 49 in the PBS Professional Hooks Guide.

5.7.1.3.iii Setting Estimated Values

If the `PBS_est` built-in hook is enabled, PBS automatically sets the value of the estimated.start_time job resource to the estimated start time for each job. Otherwise, PBS sets the value only for top jobs.

5.7.2 Setting Values for Global Static Resources

To set the value for a global vnode, queue, or server resource, use the `qmgr` command to set the value of the appropriate resources_available.<resource name> attribute.

Example 5-1: Set the value of floatlicenses at the server to *10*:

```
Qmgr: set server resources_available.floatlicenses = 10
```

Example 5-2: Set the value of RunsMyApp to *True* at the vnode named *vnode1*:

```
Qmgr: set node vnode1 resources_available.RunsMyApp = True
```

5.7.2.1 Restrictions on Setting Values for Global Static Resources

When setting global static vnode resources on multi-vnode machines, follow the rules in section 3.4.5, "Configuring Vnode Resources", on page 49.

5.7.3 Setting Values for Local Static Resources

It is not recommended to use local static resources, because these resources cannot be requested, and cannot be viewed using `qstat` or managed using `qmgr`. To set the value of a parent vnode resource, edit `PBS_HOME/mom_priv/config` and change the value section of the resource's line.

5.7.4 Setting Values for String Arrays

A string array that is defined on vnodes can be set to a different set of strings on each vnode.

Example of defining and setting a string array:

- Define a new resource:
  ```
  Qmgr: create resource foo_arr type=string_array, flag=h
  ```
- Setting via `qmgr`:
  ```
  Qmgr: set node n4 resources_available.foo_arr="f1, f3, f5"
  ```
- Vnode n4 has 3 values of `foo_arr`: f1, f3, and f5. We add f7:
  ```
  Qmgr: set node n4 resources_available.foo_arr+=f7
  ```
- Vnode n4 now has 4 values of `foo_arr`: f1, f3, f5 and f7.
- We remove f1:
  ```
  Qmgr: set node n4 resources_available.foo_arr-=f1
  ```
- Vnode n4 now has 3 values of foo_arr: f3, f5, and f7.
- Submission:
  ```
  qsub -l select=1:ncpus=1:foo_arr=f3
  ```

5.7.5 When Resource Changes Take Effect

If you change the value of a resource via the `qmgr` command, the change takes effect immediately.

If you change the value of a resource in a configuration file, the change takes effect the next time the configuration file is read.

5.7.6 Caveats for Setting Resource Values

- It is not recommended to set the value for resources_available.ncpus. The exception is when you want to oversubscribe CPUs. See section 9.6.5.1.iii, “How To Share CPUs”, on page 448.
- Do not attempt to set values for resources_available.<resource name> for dynamic resources.
- Do not set values for any resources, except those such as shared scratch space or floating licenses, at the server or a queue, because the scheduler will not allocate more than the specified value. For example, if you set resources_available.walltime at the server to *10:00:00*, and one job requests 5 hours and one job requests 6 hours, only one job will be allowed to run at a time, regardless of other idle resources.

5.7.6.1 Caveats for Setting Resource Values at Multi-vnode Machines

- When setting global static vnode resources on multi-vnode machines, follow the rules in section 3.4.5, “Configuring Vnode Resources”, on page 49.
- It is not recommended to change the value of ncpus at vnodes on a multi-vnoded machine.
- On the parent vnode, all values for resources_available.<resource name> should be *zero* (*0*), unless the resource is being shared among other vnodes via indirection.

5.8 Overview of Ways Resources Are Used

Resources are used in several ways in PBS. The following table lists the ways resources are used, and gives links to the section describing each one:

Table 5-4: How Resources Are Used

Use	Description
Allocation to and use by jobs	See section 5.9, “Resources Allocated to Jobs and Reservations”, on page 246
Limiting job resource usage	See section 5.15.2, “Placing Resource Limits on Jobs”, on page 307
Restricting access to server and queues	See section 5.13, “Using Resources to Restrict Server or Queue Access”, on page 256
Routing jobs	See section 2.3.6.4, “Using Resources to Route Jobs Between Queues”, on page 28
Describing topology and placing jobs	See section 5.11, “Using Resources for Topology and Job Placement”, on page 255
Setting job execution priority	See section 5.12, “Using Resources to Prioritize Jobs”, on page 256
Reserving resources ahead of time	See section 4.9.37, “Reservations”, on page 199.
Tracking and controlling allocation	See section 5.10, “Using Resources to Track and Control Allocation”, on page 254
Determining job preemption priority	See section 4.9.33, “Using Preemption”, on page 182

5.8.1 How the Scheduler Uses Resources

How the scheduler uses resources is described in section 4.9.28, “Matching Jobs to Resources”, on page 161.

5.8.2 Advice on Using string and string_array Resources

Resource names are case-insensitive.

5.8.2.1 Using string Resources

Format of string resources:

Any character, including the space character.

Only one of the two types of quote characters, " or ', may appear in any given value.

Values:[_a-zA-Z0-9][[-_a-zA-Z0-9 ! " # $ % ´ ( ) * + , - . / : ; < = > ? @ [\ ] ^ _ ' { | } ~] ...]

String resource values are case-sensitive. No limit on length.

Non-consumable.

We do not recommend using non-printing characters.

When using `qsub -l <string resource>=<string value>`, you must escape string values for both `qsub` and the shell. Example:

```
qsub -lteststring='\"abc def\"'
```

The final quote should be single, not double.

5.8.2.2 Using string_array Resources

Format of string_array resources:

> Comma-separated list of strings.
>
> Strings in string_array may not contain commas. No limit on length.
>
> Python type is *str*.
>
> A string array resource with one value works exactly like a string resource.

Non-consumable. Resource request will succeed if request matches one of the values. Resource request can contain only one string.

The value of resources_default.<string array resource> can only be one string.

5.9 Resources Allocated to Jobs and Reservations

Resources allocated to jobs provide the job with amounts of CPUs and memory to be consumed by the job's processes, as well as qualities such as architecture and host. The resources allocated to a job are those that the job requests and those that are assigned to it through resource defaults that you define, or by hooks you write.

Jobs use resources at the job-wide and chunk level. Job-wide resources such as walltime or vmem are applied to and requested by the job as a whole. Chunk-level resources, such as ncpus, are applied and requested in individual chunks.

Jobs explicitly request resources either at the vnode level in chunks defined in a selection statement, or in job-wide resource requests. See "Resources Built Into PBS" on page 267 of the PBS Professional Reference Guide and "Requesting Resources", on page 51 of the PBS Professional User's Guide.

Jobs inherit resource defaults for resources not explicitly requested. See section 5.9.4, "Allocating Default Resources to Jobs", on page 249.

Chunk-level resources are made available at the host (vnode) level by defining them via resources_available.<resource name> at the vnode, and are requested using `-l select=<resource name>=<value>`.

Job-wide resources are made available by defining them via resources_available.<resource name> at the queue or server. These resources are requested using `-l <resource name> =<value>`.

The scheduler matches requested resources with available resources, according to rules defined by the administrator.

When a job is requesting a string array resource, it can request only one of the values set in the string array resource. The job will only be placed on a vnode where the job's requested string matches one of the values of the string array resource. For example, if the resource named *Colors* is set to "*red, blue, green*" on vnode V1, and "*red, blue*" on V2:

- A job can request only one of "*red*", "*blue*", or "*green*"
- A job requesting `Colors=green` will only be placed on V1

5.9.1 Allocating Chunks

Chunks cannot be split across hosts. Chunks can be made up of vchunks. If a chunk is broken up over multiple vnodes, all participating vnodes must belong to the same execution host. Each vnode supplies a vchunk. These participating vnodes are supplying the vchunks that make up the chunk. A chunk defines a logical set of resources, for example, those needed for an MPI task. The resources must come from a single host, but if the requested resources exceed that of any one vnode, the physical resources can be taken from multiple vnodes on the same host.

5.9.2 Resources Requested by Job

The job's Resource_List attribute lists the following resources requested by the job:

- Job-wide resources explicitly requested by the job, inherited from defaults, or assigned by hooks
- The following built-in chunk-level resources explicitly requested by the job, inherited from defaults, or assigned by hooks:

  mpiprocs

  ncpus

  mem

  vmem
- Custom vnode-level (chunk-level) resources that are global and have the n, q, or f flags set, explicitly requested by the job, inherited from defaults, or assigned by hooks

5.9.3 Specifying Job Default Resources

You can specify which resources are automatically added to job resource requests. When a job does not request a specific resource, the default value for that resource is automatically added to the job's resource request.

You can also use hooks to add resources to a job's resource request, but we describe that elsewhere in the PBS Professional Hooks Guide.

The amount of each resource a job is allowed to use is the amount in its resource request. See section 5.15.2, “Placing Resource Limits on Jobs”, on page 307. Therefore you may wish to add default limits on resource usage. This is done by adding default resources to the job's resource request. For example, if a job does not request walltime, but you do not want jobs not specifying walltime to run for more than 12 hours, you can specify a default of 12 hours for walltime. Jobs that do specify walltime do not inherit this default; they keep their requested amount.

You can use default resources to manage jobs. For example, if you want to keep track of and limit the number of jobs using something such as a disk arm, you can have each job using the disk arm automatically request one counting resource. Then you can place a limit on the amount of this resource that can be in use at one time. This technique is described in section 5.10, “Using Resources to Track and Control Allocation”, on page 254.

Default resources can be defined for the server and for each queue. Default resources defined at the server are applied to all jobs. Default resources at a queue are applied only to the jobs that are in that queue.

Default resources on the server and queue can be job-wide, which is the same as adding `-l <resource name>` to the job's resource request, or they can be chunk resources, which is the same as adding `:<resource name>=<value>` to a chunk.

Job-wide resources are specified via resources_default on the server or queue, and chunk resources are specified via default_chunk on the server or queue. You can also specify default resources to be added to any `qsub` arguments. In addition, you can specify default placement of jobs.

5.9.3.1 Specifying Job-wide Default Resources at Server

To specify a server-level job-wide default resource, use the `qmgr` command to set the server's resources_default attribute:

Qmgr: set server resources_default.<resource name>=<value>

For example, to set the default architecture on the server:

```
Qmgr: set server resources_default.arch=linux
```

5.9.3.2 Setting Server and Queue Default Job Chunk Resource Values

If a job doesn't request a specific resource, PBS can assign a default value you specify. PBS stores default values for job chunk resources in the default_chunk.<resource name> attribute for the server and each queue.

PBS automatically sets the value for default_chunk.ncpus to *1* at the server and queues.

5.9.3.2.i Specifying Chunk Default Resources at Server

To specify a server-level chunk default resource, use the `qmgr` command to set the server's default_chunk attribute:

Qmgr: set server default_chunk.<resource name>=<value>

For example, if you want all chunks that don't specify ncpus or mem to inherit the values you specify:

```
Qmgr: set server  default_chunk.ncpus=1
Qmgr: set server  default_chunk.mem=1gb
```

5.9.3.2.ii Specifying Chunk Default Resources at Queue

To specify a queue-level chunk default resource, use the `qmgr` command to set the queue's default _chunk attribute:

Qmgr: set queue <queue name> default_chunk.<resource name>=<value>

For example, if you want all chunks that don't specify ncpus or mem to inherit the values you specify:

```
Qmgr: set queue small default_chunk.ncpus=1
Qmgr: set queue small default_chunk.mem=512mb
```

5.9.3.3 Specifying Job-wide Default Resources at Queue

To specify a default for a job-wide resource at a queue, use the `qmgr` command to set the queue's resources_default attribute:

Qmgr: set queue <queue name> resources_default.<resource name> = <value>

5.9.3.4 Specifying Default `qsub` Arguments

You can set defaults for any `qsub` arguments not explicitly requested by each job. You do this at the server by using the `qmgr` command to set the server's default_qsub_arguments attribute:

Qmgr: set server default_qsub_arguments=<string containing arguments>

For example, to set the default for the Rerunable job attribute in each job's resource request, and the name of the job:

```
Qmgr: set server default_qsub_arguments= "-r y -N MyJob"
```

Or to set a default Boolean in each job's resource request so that jobs don't run on *Red* unless they explicitly ask to do so:

```
Qmgr: set server default_qsub_arguments="-l Red=False"
```

5.9.3.5 Specifying Default Job Placement

You can specify job placement defaults at both the server and queue level. You use the `qmgr` command to set the resources_default.place attribute at the server or queue:

Qmgr: set queue <queue name> resources_default.place=<value>

For example, to set the default job placement for a queue:

```
Qmgr: set queue Q1 resources_default.place=free
```

When setting default placement involving a colon, enclose the value in double quotes:

```
Qmgr: set server resources_default.place="<value>"
```

For example, to set default placement at the server to *pack:shared*, do the following:

```
Qmgr: set server resources_default.place= "pack:shared"
```

See "Specifying Job Placement", on page 64 of the PBS Professional User's Guide for detailed information about how -l `place` is used.

5.9.3.6 Using Gating Values As Defaults

For most resources, if the job does not request the resource, and no server or queue defaults are set, the job inherits the maximum gating value for the resource. If this is set at the queue, the queue value of resources_max.<resource name> is used. If this is set only at the server, the job inherits the value set at the server.

5.9.3.7 Default Resource Caveats

- While users cannot request custom resources that are created with the `r` flag, jobs can inherit these as defaults from the server or queue resources_default.<resource name> attribute.
- A `qsub` or `pbs_rsub` hook does not have resources inherited from the server or queue resources_default or default_chunk as an input argument.
- Default `qsub` arguments and server and queue defaults are applied to jobs at a coarse level. Each job is examined to see whether it requests a select and a place. This means that if you specify a default placement, such as *excl*, with `-lplace=excl`, and the user specifies an arrangement, such as *pack*, with `-lplace=pack`, the result is that the job ends up with `-lplace=pack`, NOT `-lplace=pack:excl`. The same is true for select; if you specify a default of `-lselect=2:ncpus=1`, and the user specifies `-lselect=mem=2GB`, the job ends up with `-lselect=mem=2GB`.

5.9.4 Allocating Default Resources to Jobs

Jobs inherit default resources, job-wide or per-chunk, with the following order of precedence.

Table 5-5: Order In Which Default Resources Are Assigned to Jobs

Order of assignment	Default value	Affects Chunks?	Job-wide?
1	Default `qsub` arguments	If specified	If specified
2	Queue's default_chunk	Yes	No
3	Server's default_chunk	Yes	No
4	Queue's resources_default	No	Yes
5	Server's resources_default	No	Yes
6	Queue's resources_max	No	Yes
7	Server's resources_max	No	Yes

See section 5.9.3, "Specifying Job Default Resources", on page 247 for how to set these defaults.

For each chunk in the job's selection statement, first default `qsub` arguments are applied, then queue chunk defaults are applied, then server chunk defaults are applied. If the chunk does not contain a resource defined in the defaults, the default is added. The chunk defaults are specified in the default_chunk.<resource name> server or queue attribute.

For example, if the queue in which the job is enqueued has the following defaults defined,

```
default_chunk.ncpus=1
default_chunk.mem=2gb
```

then a job submitted with this selection statement:

```
select=2:ncpus=4+1:mem=9gb
```

will have this specification after the default_chunk elements are applied:

```
select=2:ncpus=4:mem=2gb+1:ncpus=1:mem=9gb
```

In the above, `mem=2gb` and `ncpus=1` are inherited from default_chunk.

The job-wide resource request is checked against queue resource defaults, then against server resource defaults, then against the queue's resources_max.<resource name>, then against the server's resources_max.<resource name>. If a default or maximum resource is defined which is not specified in the resource request, it is added to the resource request.

5.9.4.1 Default Resource Allocation for min_walltime and max_walltime

The min_walltime and max_walltime resources inherit values differently. A job can inherit a value for max_walltime from resources_max.walltime; the same is not true for min_walltime. This is because once a job is shrink-to-fit, PBS can use a walltime limit for max_walltime. See section 4.9.42.3.ii, "Inheriting Values for min_walltime and max_walltime", on page 214.

5.9.4.2 Default Resource Allocation Caveats

- Resources assigned from the default_qsub_arguments server attribute are treated as if the user requested them. A job will be rejected if it requests a resource that has a resource permission flag, whether that resource was requested by the user or came from default_qsub_arguments. Be aware that creating custom resources with permission flags and then using these in the default_qsub_arguments server attribute can cause jobs to be rejected. See section 5.14.2.3.vi, "Resource Permission Flags", on page 262.
- Default `qsub` arguments and server and queue defaults are applied to jobs at a coarse level. Each job is examined to see whether it requests a select and a place. This means that if you specify a default placement, such as *excl*, with `-lplace=excl`, and the user specifies an arrangement, such as *pack*, with `-lplace=pack`, the result is that the job ends up with `-lplace=pack`, NOT `-lplace=pack:excl`. The same is true for select; if you specify a default of `-lselect=2:ncpus=1`, and the user specifies `-lselect=mem=2GB`, the job ends up with `-lselect=mem=2GB`.

5.9.4.3 Moving Jobs Between Queues or Servers Changes Defaults

If the job is moved from the current queue to a new queue or server, any default resources in the job's Resource_List inherited from the current queue or server are removed. The job then inherits any new default resources. This includes a select specification and place directive generated by the rules for conversion from the old syntax. If a job's resource is unset (undefined) and there exists a default value at the new queue or server, that default value is applied to the job's resource list. If either select or place is missing from the job's new resource list, it will be automatically generated, using any newly inherited default values.

Jobs may be moved between servers when peer scheduling is in operation. Given the following set of queue and server default values:

- Server

  resources_default.ncpus=1
- Queue QA

resources_default.ncpus=2

default_chunk.mem=2GB

- Queue QB

  default_chunk.mem=1GB

  no default for ncpus

The following illustrate the equivalent select specification for jobs submitted into queue QA and then moved to (or submitted directly to) queue QB:

Example 5-3: Submission:

```
qsub -l ncpus=1 -lmem=4gb
```

- In QA:

  `select=1:ncpus=1:mem=4gb`

  - No defaults need be applied
- In QB:

  `select=1:ncpus=1:mem=4gb`

  - No defaults need be applied

Example 5-4: Submission:

```
qsub -l ncpus=1
```

- In QA:

  `select=1:ncpus=1:mem=2gb`

  - Picks up 2GB from queue default chunk and 1 ncpus from `qsub`
- In QB:

  `select=1:ncpus=1:mem=1gb`

  - Picks up 1GB from queue default_chunk and 1 ncpus from `qsub`

Example 5-5: Submission:

```
qsub -lmem=4gb
```

- In QA:

  `select=1:ncpus=2:mem=4gb`

  - Picks up 2 ncpus from queue level job-wide resource default and 4GB mem from `qsub`
- In QB:

  `select=1:ncpus=1:mem=4gb`

  - Picks up 1 ncpus from server level job-wide default and 4GB mem from `qsub`

Example 5-6: Submission:

```
qsub -lnodes=4
```

- In QA:

  `select=4:ncpus=1:mem=2gb`

  - Picks up a queue level default memory chunk of 2GB. (This is not 4:ncpus=2 because in prior versions, "nodes=x" implied 1 CPU per node unless otherwise explicitly stated.)
- In QB:

  `select=4:ncpus=1:mem=1gb`

(In prior versions, "nodes=x" implied 1 CPU per node unless otherwise explicitly stated, so the ncpus=1 is not inherited from the server default.)

Example 5-7: Submission:

```
qsub -l mem=16gb -lnodes=4
```

- In QA:

  ```
  select=4:ncpus=1:mem=4gb
  ```

  (This is not 4:ncpus=2 because in prior versions, "nodes=x" implied 1 CPU per node unless otherwise explicitly stated.)
- In QB:

  ```
  select=4:ncpus=1:mem=4gb
  ```

  (In prior versions, "nodes=x" implied 1 CPU per node unless otherwise explicitly stated, so the ncpus=1 is not inherited from the server default.)

5.9.5 Dynamic Resource Allocation Caveats

When a job requests a dynamic resource, PBS checks to see how much of the resource is available, but cannot know how much will be used by another job while this job executes. This can lead to a resource shortage. For example, there is 20GB of scratch on a disk, no jobs are running, and a job requests 15GB. This job writes to 5GB during the first part of its execution, then another job requests 10GB. The second job is started by PBS, because there is 15GB available. Now there is a shortage of scratch space.

You can avoid this problem by configuring a static consumable resource to represent scratch space. Set it to the amount of available scratch space. See section 5.14.5.3, "Static Server-level Scratch Space", on page 276 and section 5.14.5.4, "Static Host-level Scratch Space", on page 277.

5.9.6 Period When Resource is Used by Job

5.9.6.1 Exiting Job Keeps Resource

A job that is exiting is still consuming resources assigned to it. Those resources are available for other jobs only when the job is finished.

5.9.6.2 Job Suspension and Resource Usage

5.9.6.2.i Resource Usage on Suspension

When suspended, a job is not executing and is not charged for walltime.

5.9.6.2.ii Releasing Resources on Suspension

You can specify which consumable resources should be released by PBS when a job is suspended, using the restrict_res_to_release_on_suspend server attribute. In this attribute you list all of the resources that should be released when a job is suspended. If you leave this attribute unset, PBS releases all of a job's consumable resources when the job is suspended. This does not include the licenses used by the application, if any. You can modify the list to add and remove resources using "+=" and "-=" operators.

Server attribute where you specify resources to be released:

restrict_res_to_release_on_suspend

Comma-separated list of consumable resources to be released when jobs are suspended. If unset, all consumable resources are released on suspension.

Format: *Comma-separated list*

Python type: *list*

Default value: unset, meaning all consumable resources are released on suspension

You can see which resources have been released for a given job by looking at these job attributes:

resources_released

Listed by vnode, consumable resources that were released when the job was suspended. Populated only when restrict_res_to_release_on_suspend server attribute is set. Set by server.

Format: String of the form: *(<vnode>:<resource name>=<value>:<resource name>=<value>:...)+(<vnode>:<resource name>=<value>:...)*

Python type: *str*

resource_released_list

Sum of each consumable resource requested by the job that was released when the job was suspended. Populated only when restrict_res_to_release_on_suspend server attribute is set. Set by server. You will also see this amount released at the queue and/or server.

Format: String of the form: *resource_released_list.<resource name>=<value>,resource_released_list.<resource name>=<value>, ...*

Python type: *pbs.pbs_resource*

Jobs are suspended when they are preempted and via `qsig -s suspend`.

A job is resumed only when sufficient resources are available. When a person resumes a job via `qsig -s resume`, the job is not run until resources are available.

5.9.6.2.iii Releasing Resources on Suspension on Cray XC

On Cray XC, when a job is suspended, PBS releases ncpus, but all other resources remain assigned.

5.9.6.2.iv Suspension/resumption Resource Caveats

Dynamic resources can cause problems with suspension and resumption of jobs.

When a job is suspended, its resources are freed, but the scratch space written to by the job is not available.

A job that uses scratch space may not suspend and resume correctly. This is because if the job writes to scratch, and is then suspended, when PBS queries for available scratch to resume the job, the script may return a value too small for the job's request. PBS cannot determine whether the job itself is the user of the scratch space; PBS can only determine how much is still unused. If a single suspended job has left less scratch space available than it requests, that job cannot be resumed.

The above is true for any dynamic resource, such as application licenses.

When suspended, a job is not executing and is not charged for walltime.

5.9.6.3 Shrink-to-fit Jobs Get walltime When Executed

PBS computes the walltime value for each shrink-to-fit job when the scheduler runs the job, not before. See section 4.9.42.3.iii, “Setting walltime for Shrink-to-fit Jobs”, on page 214.

5.10 Using Resources to Track and Control Allocation

You can use resources to track and control usage of things like hardware and application licenses. For example, you might want to limit the number of jobs using floating licenses or a particular vnode. There is more than one way to accomplish this.

Example 5-8: You can set a complex-wide limit on the number of jobs using a type of complex-wide floating application license. This example uses a single queue for the entire complex. This method requires job submitters to request one of a floatlicensecount resource in order to be able to use the license. To set a complex-wide limit, take the following steps:

1. Create a custom static integer license resource that will be tracked at the server and queue:
   a. Use `qmgr` to create the resource:

      ```
      Qmgr: create resource floatlicensecount   type=long, flag=q
      ```

   b. Add the resource to the `resources:` line in `<sched_priv directory>/sched_config`:

      ```
      resources: "[...], floatlicensecount"
      ```

2. HUP the scheduler:

   ```
   kill -HUP <scheduler PID>
   ```

3. Set the available resource at the server using `qmgr`. If you have enough floating licenses for 4 jobs:

   ```
   Qmgr: set server resources_available.floatlicensecount = 4
   ```

4. Inform job submitters that jobs using they must request one job-wide floatlicensecount resource via the following:

   ```
   qsub -l floatlicensecount=1
   ```

   The scheduler will schedule up to 4 jobs at a time using the licenses. You do not need to set the resource at any queue.

Example 5-9: Here, your job submitters don't need to request a counting resource. Jobs are routed based on the size of the request for memory, and the counting resource is inherited from a default. In this example, we are limiting the number of jobs from each group that can use a particular vnode that has a lot of memory. This vnode is called *MemNode*.

Jobs that request 8GB or more of memory are routed into queue *BigMem*, and inherit a default counting resource called *memcount*. All other jobs are routed into queue *SmallMem*. The routing queue is called *RouteQueue*.

1. Create a custom static integer memcount resource that will be tracked at the server and queue:
   a. Use `qmgr` to create the resource:
   ```
   Qmgr: create resource memcount   type=long, flag=q
   ```
   b. Add the resource to the resources: line in `<sched_priv directory>/sched_config`:
   ```
   resources: "[...], memcount"
   ```
2. HUP the scheduler:
   ```
   kill -HUP <scheduler PID>
   ```
3. Set limits at *BigMem* and *SmallMem* so that they accept the correct jobs:
   ```
   Qmgr: set queue BigMem resources_min.mem = 8gb
   Qmgr: set queue SmallMem resources_max.mem = 8gb
   ```
4. Set the order of the destinations in the routing queue so that *BigMem* is tested first, so that jobs requesting exactly 8GB go into *BigMem*:
   ```
   Qmgr: set queue RouteQueue route_destinations = "BigMem, SmallMem"
   ```
5. Set the available resource at *BigMem* using `qmgr`. If you want a maximum of 6 jobs from *BigMem* to use *MemNode*:
   ```
   Qmgr: set queue BigMem resources_available.memcount = 6
   ```
6. Set the default value for the counting resource at *BigMem*, so that jobs inherit the value:
   ```
   Qmgr: set queue BigMem resources_default.memcount = 1
   ```
7. Associate the vnode with large memory with the *BigMem* queue. See section 4.9.2, "Associating Vnodes with Queues", on page 105.

   The scheduler will only schedule up to 6 jobs from *BigMem* at a time on the vnode with large memory.

5.11 Using Resources for Topology and Job Placement

Using the topology information in the server's node_group_key attribute, PBS examines the values of resources at vnodes, and uses those values to create placement sets. Jobs are assigned to placement sets according to their resource requests. Users can specify particular placement sets by requesting the resources that define that particular placement set. For example, if the switch named *A25* connects the desired set of vnodes, a user can request the following:

```
-l switch=A25
```

See section 4.9.32, "Placement Sets", on page 170.

5.11.1 Restrictions on Using Resources for Job Placement

Only vnode-level resources can be used to direct jobs to particular vnodes.

5.12 Using Resources to Prioritize Jobs

You can define the formula the scheduler uses to compute job execution priorities. Elements in this formula can be inherited default custom resources. These resources must be job-wide numeric resources, or consumable host-level resources. See section 5.9.3, "Specifying Job Default Resources", on page 247 and section 4.9.21, "Using a Formula for Computing Job Execution Priority", on page 151.

You can make jobs inherit numeric resources according to non-numeric qualities, such as the job owner's group or whether the job requests a Boolean or string resource. You can do this by either of the following methods:

- Use a hook to identify the jobs you want and alter their resource requests to include the custom resources for the formula. See the PBS Professional Hooks Guide
- Use a routing queue and minimum and maximum resource limits to route jobs to queues where they inherit the default custom resources for the formula. See section 2.3.6.4, "Using Resources to Route Jobs Between Queues", on page 28

For details on how job execution priority is calculated, see section 4.9.16, "Calculating Job Execution Priority", on page 136.

For a complete description of how PBS prioritizes jobs, see section 4.3.5, "Job Prioritization and Preemption", on page 66.

5.13 Using Resources to Restrict Server or Queue Access

You can set resource limits at the server and queues so that jobs must conform to the limits in order to be admitted. This way, you can reject jobs that request more of a resource than the complex or a queue can supply. You can also force jobs into specific queues where they will inherit the desired values for unrequested or custom resources. You can then use these resources to manage jobs, for example by using them in the job sorting formula or to route jobs to particular vnodes.

You set a maximum for each resource at the server using the resources_max.<resource name> server attribute; there is no resources_min.<resource name> at the server.

You can set a minimum and a maximum for each resource at each queue using the resources_min.<resource name> and resources_max.<resource name> queue attributes.

Job resource requests are compared to resource limits the same way, whether at the server or a queue. For a complete description of how jobs are tested against limits, see section 2.3.6.4.i, "How Queue and Server Limits Are Applied, Except Running Time", on page 28.

Job resource requests are compared first to queue admittance limits. If there is no queue admittance limit for a particular resource, the job's resource request is compared to the server's admittance limit.

5.13.1 Admittance Limits for walltime, min_walltime, and max_walltime

Because min_walltime and max_walltime are themselves limits, they behave differently from other time-based resources. When a shrink-to-fit job (a job with a value for min_walltime) is compared to server or queue limits, the following must be true in order for the job to be accepted:

- Both min_walltime and max_walltime must be greater than or equal to resources_min.walltime.
- Both min_walltime and max_walltime must be less than or equal to resources_max.walltime.

You cannot set resources_min or resources_max for min_walltime or max_walltime.

5.13.2 Restrictions on Resources Used for Admittance

For a list of resources that are compared to admittance limits, see section 2.3.6.4.iii, "Resources Used for Routing and Admittance", on page 29. For information on using strings, string arrays, and Booleans for admittance controls, see section 2.3.6.4.iv, "Using String, String Array, and Boolean Values for Routing and Admittance", on page 29.

5.14 Custom Resources

You can define, that is, create, new resources within PBS. This section describes how to define and use custom resources.

Once new resources are defined, jobs may request these new resources and the scheduler can schedule on the new resources.

Using this feature, it is possible to schedule resources where the number or amount available is outside of PBS's control.

Custom resources can be made invisible to users or unalterable by users via resource permission flags. See section 5.14.2.3.vi, "Resource Permission Flags", on page 262. A user will not be able to print or list custom resources which have been made either invisible or unalterable.

PBS provides certain custom resources that are designed to reflect resources or properties found on specific systems. Do not create custom resources with the names that PBS uses for these resources. See "Resources Built Into PBS" on page 267 of the PBS Professional Reference Guide.

5.14.1 How to Use Custom Resources

Custom resources can be static or dynamic, server-level or host-level, and local or global. They can also be shared or not.

5.14.1.1 Choosing the Resource Category

Use dynamic resources for quantities that PBS does not control, such as externally-managed application licenses or scratch space. PBS runs a script or program that queries an external source for the amount of the resource available and returns the value via `stdout`. Use static resources for things PBS does control. PBS tracks these resources internally.

Use server-level resources for things that are not tied to specific hosts, that is, they can be available to any of a set of hosts. An example of this is a floating application license. Use host-level resources for things that are tied to specific hosts, like the scratch space on a machine or node-locked application licenses.

5.14.1.1.i Examples of Configuring a Custom Resource

The following table gives examples of configuring each kind of custom resource:

Table 5-6: Examples of Configuring Custom Resources

Use for Resource	Link to Example
License: Floating, externally-managed	See section 5.14.6.3.i, "Example of Floating, Externally-managed License", on page 278
License: Floating, externally-managed with features	See section 5.14.6.3.ii, "Example of Floating, Externally-managed License with Features", on page 279
License: Floating, PBS-managed	See section 5.14.6.3.iii, "Example of Floating License Managed by PBS", on page 280

Table 5-6: Examples of Configuring Custom Resources

Use for Resource	Link to Example
License: Node-locked, per-host	See section 5.14.6.4.iv, “Example of Per-host Node-locked Licensing”, on page 282
License: Node-locked, per-CPU	See section 5.14.6.4.vi, “Example of Per-CPU Node-locked Licensing”, on page 284
License: Node-locked, per-use	See section 5.14.6.4.v, “Example of Per-use Node-locked Licensing”, on page 283
FPGAs	See section 5.14.8, “Using FPGAs”, on page 289
GPUs	See section 5.14.7, “Using GPUs”, on page 286
Scratch space: shared	See section 5.14.5.1, “Dynamic Server-level (Shared) Scratch Space”, on page 276 and section 5.14.5.3, “Static Server-level Scratch Space”, on page 276
Scratch space: local to a host	See section 5.14.5.2, “Dynamic Host-level Scratch Space”, on page 276 and section 5.14.5.4, “Static Host-level Scratch Space”, on page 277
Generic dynamic server-level	See section 5.14.3.1.iii, “Example of Configuring Dynamic Server-level Resource”, on page 269
Generic static server-level	See section 5.14.3.2.i, “Example of Configuring Static Server-level Resource”, on page 270
Generic dynamic host-level	See section 5.14.4.1.i, “Example of Configuring Dynamic Host-level Resource”, on page 272
Generic static host-level	See section 5.14.4.2.i, “Example of Configuring Static Host-level Resource”, on page 273
Generic shared static host-level	See section 5.14.4.3.v, “Configuring Shared Static Resources”, on page 274

5.14.1.2 Dynamic Custom Resources

A dynamic resource is one which is not under the control of PBS, meaning it can change independently of PBS. In order to use a dynamic resource, PBS must run a query to discover the available amount of that resource. Dynamic custom resources can be defined at the server or vnodes.

5.14.1.2.i Dynamic Server-level Custom Resources

A dynamic server-level custom resource is used to track a resource that is available at the server. You use a dynamic server-level resource to track something that is not under the control of PBS, and changes outside of PBS, for example, floating application licenses. At each scheduler cycle, the scheduler runs a script at the server host to determine the available amount of that resource. Server-level custom resources are used as job-wide resources.

5.14.1.2.ii Dynamic Host-level Custom Resources

A dynamic host-level custom resource is used to track a resource that is available at the execution host or hosts. You use a dynamic host-level resource for a resource that is not under the control of PBS, and changes outside of PBS, for example, scratch space. At each scheduler cycle, the scheduler queries the MoM for the available amount of the resource. The MoM runs a script which returns the current value of the resource. Host-level dynamic resources are used inside chunks.

5.14.1.3 Static Custom Resources

A static resource is one which is under the control of PBS. Any changes to the value are performed by PBS or by the administrator. Static custom resources are defined ahead of time, at the server, queues or vnodes. Static custom resources can be local or global.

5.14.1.3.i Global Static Custom Resources

Global static custom resource values at vnode, queue and server are set via `qmgr`, by setting resources_available.<custom resource name> = <value>. These resources are available at the server, queues, or vnodes.

5.14.1.3.ii Local Static Custom Resources

Local static custom resources are defined in `PBS_HOME/mom_priv/config`, and are available only at the host where they are defined. Note that these resources cannot be set via `qmgr` or viewed via `qstat`. It is not recommended to use local static custom resources.

5.14.1.4 Shared Vnode Resources

A shared vnode resource is managed at one vnode, but available to be used by jobs at others. This allows flexible allocation of the resource. See section 5.14.4.3, “Shared Host-level Resources”, on page 273 for information on resources shared across vnodes.

5.14.1.5 Using Custom Resources for Application Licenses

The following table lists application licenses and what kind of custom resource to define for them. See section 5.14.6, “Supplying Application Licenses”, on page 277 for specific instructions on configuring each type of license and examples of configuring custom resources for application licenses.

Table 5-7: Custom Resources for Application Licenses

Floating or Node-locked	Unit Being Licensed	How License is Managed	Level	Resource Type
Floating (site-wide)	Token	External license manager	Server	Dynamic
Floating (site-wide)	Token	PBS	Server	Static
Node-locked	Host	PBS	Host	Static
Node-locked	CPU	PBS	Host	Static
Node-locked	Instance of Application	PBS	Host	Static

5.14.1.6 Using Custom Resources for Scratch Space

You can configure a custom resource to report how much scratch space is available on machines. Jobs requiring scratch space can then be scheduled onto machines which have enough. This requires dynamic host-level resources. See section 5.14.5, “Using Scratch Space”, on page 276 and section 5.14.4.1, “Dynamic Host-level Resources”, on page 271.

5.14.2 Defining New Custom Resources

You can define new custom resources as follows:

- To define any custom resource, you can use `qmgr`.
- To define custom host-level non-consumable resources at vnodes, you can use hooks; see "Adding Custom Non-consumable Host-level Resources" on page 64 in the PBS Professional Hooks Guide.

5.14.2.1 Defining and Setting Static and Dynamic Custom Resources

The following table lists the differences in defining and setting static and dynamic custom resources at the server, queue and host level.

Table 5-8: Defining and Setting New Custom Resources

Resource Type	Server-level	Queue-level	Host-level
static	Set via `qmgr`	Set via `qmgr`	Set via `qmgr` or hook
dynamic	Add to `server_dyn_res` line in `<sched_priv directory>/sched_config`	Cannot be used.	Add to MoM config file `PBS_HOME/mom_priv/config` and `mom_resources` line (**deprecated** as of 18.2.1) in `<sched_priv directory>/sched_config`

5.14.2.2 Custom Resource Values

The rules for custom resource values are the same as for built-in resource values. See "Resource Formats" on page 361 of the PBS Professional Reference Guide.

If a string resource value contains spaces or shell metacharacters, enclose the string in quotes, or otherwise escape the space and metacharacters. Be sure to use the correct quotes for your shell and the behavior you want. If the string resource value contains commas, the string must be enclosed in an additional set of quotes so that the command (e.g. `qsub`, `qalter`) will parse it correctly. If the string resource value contains quotes, plus signs, equal signs, colons or parentheses, the string resource value must be enclosed in yet another set of additional quotes.

5.14.2.3 Resource Flags

5.14.2.3.i Resource Accumulation Flags

When you define a custom resource, you can specify whether it is server-level or host-level, and whether it is consumable or not. This is done by setting resource accumulation flags via `qmgr`. A consumable resource is tracked, or accumulated, in the server, queue or vnode resources_assigned attribute. The resource accumulation flags determine where the value of resources_assigned.<resource name> is incremented.

5.14.2.3.ii Allowable Values for Resource Accumulation Flags

The value of <*resource flags*>, which is the resource accumulation flag for a resource can be one of the following:

Table 5-9: Resource Accumulation Flags

Flag	Meaning
(no flags)	Indicates a queue-level or server-level resource that is not consumable.
fh	The amount is consumable at the host level for only the first vnode allocated to the job (vnode with first task.) Must be consumable or time-based. Cannot be used with Boolean or string resources. . This flag specifies that the resource is accumulated at the first vnode, meaning that the value of resources_assigned.<resource> is incremented only at the first vnode when a job is allocated this resource or when a reservation requesting this resource on this vnode starts.
h	Indicates a host-level resource. Used alone, means that the resource is not consumable. Required for any resource that will be used inside a select statement. This flag selects hardware. This flag indicates that the resource must be requested inside of a select statement. Example: for a Boolean resource named "green": `Qmgr: create resource green type=boolean, flag=h`
nh	The amount is consumable at the host level, for all vnodes assigned to the job. Must be consumable or time-based. Cannot be used with Boolean or string resources. This flag specifies that the resource is accumulated at the vnode level, meaning that the value of resources_assigned.<resource> is incremented at relevant vnodes when a job is allocated this resource or when a reservation requesting this resource on this vnode starts. This flag is not used with dynamic consumable resources. The scheduler will not oversubscribe dynamic consumable resources.
q	The amount is consumable at the queue and server level. When a job is assigned one unit of a resource with this flag, the resources_assigned.<resource> attribute at the server and any queue is incremented by one. Must be consumable or time-based. This flag specifies that the resource is accumulated at the queue and server level, meaning that the value of resources_assigned.<resource> is incremented at each queue and at the server when a job is allocated this resource. When a reservation starts, allocated resources are added to the server's resources_assigned attribute. This flag is not used with dynamic consumable resources. The scheduler will not oversubscribe dynamic consumable resources.

5.14.2.3.iii When to Use Accumulation Flags

The following table shows when to use accumulation flags.

Table 5-10: When to Use Accumulation Flags

Resource Category	Server	Queue	Host
Static, consumable	flag = q	flag = q	flag = nh or fh
Static, not consumable	flag = (none of h, n, q or f)	flag = (none of h, n, q or f)	flag = h
Dynamic	`server_dyn_res` line in `sched_config`, flag = (none of h, n, q or f)	(cannot be used)	MoM config and `mom_resources` line (**deprecated** as of 18.2.1) in `sched_config`, flag = h

5.14.2.3.iv Example of Resource Accumulation Flags

When defining a static consumable host-level resource, such as a node-locked application license, you would use the "n" and "h" flags.

When defining a dynamic resource such as a floating license, you would use no flags.

5.14.2.3.v Resource Accumulation Flag Restrictions and Caveats

- Numeric dynamic resources cannot have the q or n flags set. This would cause these resources to be under-used. These resources are tracked automatically by the scheduler.

5.14.2.3.vi Resource Permission Flags

When you define a custom resource, you can specify whether unprivileged users have permission to view or request the resource, and whether users can `qalter` a request for that resource. This is done by setting a resource permission flag via `qmgr`.

5.14.2.3.vii Allowable Values for Resource Permission Flags

The permission flag for a resource can be one of the following:

Table 5-11: Resource Permission Flags

Flag	Meaning
(no flag)	Users can view and request the resource, and `qalter` a resource request for this resource.
i	"Invisible". Users cannot view or request the resource. Users cannot `qalter` a resource request for this resource.
r	"Read only". Users can view the resource, but cannot request it or `qalter` a resource request for this resource.

5.14.2.3.viii Effect of Resource Permission Flags

- PBS Operators and Managers can view and request a resource, and `qalter` a resource request for that resource, regardless of the i and r flags.
- Users, operators and managers cannot submit a job which requests a restricted resource. Any job requesting a restricted resource will be rejected. If a manager needs to run a job which has a restricted resource with a different value from the default value, the manager must submit the job without requesting the resource, then `qalter` the resource value.
- While users cannot request these resources, their jobs can inherit default resources from resources_default.<resource name> and default_chunk.<resource name>.

  If a user tries to request a resource or modify a resource request which has a resource permission flag, they will get an error message from the command and the request will be rejected. For example, if they try to `qalter` a job's resource request, they will see an error message similar to the following:

  ```
  "qalter: Cannot set attribute, read only or insufficient permission  Resource_List.hps 173.mars"
  ```

5.14.2.3.ix Resource Permission Flag Restrictions and Caveats

- You can specify only one of the i or r flags per resource. If both are specified, the resource is treated as if only the i flag were specified, and an error message is logged at the default log level and printed to standard error.
- Resources assigned from the default_qsub_arguments server attribute are treated as if the user requested them. A job will be rejected if it requests a resource that has a resource permission flag whether that resource was requested by the user or came from default_qsub_arguments.
- The behavior of several command-line interfaces is dependent on resource permission flags. These interfaces are those which view or request resources or modify resource requests:

  `pbsnodes`

  Users cannot view restricted host-level custom resources.

  `pbs_rstat`

  Users cannot view restricted reservation resources.

  `pbs_rsub`

  Users cannot request restricted custom resources for reservations.

  `qalter`

  Users cannot alter a restricted resource.

  `qmgr`

  Users cannot print or list a restricted resource.

  `qselect`

  Users cannot specify restricted resources via -l Resource_List.

  `qsub`

  Users cannot request a restricted resource.

  `qstat`

  Users cannot view a restricted resource.

5.14.2.3.x Allowing Execution Hooks to Read Custom Job Resources Faster

You can make it faster for execution hooks to read custom job resources. Execution hooks cannot read custom job resources via the event, only via the server. However, you can cache a copy of a custom job resource at the MoMs for faster local reading by execution hooks, by setting the *m* flag for the resource. The job resources that can be cached are found in the following job attributes:

exec_vnode
Resource_List
resources_used

To create a resource with the *m* flag set, include the flag. For example, to create two host-level consumable resources r1 and r2 of type long that will be cached at MoMs:

```
qmgr -c "create resource r1,r2 type=long,flag=mnh"
```

To unset this flag for r1:

```
qmgr -c "set resource r1 flag=nh"
```

You can combine this flag with any other resource flag. Job resources created in an exechost_startup hook have the m flag set automatically.

5.14.2.3.xi Caveats for Caching Custom Job Resources

Large numbers of job resources that are cached at MoMs can slow things down. If you don't need execution hooks to be able to read a custom job resource often, don't cache the resource at the MoMs.

5.14.2.3.xii Setting Types and Flags for Custom Resources via qmgr

To set the type for a resource:

set resource <resource name> type = <type>

For example:

```
qmgr -c "set resource foo type=string_array"
```

To set the flags for a resource:

set resource <resource name> flag=<flag(s)>

For example:

```
qmgr -c "set resource foo flag=nh"
```

To set the type and flags for a resource:

set resource <resource name> type=<type>, flag=<flag(s)>

For example:

```
qmgr -c "set resource foo type=long,flag=nhi"
```

You can set multiple resources by separating the names with commas. For example:

```
qmgr -c "set resource r1, r2 type=long"
```

You cannot set the *nh*, *fh*, or *q* flag for a resource of type string, string_array, or Boolean.

You cannot set both the *n* and the *f* flags on one resource.

You cannot have the *n* or *f* flags without the *h* flag.

You cannot set both the *i* and *r* flags on one resource.

You cannot unset the type for a resource.

You cannot set the type for a resource that is requested by a current or history job or reservation, or set on a server, queue, or vnode.

You cannot set the flag(s) to *h*, *nh*, *fh*, or *q* for a resource that is currently requested by a current or history job or reservation.

You cannot unset the flag(s) for a resource that is currently requested by a current or history job or a reservation, or set on any server, queue, or vnode.

You cannot alter a built-in resource.

You can unset custom resource flags, but not their type.

5.14.2.3.xiii

5.14.2.4 Defining Custom Resources via qmgr

You can use `qmgr` to create and delete custom resources, and to set their type and flags.

You must have PBS Manager privilege to operate on resources via `qmgr`.

5.14.2.4.i Creating Custom Resources via qmgr

When you define or change a custom resource via `qmgr`, the changes take place immediately, and you do not have to restart the server, but you do have to restart scheduler(s).

To create a resource:

qmgr -c 'create resource <resource name>[,<resource name>] [type = <type>], [flag = <flags>]'

For example:

```
Qmgr: create resource foo type=long,flag=q
```

To create multiple resources of the same type and flag, separate each resource name with a comma:

```
qmgr -c "create resource r1,r2 type=long,flag=nh"
```

You can abbreviate "resource" to "r":

```
qmgr -c "create r foo type=long,flag=nh"
```

You cannot create a resource with the same name as an existing resource.

After you have defined your new custom resource, tell the scheduler how to use it. See section 5.14.2.6, "Allowing Jobs to Use a Resource", on page 267.

5.14.2.4.ii Caveats for Defining Host-level Custom Resources via qmgr

If you plan on using a hook to set a job's resources_used value for a custom host-level resource, or you want to have a custom resource summed in a job's resources_used attribute and shown in the accounting log, you must create that resource using a hook.

5.14.2.4.iii Deleting Custom Resources

If you want to be able to delete a custom resource, make sure that the resource is not requested by any current or history jobs or current reservations. You can let those jobs finish, `qalter` them, or delete them. Delete and re-create any reservations that request the resource.

Before you delete a custom resource, you must remove all references to that resource, including where it is used in hooks or the scheduling formula. When you delete a resource that is set on the server, a queue, or a vnode, PBS unsets the resource for you.

You cannot delete a custom resource that is listed in the restrict_res_to_release_on_suspend server attribute. You must first remove the resource from the list:

```
Qmgr: set server restrict_res_to_release_on_suspend -= <resource name>
```

You cannot delete a built-in resource.

To remove a custom resource:

1. Remove all references to the resource
   - Remove it from the formula
   - Remove it from hooks
   - Let jobs requesting it finish, requeue and then `qalter` them while they are queued, or delete them
   - Delete and re-create any reservations that request the resource
2. Edit the `resources:` line in `<sched_priv directory>/sched_config` to remove the unwanted resource name:
   - If the resource is a server dynamic resource, remove the resource name from the `server_dyn_res`: line
   - If the resource is a MoM dynamic resource, remove the resource from the `mom_resources:` line (**deprecated** as of 18.2.1)
3. For each MoM whose Version 2 configuration file contains references to the resource, use the `pbs_mom -s insert` command to update the Version 2 configuration file. See section 3.4.3, “Version 2 Vnode Configuration Files”, on page 44.
4. If the resource is a local dynamic resource, defined in the MoM Version 1 configuration file:

   For each host where the unwanted resource is defined, edit `PBS_HOME/mom_priv/config` and remove the resource entry line.
5. HUP each MoM; for Linux, see “Restarting and Reinitializing MoM” on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see “Restarting MoMs” on page 173 in the PBS Professional Installation & Upgrade Guide.
6. Delete the resource using `qmgr:`

   qmgr -c 'delete resource <resource name>'

   For example:

   ```
   qmgr -c "delete resource foo"
   ```

5.14.2.5 Defining Custom Resources via Hooks

You can use hooks to add new custom host-level non-consumable resources, and set their values. See "Adding Custom Non-consumable Host-level Resources" on page 64 in the PBS Professional Hooks Guide.

You must make the resource usable by the scheduler: see section 5.14.2.6, “Allowing Jobs to Use a Resource”, on page 267.

To delete a custom resource created in a hook, use `qmgr`. See section 5.14.2.4.iii, “Deleting Custom Resources”, on page 265.

5.14.2.6 Allowing Jobs to Use a Resource

After you define your resource, you need to make it usable by jobs:

1. Put the resource in the "`resources:`" line in `<sched_priv directory>/sched_config.` If the resource is a host-level boolean, you do not need to add it here.
2. If the resource is static, set the value via `qmgr`.
3. If the resource is dynamic, add it to the correct line in the scheduler's configuration file:
   - If it's a host -level dynamic resource, it must be added to the `mom_resources` line (**deprecated** as of 18.2.1)
   - If it's a server-level resource, it must be added to the `server_dyn_res` line
4. HUP the scheduler(s)

5.14.2.7 Editing Configuration Files Under Windows

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

5.14.2.8 Example of Defining Each Type of Custom Resource

In this example, we add five custom resources: a static and a dynamic host-level resource, a static and a dynamic server-level resource, and a static queue-level resource.

1. The resource must be defined, with appropriate flags set:
```
Qmgr: create resource staticserverresource   type=long, flag=q
Qmgr: create resource statichostresource     type=long, flag=nh
Qmgr: create resource dynamicserverresource  type=long
Qmgr: create resource dynamichostresource    type=long, flag=h
Qmgr: create resource staticqueueresource    type=long, flag=q
```
2. The resource must be added to the scheduler's list of resources:

   Add resource to "`resources`:" line in `<sched_priv directory>/sched_config:`
```
resources:  "[...], staticserverresource, statichostresource, dynamicserverresource,
    dynamichostresource, staticqueueresource"
```
   Host-level Boolean resources do not need to be added to the "`resources:`" line.
3. HUP the scheduler:
```
kill -HUP <scheduler PID>
```
4. If the resource is static, use `qmgr` to set it at the host, queue or server level:
```
Qmgr: set node Host1 resources_available.statichostresource=1
Qmgr: set queue Queue1 resources_available.staticqueueresource=1
Qmgr: set server resources_available.staticserverresource=1
```
   See "qmgr" on page 150 of the PBS Professional Reference Guide.
5. If the resource is dynamic:
   a. If it's a host-level resource, add it to the "`mom_resources`" line (**deprecated** as of 18.2.1) in `<sched_priv directory>/sched_config`:
```
mom_resources: "dynamichostresource"
```
   b. Add it to the MoM `config` file `PBS_HOME/mom_priv/config`:

Linux or Windows:

```
dynamichostresource !path-to-command
```

Windows, spaces in path:

```
dynamichostresource !"path-to-command"
```

c. If it's a server-level resource, add it to the "`server_dyn_res`" line in `<sched_priv directory>/sched_config`:

Linux:

```
server_dyn_res:  "dynamicserverresource !path-to-
command"
```

Windows, no spaces in path:

```
server_dyn_res: 'dynamicserverresource !path-to-
command'
```

or:

```
server_dyn_res: "dynamicserverresource !path-to-
command"
```

Windows, spaces in path:

```
server_dyn_res: 'dynamicserverresource !"path-to-
command including spaces"'
```

d. Make sure that the script meets the requirements in "Requirements for Scripts that Update Dynamic Resources"

5.14.3 Creating Server-level Custom Resources

You can have PBS track the availability of an externally-managed dynamic server-level resource, by running a script or program specified in the `server_dyn_res` line of `<sched_priv directory>/sched_config`. PBS updates the value for resources_available.<resource name> at each scheduling cycle using the value returned by the script. This script is run at the host where the scheduler runs, once per scheduling cycle. Dynamic server-level resources are usually used for site-wide externally-managed floating application licenses.

The scheduler runs the query and waits for it to finish or time out. The default timeout for a server dynamic resource script is 30 seconds. You can specify a timeout for server dynamic resources in each scheduler's server_dyn_res_alarm attribute. If the script does not finish before the timeout, the scheduler uses a value of zero for the dynamic server resource. If you set the timeout to zero, the scheduler does not place a time limit on the script.

The scheduler tracks how much of each numeric dynamic server-level custom resource has been assigned to jobs, and will not overcommit these resources.

5.14.3.1 Creating Server Dynamic Resource Scripts

You create the script or program that PBS uses to query the external source. The external source can be a license manager or a command, as when you use the `df` command to find the amount of available disk space.

The format of a dynamic server-level resource query is a shell escape:

server_dyn_res: "<resource name> !<path to command>"

where

<resource name> is the name of the dynamic resource

<path to command> is typically the full path to the script or program that performs the query in order to determine the status and/or availability of the new resource you have added. This usually means querying a license server.

Place the script on the server host. For example, it could be placed in `/usr/local/bin/serverdyn.pl`. Make sure the script meets the requirements in "Requirements for Scripts that Update Dynamic Resources".

5.14.3.1.i Requirements for Scripts that Update Dynamic Resources

The script:

- Owned by root
- Has permissions of 0755
- Returns its output via `stdout`, and the output must be in a single line ending with a newline
- The scheduler has access to the script, and can run it
- If you have set up peer scheduling, make sure that the script is available to any scheduler that needs to run it

The directory containing the script:

- Owned by root
- Accessible only by root (must not give write permission to *group* or *others*)
- Has permissions 0550

5.14.3.1.ii Caveats and Restrictions for Server Dynamic Resources

- Server dynamic resources are available only to the scheduler.
- Server dynamic resource values have no resources_available.<resource name> representation anywhere in PBS.
- A server dynamic resource shows up in the output of `qstat` only if a job has requested it.

5.14.3.1.iii Example of Configuring Dynamic Server-level Resource

For a site-wide externally-managed floating application license you will need two resources: one to represent the licenses themselves, and one to mark the vnodes on which the application can be run. The first is a server-level dynamic resource and the second is a host-level Boolean, set on the vnodes to send jobs requiring that license to those vnodes.

These are the steps for configuring a dynamic server-level resource for a site-wide externally-managed floating license. If this license could be used on all vnodes, the Boolean resource would not be necessary.

1. Define the resources, for example floatlicense and CanRun:
   ```
   Qmgr: create resource floatlicense type=long
   Qmgr: create resource CanRun type=boolean, flag=h
   ```
2. Write a script, for example `serverdyn.pl`, that returns the available amount of the resource via stdout, and place it on the server host. For example, it could be placed in `/usr/local/bin/serverdyn.pl`
3. Make sure that the script and the directory containing meet the requirements in "Requirements for Scripts that Update Dynamic Resources".
4. Configure the scheduler to use the script by adding the resource and the path to the script in the `server_dyn_res` line of `<sched_priv directory>/sched_config`:
   ```
   server_dyn_res: "floatlicense !/usr/local/bin/serverdyn.pl"
   ```
5. Optional: give the scheduler a time limit for the script by setting its server_dyn_res_alarm attribute:
   ```
   Qmgr: set sched <scheduler name> server_dyn_res_alarm=<new value>
   ```
6. Add the new dynamic resource to the `resources:` line in `<sched_priv directory>/sched_config`:
   ```
   resources: "ncpus, mem, arch, [...], floatlicense"
   ```
7. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.
8. Set the Boolean resource on the vnodes where the floating licenses can be run. Here we designate *vnode1* and *vnode2* as the vnodes that can run the application:
   ```
   Qmgr: active node vnode1,vnode2
   Qmgr: set node resources_available.CanRun=True
   ```

To request this resource, the job's resource request would include:

```
-l floatlicense=<number of licenses or tokens required>
-l select=1:ncpus=N:CanRun=1
```

5.14.3.2 Static Server-level Resources

Static server-level resources are used for resources like floating licenses that PBS will manage. PBS keeps track of the number of available licenses instead of querying an external license manager.

5.14.3.2.i Example of Configuring Static Server-level Resource

These are the steps for configuring a static server-level resource:

1. Define the resource, for example sitelicense:
   ```
   Qmgr: create resource sitelicense type=long, flag=q
   ```
2. Use the `qmgr` command to set the value of the resource on the server:
   ```
   Qmgr: set server resources_available.sitelicense=<number of licenses>
   ```
3. Add the new resource to the `resources:` line in `<sched_priv directory>/sched_config`.
   ```
   resources: "ncpus, mem, arch, [...], sitelicense"
   ```
4. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

5.14.4 Configuring Host-level Custom Resources

Host-level custom resources can be static and consumable, static and not consumable, or dynamic. Dynamic host-level resources are used for things like scratch space.

5.14.4.1 Dynamic Host-level Resources

Deprecated as of 18.2.1

For dynamic host-level custom resources, the scheduler sends a resource query to each MoM to get the current availability for the resource, and uses that value for scheduling. If the MoM returns a value, this value replaces the resources_available value reported by the server. If the MoM returns no value, the value from the server is kept. If neither specifies a value, the scheduler sets the resource value to 0.

The available amount of the resource is determined by running a script or program which returns the amount via `stdout`. This script or program is specified in the `mom_resources` line in `<sched_priv directory>/sched_config`.

The script is run once per scheduling cycle. For a multi-vnode machine, the script is run for the parent vnode. The resource is shared among the MoM's vnodes.

The default timeout for a server dynamic resource script is 30 seconds. You can specify a timeout for server dynamic resources in each scheduler's server_dyn_res_alarm attribute. If the script does not finish before the timeout, the scheduler uses a value of zero for the dynamic server resource. If you set the timeout to zero, the scheduler does not place a time limit on the script.

The scheduler tracks how much of each numeric dynamic server-level custom resource has been assigned to jobs, and will not overcommit these resources.

You create the script or program that PBS uses to query the external source. The external source can be a license manager or a command, as when you use the `df` command to find the amount of available disk space. Place the script on the host(s) where it will be used.

The format of a dynamic host-level resource query is a shell escape:

<resource name> !<path to command>

In this query,

<resource name> is the name of the resource.

<path to command> is typically the full path to the script or program that performs the query in order to determine the status and/or availability of the new resource you have added.

Make sure that the script meets the requirements in "Requirements for Scripts that Update Dynamic Resources".

MoM starts the query and waits for output. The default amount of time that MoM waits is 10 seconds; this period can be set via the `-a alarm_timeout` command line option to `pbs_mom`. For Linux, see "Restarting and Reinitializing MoM" on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see "Restarting MoMs" on page 173 in the PBS Professional Installation & Upgrade Guide. If the timeout is exceeded and the shell escape process has not finished, a log message, "resource read alarm" is written to the MoM's log file. The process is given another alarm period to finish and if it does not, another log message is written. The user's job may not run.

An example of a dynamic host-level resource is scratch space on the execution host.

Host dynamic resource values are never visible in `qstat`, and have no resources_available.<resource name> representation anywhere in PBS.

5.14.4.1.i Example of Configuring Dynamic Host-level Resource

In this example, we configure a custom resource to track host-level scratch space. The resource is called *dynscratch*. These are the steps for configuring a dynamic host-level resource:

1. Define the resource, for example dynscratch:

   ```
   Qmgr: create resource dynscratch type=size, flag=h
   ```

2. Write a script, for example `hostdyn.pl`, that returns the available amount of the resource via `stdout`. The script must return the value in a single line, ending with a newline. Place the script on each host where it will be used. For example, it could be placed in `/usr/local/bin/hostdyn.pl`.

3. Configure each MoM to use the script by adding the resource and the path to the script in `PBS_HOME/mom_priv/config`:

   Linux:

   ```
   dynscratch !/usr/local/bin/hostdyn.pl
   ```

   Windows:

   ```
   dynscratch !"C:\Program Files\PBS\hostdyn.pl"
   ```

4. Reinitialize the MoMs. For Linux, see “Restarting and Reinitializing MoM” on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see “Restarting MoMs” on page 173 in the PBS Professional Installation & Upgrade Guide.

5. You may optionally specify any limits on that resource via `qmgr`, such as the maximum amount available, or the maximum that a single user can request. For example:

   ```
   Qmgr: set server resources_max.scratchspace=1gb
   ```

6. Add the new resource to the `resources:` line in `<sched_priv directory>/sched_config`:

   ```
   resources: "ncpus, mem, arch, [...], dynscratch"
   ```

7. Add the new resource to the `mom_resources:` line (**deprecated** as of 18.2.1) in `<sched_priv directory>/sched_config`. Create the line if necessary:

   ```
   mom_resources: "dynscratch"
   ```

8. Restart the scheduler. See “Restarting and Reinitializing Scheduler or Multisched” on page 166 in the PBS Professional Installation & Upgrade Guide.

To request this resource, the resource request would include

```
-l select=1:ncpus=N:dynscratch=10MB
```

5.14.4.2 Static Host-level Resources

Use static host-level resources for things that are managed by PBS and available at the host level, such as GPUs.

5.14.4.2.i Example of Configuring Static Host-level Resource

In this example, we configure a consumable host-level resource to track GPUs. These are the steps for configuring a static host-level resource:

1. Define the resource, for example ngpus:

   ```
   Qmgr: create resource ngpus type=long, flag=nh
   ```

2. Use the `qmgr` command to set the value of the resource on the host:

   ```
   Qmgr: set node Host1 ngpus=<number of GPUs>
   ```

3. Add the new resource to the `resources` line in `<sched_priv directory>/sched_config`.

   ```
   resources: "ncpus, mem, arch, [...], ngpus"
   ```

4. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.
5. If the GPU host is a multi-vnode machine, you may want to define which GPUs belong in which vnodes. In this case, do the following:
   a. Create a vnode definition file. See section 3.4.3, "Version 2 Vnode Configuration Files", on page 44.
   b. Restart the MoM. For Linux, see "Restarting and Reinitializing MoM" on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see "Restarting MoMs" on page 173 in the PBS Professional Installation & Upgrade Guide.

See section 5.14.6.4.iv, "Example of Per-host Node-locked Licensing", on page 282, section 5.14.6.4.v, "Example of Per-use Node-locked Licensing", on page 283, and section 5.14.6.4.vi, "Example of Per-CPU Node-locked Licensing", on page 284. These sections give examples of configuring each kind of node-locked license.

5.14.4.3 Shared Host-level Resources

Two or more vnodes can share the use of a resource. The resource is managed at one vnode, but available for use at other vnodes. The MoM manages the sharing of the resource, allocating only the available amount to jobs. For example, if you want jobs at two separate vnodes to be able to use the same 4GB of memory, you can make the memory be a shared resource. This way, if a job at one vnode uses all 4GB, no other jobs can use it, but if one job at one vnode uses 2GB, other jobs at either vnode can use up to 2GB.

5.14.4.3.i Shared Resource Glossary

Borrowing vnode

The vnode where a shared vnode resource is available, but not managed.

Indirect resource

A shared vnode resource at vnode(s) where the resource is not defined, but which share the resource.

Managing vnode

The vnode where a shared vnode resource is defined, and which manages the resource.

Shared resource

A vnode resource defined at managed at one vnode, but available for use at others.

5.14.4.3.ii Configuring Shared Host-level Resources

The resource to be shared is defined as usual at one vnode. This is the managing vnode for that resource. For example, to make memory be managed at Vnode1:

```
Qmgr: set node Vnode1 mem = 4gb
```

At vnodes which will use the same resource, the resource is defined to be indirect. For example, to make memory be shared and borrowed at *Vnode2*:

```
Qmgr: set node Vnode2 mem = @Vnode1
```

5.14.4.3.iii Shared Dynamic Host-level Resources

Vnode-level dynamic resources, meaning those listed in the `mom_resources:` line (**deprecated** as of 18.2.1) in `<sched_priv directory>/sched_config`, are shared resources.

5.14.4.3.iv Shared Static Host-level Resources

You can define a static host-level resource to be shared between vnodes. The resource is not shared if you set it to a value at each vnode.

5.14.4.3.v Configuring Shared Static Resources

1. If the resource to be shared is a custom resource, you must define the resource before setting its value:
   ```
   Qmgr: create resource <resource name> type=<resource type> [flag = <flags>]
   ```
2. Set the resource on the managing vnode:

   To set a static value via `qmgr`:
   ```
   Qmgr: s n managing_vnode resources_available.<resource name> =<value>
   ```
   To set a static value, in a Version 2 configuration file:
   ```
   managing_vnode:<resource name>=<value>
   ```
3. Next, set the resource on the borrowing vnode:

   To set a shared resource on a borrowing vnode via `qmgr`:
   ```
   Qmgr: s n borrowing_vnode resources_available.<resource name>=@managing_vnode
   ```
   To set a shared resource in a Version 2 configuration file:
   ```
   borrowing_vnode:<resource name>=@managing_vnode
   ```
4. HUP the MoMs involved; for Linux, see “Restarting and Reinitializing MoM” on page 167 in the PBS Professional Installation & Upgrade Guide, and for Windows, see “Restarting MoMs” on page 173 in the PBS Professional Installation & Upgrade Guide.

Example 5-10: To make a static host-level license `dyna-license` on hostA be managed by the parent vnode at hostA and indirect at vnodes hostA0 and hostA1:

```
Qmgr: set node hostA resources_available.dyna-license=4
Qmgr: set node hostA0 resources_available.dyna-license=@hostA
Qmgr: set node hostA1 resources_available.dyna-license=@hostA
```

5.14.4.3.vi Restrictions on Shared Host-level Resources

- If your vnodes represent physical units such as blades, sharing resources like ncpus across vnodes may not make sense.
- If you want to make a resource shared across vnodes, remember that you do not want to schedule jobs on the parent vnode. To avoid this, the following resources should not be explicitly set on the parent vnode:

  ncpus

  mem

  vmem

5.14.4.3.vii Defining Shared and Non-shared Resources for Multi-vnode Machines

On a multi-vnode machine, you can manage the resources at each vnode. For dynamic host-level resources, the resource is shared across all the vnodes on the machine, and MoM manages the sharing. For static host-level resources, you can either define the resource as shared or not. Shared resources are usually set on the parent vnode and then made indirect at any child vnodes on which you want the resource available. For resources that are not shared, you can set the value at each vnode.

Example 5-11: To set the resource `string_res` to *round* on the parent vnode of host03 and make it indirect at host03[0] and host03[1]:

```
Qmgr: set node host03 resources_available.string_res=round
Qmgr: s n host03[0] resources_available.string_res=@host03
Qmgr: s n host03[1] resources_available.string_res=@host03
pbsnodes -va
host03
    ...
    string_res=round
    ...
host03[0]
    ...
    string_res=@host03
    ...
host03[1]
    ...
    string_res=@host03
    ...
```

If you had set the resource string_res individually on host03[0] and host03[1]:

```
Qmgr: s n host03[0] resources_available.string_res=round
Qmgr: s n host03[1] resources_available.string_res=square
pbsnodes -va
host03
    ...
        <--------string_res not set on parent vnode
    ...
host03[0]
    ...
    string_res=round
    ...
host03[1]
    ...
    string_res=square
    ...
```

5.14.4.3.viii Shared Resource Restrictions for Multi-vnode Machines

- On the parent vnode, all values for resources_available.<resource name> should be *zero* (*0*), unless the resource is being shared among other vnodes via indirection.

5.14.5 Using Scratch Space

5.14.5.1 Dynamic Server-level (Shared) Scratch Space

If you have scratch space set up so that it's available to all execution hosts, you can use a server-level custom dynamic resource to track it. The following are the steps for configuring a dynamic server-level resource called globalscratch to track globally available scratch space:

1. Define the resource:

   ```
   Qmgr: create resource globalscratch type=long
   ```

2. Write a script, for example `serverdynscratch.pl`, that returns the available amount of the resource via `stdout`, and place it on the server host. For example, it could be placed in `/usr/local/bin/serverdynscratch.pl`
3. Configure the scheduler to use the script by adding the resource and the path to the script in the `server_dyn_res` line of `<sched_priv directory>/sched_config`:

   ```
   server_dyn_res: "globalscratch !/usr/local/bin/serverdynscratch.pl"
   ```

4. Optional: give the scheduler a time limit for the script by setting its server_dyn_res_alarm attribute:

   ```
   Qmgr: set sched <scheduler name> server_dyn_res_alarm=<new value>
   ```

5. Add the new dynamic resource to the `resources:` line in `<sched_priv directory>/sched_config`:

   ```
   resources: "ncpus, mem, arch, [...], globalscratch"
   ```

6. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

To request this resource, the job's resource request would include:

```
-l globalscratch=<space required>
```

5.14.5.2 Dynamic Host-level Scratch Space

Say you have jobs that require a large amount of scratch disk space during their execution. To ensure that sufficient space is available during job startup, create a custom dynamic resource so that jobs can request scratch space. To create this resource, take the steps outlined in section 5.14.4.1.i, "Example of Configuring Dynamic Host-level Resource", on page 272.

5.14.5.3 Static Server-level Scratch Space

If you want to prevent jobs from stepping on each others' scratch space, you can define additional vnodes that are used only to allocate scratch devices, with one vnode per scratch device. Set the sharing attribute on each scratch vnode to *force_excl*, so that only one job can request each scratch device. To set the sharing attribute, follow the rules in section 3.4.4, "Configuring the Vnode Sharing Attribute", on page 48. For example, the scratch devices are `/scratch1`, `/scratch2`, `/scratch3`, etc. On each scratch device, set resources as follows:

```
resources_available.ncpus = 0
resources_available.mem = 0
resources_available.scratch = 1
sharing = force_excl
```

Jobs then request one additional chunk to represent the scratch device, for example:

```
-l 16:ncpus=1+1:scratch=1
```

If a job needs to request a specific scratch device, for example `/scratch2`, that can be done by additionally asking for the scratch resource:

```
:scratch=1
```

5.14.5.4 Static Host-level Scratch Space

If the scratch areas are not mounted on all execution hosts, you can specify which scratch areas are shared among which subsets of vnodes using indirect resources. See section 5.14.4.3, "Shared Host-level Resources", on page 273.

5.14.5.5 Caveats for Scratch Space and Jobs

When more than one job uses scratch space, or when a job is suspended, scratch space usage may not be handled correctly. See section 5.9.5, "Dynamic Resource Allocation Caveats", on page 252 and section 5.9.6, "Period When Resource is Used by Job", on page 252.

5.14.6 Supplying Application Licenses

5.14.6.1 Types of Licenses

Application licenses may be managed by PBS or by an external license manager. Application licenses may be floating or node-locked, and they may be *per-host*, where any number of instances can be running on that host, *per-CPU*, where one license allows one CPU to be used for that application, or *per-run*, where one license allows one instance of the application to be running. Each kind of license needs a different form of custom resource.

5.14.6.1.i Externally-managed Licenses

Whenever an application license is managed by an external license manager, you must create a custom dynamic resource for it. This is because PBS has no control over whether these licenses are checked out, and must query the external license manager for the availability of those licenses. PBS does this by executing the script or program that you specify in the dynamic resource. This script returns the amount via `stdout`, in a single line ending with a newline.

5.14.6.1.ii Preventing Oversubscription of Externally-managed Licenses

Some applications delay the actual license checkout until some time after the application begins execution. Licenses could be oversubscribed when the scheduler queries for available licenses, and gets a result including licenses that essentially belong to a job that is already running but has not yet checked them out. To prevent this, you can create a consumable custom static integer resource, assign it the total number of licenses, and make each job that requests licenses request this resource as well. You can use a hook to accomplish this. Alternatively, if you know the maximum number of jobs that can run using these licenses, you can create a consumable custom static integer resource to track the number of jobs using licenses, and make each job request this resource.

If licenses are also checked out by applications outside of the control of PBS, this technique will not work.

5.14.6.1.iii PBS-managed Licenses

When an application license is managed by PBS, you can create a custom static resource for it. You set the total number of licenses using `qmgr`, and PBS will internally keep track of the number of licenses available.

Use static host-level resources for node-locked application licenses managed by PBS, where PBS is in full control of the licenses. These resources are *static* because PBS tracks them internally, and *host-level* because they are tracked at the host.

5.14.6.2 License Units and Features

Different licenses use different license units to track whether an application is allowed to run. Some licenses track the number of CPUs an application is allowed to run on. Some licenses use tokens, requiring that a certain number of tokens be available in order to run. Some licenses require a certain number of features to run the application.

When using units, after you have defined the license resource called license_name to the server, be sure to set resources_available.license_name to the correct number of units.

Before starting you should have answers to the following questions:

- How many units of a feature does the application require?
- How many features are required to execute the application?
- How do I query the license manager to obtain the available licenses of particular features?

With these questions answered you can begin configuring PBS Professional to query the license manager servers for the availability of application licenses. Think of a license manager feature as a resource. Therefore, you should associate a resource with each feature.

5.14.6.3 Server-level (Floating) Licenses

5.14.6.3.i Example of Floating, Externally-managed License

Here is an example of setting up floating licenses that are managed by an external license server.

For this example, we have a 6-host complex, with one CPU per host. The hosts are numbered 1 through 6. On this complex we have one licensed application which uses floating licenses from an external license manager. Furthermore we want to limit use of the application only to specific hosts. The table below shows the application, the number of licenses, the hosts on which the licenses should be used, and a description of the type of license used by the application.

Application	Licenses	Hosts	DESCRIPTION
AppF	4	3-6	Uses licenses from an externally managed pool

For the floating licenses, we will use three resources. One is a dynamic server resource for the licenses themselves. One is a global server-level integer to prevent oversubscription. The last is a Boolean resource used to indicate that the floating license can be used on a given host.

Server Configuration

1. Define the new resources. Specify the resource names, type, and flag(s):
```
Qmgr: create resource <resource name> type=<type>,flag=<flags>
```

Host Configuration

2. Set the Boolean resource on the hosts where the floating licenses can be used.
```
Qmgr: active node host3,host4,host5,host6
Qmgr: set node resources_available.runsAppF = True
```

Scheduler Configuration

3. Edit the scheduler configuration file:

```
cd $<sched_priv directory>/
[edit] sched_config
```

4. Append the new resource names to the `resources:` line:

```
resources: "ncpus, mem, arch, host, [...], AppF, AppFcount, runsAppF"
```

5. Edit the `server_dyn_res:` line:

```
server_dyn_res: "AppF !/local/flex_AppF"
```

6. Optional: give the scheduler a time limit for the script by setting its server_dyn_res_alarm attribute:

```
Qmgr: set sched <scheduler name> server_dyn_res_alarm=<new value>
```

7. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

You can write a hook that examines the number of AppF licenses requested by each job, and assigns that many AppFcount to the job, or you can ask your users to request AppFcount.

To request a floating license for AppF and a host on which AppF can run:

```
qsub -l AppF=1 -l AppFcount=1
-l select=runsAppF=True
```

The example below shows what the host configuration would look like. What is shown is actually truncated output from the `pbsnodes -a` command. Similar information could be printed via the `qmgr -c "print node @default"` command as well.

```
host1
host2
host3
     resources_available.runsAppF = True
host4
     resources_available.runsAppF = True
host5
     resources_available.runsAppF = True
host6
     resources_available.runsAppF = True
```

5.14.6.3.ii Example of Floating, Externally-managed License with Features

This is an example of a floating license, managed by an external license manager, where the application requires a certain number of features to run. Floating licenses are treated as server-level dynamic resources. The license server is queried by an administrator-created script. This script returns the value via `stdout` in a single line ending with a newline.

The license script runs on the server host once per scheduling cycle and queries the number of available licenses/tokens for each configured application.

When submitting a job, the user's script, in addition to requesting CPUs, memory, etc., also requests licenses.

When the scheduler looks at all the enqueued jobs, it evaluates the license request alongside the request for physical resources, and if all the resource requirements can be met the job is run. If the job's token requirements cannot be met, then it remains queued.

PBS doesn't actually check out the licenses; the application being run inside the job's session does that. Note that a small number of applications request varying amounts of tokens during a job run.

Our example needs four features to run an application, so we need four custom resources.

1. Write four scripts, one to query the license server for each of your four features. Complexity of the script is entirely site-specific due to the nature of how applications are licensed.
2. Define four non-consumable server-level features. These features are defined with no flags:

   ```
   Qmgr: create resource feature1   type=long
   Qmgr: create resource feature3   type=long
   Qmgr: create resource feature6   type=long
   Qmgr: create resource feature8   type=long
   ```
3. Add the feature resources to the `resources:` line in `<sched_priv directory>/sched_config`:

   ```
   resources: "ncpus, mem, arch, [...], feature1, feature3, feature6, feature8"
   ```
4. Add each feature's script path to the `server_dyn_res:` line in `PBS_HOME/server_priv/config`:

   ```
   server_dyn_res: "feature1 !/path/to/script [args]"
   server_dyn_res: "feature3 !/path/to/script [args]"
   server_dyn_res: "feature6 !/path/to/script [args]"
   server_dyn_res: "feature8 !/path/to/script [args]"
   ```
5. Optional: give the scheduler a time limit for the scripts by setting its server_dyn_res_alarm attribute:

   ```
   Qmgr: set sched <scheduler name> server_dyn_res_alarm=<new value>
   ```
6. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

5.14.6.3.iii Example of Floating License Managed by PBS

Here is an example of configuring custom resources for a floating license that PBS manages. For this you need a server-level static resource to keep track of the number of available licenses. If the application can run only on certain hosts, then you will need a host-level Boolean resource to direct jobs running the application to the correct hosts.

In this example, we have six hosts numbered 1-6, and the application can run on hosts 3, 4, 5 and 6. The resource that will track the licenses is called *AppM*. The Boolean resource is called *RunsAppM*.

Server Configuration

1. Define the new resource. Specify the resource names, type, and flag(s):

   ```
   Qmgr: create resource <resource name> type=<type>,flag=<flags>
   ```

   Example:

   ```
   Qmgr: create resource AppM type=long, flag=q
   Qmgr: create resource runsAppM type=boolean, flag=h
   ```
2. Set a value for AppM at the server. Here, we're allowing 8 copies of the application to run at once:

   ```
   Qmgr: set server resources_available.AppM=8
   ```

Host Configuration

3. Set the value of runsAppM on the hosts. Each `qmgr` directive is typed on a single line:

   ```
   Qmgr: active node host3,host4,host5,host6
   Qmgr: set node resources_available.runsAppM = True
   ```

Scheduler Configuration

4. Edit the scheduler configuration file:

```
cd $<sched_priv directory>/
[edit] sched_config
```

5. Append the new resource name to the `resources:` line. Note that it is not necessary to add a host-level Boolean resource to this line.

```
resources: "ncpus, mem, arch, host, [...], AppM, runsAppM"
```

6. Restart the scheduler. See “Restarting and Reinitializing Scheduler or Multisched” on page 166 in the PBS Professional Installation & Upgrade Guide.

To request both the application and a host that can run AppM:

```
qsub -l AppM=1
-l select=1:runsAppM=1 <jobscript>
```

The example below shows what the host configuration would look like. What is shown is actually truncated output from the `pbsnodes -a` command. Similar information could be printed via the `qmgr -c "print node @default"` command as well. Since unset Boolean resources are the equivalent of *False*, you do not need to explicitly set them to *False* on the other hosts. Unset Boolean resources will not be printed.

```
host1
host2
host3
     resources_available.runsAppM = True
host4
     resources_available.runsAppM = True
host5
     resources_available.runsAppM = True
host5
     resources_available.runsAppM = True
```

5.14.6.4 Host-level (Node-locked) Licenses

5.14.6.4.i Per-host Node-locked Licenses

If you are configuring a custom resource for a per-host node-locked license, where the number of jobs using the license does not matter, use a host-level Boolean resource on the appropriate host. This resource is set to *True*. When users request the license, they can use the following requests:

For a two-CPU job on a single vnode:

```
-l select=1:ncpus=2:license=1
```

For a multi-vnode job:

```
-l select=2:ncpus=2:license=1
-l place=scatter
```

Users can also use "`license=True`", but this way they do not have to change their scripts.

5.14.6.4.ii Per-CPU Node-locked Licenses

If you are configuring a custom resource for a per-CPU node-locked license, use a host-level consumable resource on the appropriate vnode. This resource is set to the maximum number of CPUs you want used on that vnode. Then when users request the license, they will use the following request:

For a two-CPU, two-license job:

```
-l select=1:ncpus=2:license=2
```

5.14.6.4.iii Per-use Node-locked License

If you are configuring a custom resource for a per-use node-locked license, use a host-level consumable resource on the appropriate host. This resource is set to the maximum number of instances of the application allowed on that host. Then when users request the license, they will use:

For a two-CPU job on a single host:

```
-l select=1:ncpus=2:license=1
```

For a multi-vnode job where each chunk needs two CPUs:

```
-l select=2:ncpus=2:license=1
-l place=scatter
```

5.14.6.4.iv Example of Per-host Node-locked Licensing

Here is an example of setting up node-locked licenses where one license is required per host, regardless of the number of jobs on that host.

For this example, we have a 6-host complex, with one CPU per host. The hosts are numbered 1 through 6. On this complex we have a licensed application that uses per-host node-locked licenses. We want to limit use of the application only to specific hosts. The table below shows the application, the number of licenses for it, the hosts on which the licenses should be used, and a description of the type of license used by the application.

Application	Licenses	Hosts	DESCRIPTION
AppA	1	1-4	uses a local node-locked application license

For the per-host node-locked license, we will use a Boolean host-level resource called resources_available.runsAppA. This will be set to *True* on any hosts that should have the license, and will default to *False* on all others. The resource is not consumable so that more than one job can request the license at a time.

Server Configuration

1. Define the new resource. Specify the resource names, type, and flag(s):

   ```
   create resource <resource name> type=<type>,flag=<flag>
   ```

   Example:

   ```
   Qmgr: create resource runsAppA type=boolean, flag=h
   Qmgr: create resource AppA type=long, flag=h
   ```

Host Configuration

2. Set the value of runsAppA on the hosts. Each `qmgr` directive is typed on a single line:

   ```
   Qmgr: active node host1,host2,host3,host4
   Qmgr: set node resources_available.runsAppA = True
   ```

Scheduler Configuration

3. Edit the scheduler configuration file.

```
cd $<sched_priv directory>/
[edit] sched_config
```

4. Append the new resource name to the "resources:" line. Note that it is not necessary to add the host-level Boolean resource to this line.

```
resources: "ncpus, mem, arch, [...], AppA, runsAppA"
```

5. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

To request a host with a per-host node-locked license for AppA:

```
qsub -l select=1:runsAppA=1 <jobscript>
```

The example below shows what the host configuration would look like. What is shown is actually truncated output from the `pbsnodes -a` command. Similar information could be printed via the `qmgr -c "print node @default"` command as well. Since unset Boolean resources are the equivalent of *False*, you do not need to explicitly set them to *False* on the other hosts. Unset Boolean resources will not be printed.

```
host1
     resources_available.runsAppA = True
host2
     resources_available.runsAppA = True
host3
     resources_available.runsAppA = True
host4
     resources_available.runsAppA = True
host5
host6
```

5.14.6.4.v Example of Per-use Node-locked Licensing

Here is an example of setting up per-use node-locked licenses. Here, while a job is using one of the licenses, it is not available to any other job.

For this example, we have a 6-host complex, with 4 CPUs per host. The hosts are numbered 1 through 6. On this complex we have a licensed application that uses per-use node-locked licenses. We want to limit use of the application only to specific hosts. The licensed hosts can run two instances each of the application. The table below shows the application, the number of licenses for it, the hosts on which the licenses should be used, and a description of the type of license used by the application.

Application	Licenses	Hosts	DESCRIPTION
AppB	2	1-2	Uses a local node-locked application license

For the node-locked license, we will use one static host-level resource called resources_available.AppB. This will be set to *2* on any hosts that should have the license, and to *0* on all others. The "nh" flag combination means that it is host-level and it is consumable, so that if a host has 2 licenses, only two jobs can use those licenses on that host at a time.

Server Configuration

1. Define the new resource. Specify the resource names, type, and flag(s):

```
Qmgr: create resource <resource name> type=<type>,flag=<flags>
```

Example:

```
Qmgr: create resource AppB type=long, flag=nh
```

Host Configuration

2. Set the value of AppB on the hosts to the maximum number of instances allowed. Each `qmgr` directive is typed on a single line:

```
Qmgr: active node host1,host2
Qmgr: set node resources_available.AppB = 2
Qmgr: active node host3,host4,host5,host6
Qmgr: set node resources_available.AppB = 0
```

Scheduler Configuration

3. Edit the scheduler configuration file.

```
cd $<sched_priv directory>/
[edit] sched_config
```

4. Append the new resource name to the `resources:` line:

```
resources: "ncpus, mem, arch, host, [...], AppB"
```

5. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

To request a host with a node-locked license for AppB, where you'll run one instance of AppB on two CPUs:

```
qsub -l select=1:ncpus=2:AppB=1
```

The example below shows what the host configuration would look like. What is shown is actually truncated output from the `pbsnodes -a` command. Similar information could be printed via the `qmgr -c "print node @default"` command as well.

```
host1
     resources_available.AppB = 2
host2
     resources_available.AppB = 2
host3
     resources_available.AppB = 0
host4
     resources_available.AppB = 0
host5
     resources_available.AppB = 0
host6
     resources_available.AppB = 0
```

5.14.6.4.vi Example of Per-CPU Node-locked Licensing

Here is an example of setting up per-CPU node-locked licenses. Each license is for one CPU, so a job that runs this application and needs two CPUs must request two licenses. While that job is using those two licenses, they are unavailable to other jobs.

For this example, we have a 6-host complex, with 4 CPUs per host. The hosts are numbered 1 through 6. On this complex we have a licensed application that uses per-CPU node-locked licenses. We want to limit use of the application to specific hosts only. The table below shows the application, the number of licenses for it, the hosts on which the licenses should be used, and a description of the type of license used by the application.

Application	Licenses	Hosts	DESCRIPTION
AppC	4	3-4	uses a local node-locked application license

For the node-locked license, we will use one static host-level resource called resources_available.AppC. We will provide a license for each CPU on hosts 3 and 4, so this will be set to *4* on any hosts that should have the license, and to *0* on all others. The "nh" flag combination means that it is host-level and it is consumable, so that if a host has 4 licenses, only four CPUs can be used for that application at a time.

Server Configuration

1. Define the new resource. Specify the resource names, type, and flag(s):

   ```
   Qmgr: create resource <resource name> type=<type>,flag=<flags>
   ```

   Example:

   ```
   Qmgr: create resource AppC type=long, flag=nh
   ```

Host Configuration

2. Set the value of AppC on the hosts. Each `qmgr` directive is typed on a single line:

   ```
   Qmgr: active node host3,host4
   Qmgr: set node resources_available.AppC = 4
   Qmgr: active node host1,host2,host5,host6
   Qmgr: set node resources_available.AppC = 0
   ```

Scheduler Configuration

3. Edit the scheduler configuration file:

   ```
   cd $<sched_priv directory>/
   [edit] sched_config
   ```

4. Append the new resource name to the `resources:` line:

   ```
   resources: "ncpus, mem, arch, host, [...], AppC"
   ```

5. Restart the scheduler. See "Restarting and Reinitializing Scheduler or Multisched" on page 166 in the PBS Professional Installation & Upgrade Guide.

To request a host with a node-locked license for AppC, where you'll run a job using two CPUs:

```
qsub -l select=1:ncpus=2:AppC=2
```

The example below shows what the host configuration would look like. What is shown is actually truncated output from the `pbsnodes -a` command. Similar information could be printed via the `qmgr -c "print node @default"` command as well.

```
host1
     resources_available.AppC = 0
host2
     resources_available.AppC = 0
host3
     resources_available.AppC = 4
host4
     resources_available.AppC = 4
host5
     resources_available.AppC = 0
host6
     resources_available.AppC = 0
```

5.14.7 Using GPUs

You can configure PBS to manage GPU resources. You only need to use one method. You can use any of the following methods, but we recommend using the cgroups hook:

- Managing GPUs via Cgroups does the configuration for you, takes advantage of topology, and provides isolation. You can use this method to restrict each job to the GPU(s) assigned to it. We recommend using this method: you get device isolation, job submission is much easier, etc.
- Basic GPU Scheduling works well if you have single-GPU vnodes. The basic method will meet the needs of most job submitters; it allows a job to request the number of GPUs it needs, as long as the job requests exclusive use of each node containing the GPUs.
- Advanced GPU Scheduling allows jobs to request specific GPUs. The advanced method provides some flexibility for multi-job or multi-GPU vnodes, but does not isolate GPUs. PBS Professional allocates GPUs for jobs, but does not perform the actual binding. The application or the CUDA library binds the application to one or more GPUs. You cannot combine this with the cgroups hook.

5.14.7.1 Basic GPU Scheduling

Basic scheduling consists of prioritizing jobs based on partition or site policies, controlling access to nodes with GPUs, ensuring that GPUs are not over-subscribed, and tracking use of GPUs in accounting logs.

Configuring PBS to perform basic scheduling of GPUs is relatively simple, and only requires defining and configuring a single custom resource to represent the number of GPUs on each node.

This method allows jobs to request unspecified GPUs. Jobs should request exclusive use of the node to prevent other jobs being scheduled on their GPUs.

5.14.7.1.i Configuring PBS for Basic GPU Scheduling

You configure a single custom consumable resource to represent all GPU devices on an execution host. Create a host-level global consumable custom resource to represent GPUs. We recommend that the custom GPU resource is named *ngpus*. Set the value for this resource at each vnode to the number of GPUs on the vnode.

The ngpus resource is used exactly the way you use the ncpus resource.

5.14.7.1.ii Example of Configuring PBS for Basic GPU Scheduling

In this example, there are two execution hosts, HostA and HostB, and each execution host has 4 GPU devices.

1. Create the ngpus resource:
   ```
   Qmgr: create resource ngpus type=long, flag=nh
   ```
2. Stop the server and scheduler. On the server's host, type:
   ```
   systemctl stop pbs
   ```
   or
   ```
   /etc/init.d/pbs stop
   ```
3. Edit `<sched_priv directory>/sched_config` to add ngpus to the list of scheduling resources:
   ```
   resources: "ncpus, mem, arch, host, vnode, ngpus"
   ```
4. Start the server and scheduler. On the server's host, type:
   ```
   systemctl start pbs
   ```
   or
   ```
   /etc/init.d/pbs start
   ```
5. Add the number of GPU devices available to each execution host in the cluster via `qmgr`:
   ```
   Qmgr: set node HostA resources_available.ngpus=4
   Qmgr: set node HostB resources_available.ngpus=4
   ```

5.14.7.2 Advanced GPU Scheduling

Advanced scheduling allows a job to separately allocate (request and/or identify) each individual GPU on a node.

In this case, both PBS and the applications themselves must support individually allocating the GPUs on a node. Advanced scheduling requires defining a child vnode for each GPU.

This capability is useful for sharing a single multi-GPU node among multiple jobs, where each job requires exclusive use of its GPUs.

5.14.7.2.i Configuring PBS for Advanced GPU Scheduling

You configure each GPU device in its own vnode, and each GPU vnode has a resource to contain the device number of its GPU.

Create and set two custom resources:

- Create a host-level global consumable resource to represent the GPUs on a vnode. We recommend that this resource is called *ngpus*.

  Set ngpus on each node to the number of GPUs on that node.
- Create a host-level global non-consumable resource containing the GPU device number, which serves to tie the individual GPU to the vnode. We recommend that this resource is called *gpu_id*.

  Set gpu_id for each GPU to the device number of that GPU.

5.14.7.2.ii Example of Configuring PBS for Advanced GPU Scheduling

In this example, there is one execution host, HostA, that has two child vnodes, HostA[0] and HostA[1], as well as the parent vnode. HostA has 4 CPUs, 2 GPUs, and 16 GB of memory.

1. Create the new custom resources:
   ```
   Qmgr: create resource ngpus type=long, flag=nh
   Qmgr: create resource gpu_id type=string, flag=h
   ```
2. Stop the server and scheduler. On the server's host, type:
   ```
   systemctl stop pbs
   ```
   or
   ```
   /etc/init.d/pbs stop
   ```
3. Edit `<sched_priv directory>/sched_config` to add ngpus and gpu_id to the list of scheduling resources:
   ```
   resources: "ncpus, mem, arch, host, vnode, ngpus, gpu_id"
   ```
4. Start the server and scheduler. On the server's host, type:
   ```
   systemctl start pbs
   ```
   or
   ```
   /etc/init.d/pbs start
   ```
5. Create a vnode configuration file for each execution host where GPUs are present. See section 3.4.3, “Version 2 Vnode Configuration Files”, on page 44. The script for HostA is named *hostA_vnodes*, and is shown here:
   ```
   $configversion 2
   hostA: resources_available.ncpus = 0
   hostA: resources_available.mem = 0
   hostA[0]: resources_available.ncpus = 2
   hostA[0] : resources_available.mem = 8gb
   hostA[0] : resources_available.ngpus = 1
   hostA[0] : resources_available.gpu_id = gpu0
   hostA[0] : sharing = default_excl
   hostA[1] : resources_available.ncpus = 2
   hostA[1] : resources_available.mem = 8gb
   hostA[1] : resources_available.ngpus = 1
   hostA[1] : resources_available.gpu_id = gpu1
   hostA[1]: sharing = default_excl
   ```
6. Create a Version 2 configuration file for each host with GPUs. For example:
   ```
   PBS_EXEC/sbin/pbs_mom -s insert HostA_vnodes HostA_vnodes
   ```
7. Signal each MoM to re-read its configuration files:
   ```
   kill -HUP <pbs_mom PID>
   ```

5.14.7.3 Managing GPUs Via Cgroups Hook

We describe how to manage your GPUs via cgroups in section 16.5.5.1, “Managing GPUs via Cgroups”, on page 606.

5.14.8 Using FPGAs

You can configure a custom resource that allows PBS to track the usage of FPGAs. The FPGAs are detected outside of PBS at boot time. There are two basic methods for automatic configuration of the FPGA resource:

- Create a global static host-level resource called *nfpgas*. Create a boot-up script in `init.d` that detects the presence of the FPGAs, and sets the value of the nfpgas resource.
- Create a global dynamic host-level resource called *nfpgas*. This resource calls a script to detect the presence of FPGAs

We recommend the static resource, because FPGAs are static, and there is a performance penalty for a dynamic resource.

5.14.9 Defining Host-level Resource for Applications

You may need to tag your vnodes with the software that can run on them. You cannot use the built-in software resource for this; it is a server-level resource and cannot be set per host. You can define a custom resource named, for example, "node_software". It should be a string_array, since a host may be able to run more than one application. You can use `qmgr` to create your resource:

```
Qmgr: create resource node_software type=string_array, flag=h
```

You can use your new custom resource to route jobs: see section 4.9.39, “Routing Jobs”, on page 207.

5.14.10 Custom Resource Caveats

- Because some custom resources are external to PBS, they are not completely under the control of PBS. Therefore it is possible for PBS to query and find a resource available, schedule a job to run and use that resource, only to have an outside entity take that resource before the job is able to use it. For example, say you had an external resource of "scratch space" and your local query script simply checked to see how much disk space was free. It would be possible for a job to be started on a host with the requested space, but for another application to use the free space before the job did.
- If a resource is not put in the scheduler's `resources:` line, when jobs request the resource, that request will be ignored. If the resource is ignored, it cannot be used to accept or reject jobs at submission time. For example, if you create a string resource String1 on the server, and set it to *foo*, a job requesting "`-l String1=bar`" will be accepted. The only exception is host-level Boolean resources, which are considered when scheduling, whether or not they are in the scheduler's `resources:` line.
- Do not create resources with the same names or prefixes that PBS uses when you create custom resources for specific systems.
- Using dynamic host-level resources can slow the scheduler down, because the scheduler must wait for each resource-query script to run.

5.15 Managing Resource Usage

You can manage resource usage from different directions:

- You can manage resource usage by users, groups, and projects, and the number of jobs, at the server and queue level. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.
  - You can manage the total amount of each resource that is used by projects, users or groups, at the server or queue level. For example, you can manage how much memory is being used by jobs in queue QueueA.
  - You can manage the number of jobs being run by projects, users or groups, at the server or queue level. For example, you can limit the number of jobs enqueued in queue QueueA by any one group to *30*, and by any single user to *5*.
- You can specify how much of each resource any job is allowed to use, at the server and queue level. See section 5.15.2, "Placing Resource Limits on Jobs", on page 307 and section 5.13, "Using Resources to Restrict Server or Queue Access", on page 256.
- You can set default limits for usage for each resource, at the server or queue level, so that jobs that do not request a given resource inherit that default, and are limited to the inherited amount. For example, you can specify that any job entering queue QueueA not specifying mem is limited to using 4MB of memory. See section 5.9.3, "Specifying Job Default Resources", on page 247.
- You can set limits on the number of jobs that can be in the queued state at the server and/or queue level. You can apply these limits to users, groups, projects, or everyone. This allows users to submit as many jobs as they want, while allowing the scheduler to consider only the jobs in the execution queues, thereby speeding up the scheduling cycle. See section 5.15.3, "Limiting the Number of Jobs in Queues", on page 312.

5.15.1 Managing Resource Usage By Users, Groups, and Projects, at Server & Queues

You can set separate limits for resource usage by individual users, individual groups, individual projects, generic users, generic groups, generic projects, and the total used overall, for queued jobs, running jobs, and queued and running jobs. You can limit the amount of resources used, and the number of queued jobs, the number of running jobs, and the number of queued and running jobs. These limits can be defined separately for each queue and for the server. You define the limits by setting server and queue limit attributes. For information about projects, see section 14.4, "Grouping Jobs By Project", on page 509.

There are **two incompatible sets of server and queue limit attributes** used in limiting resource usage. The first set existed in PBS Professional before Version 10.1, and we call them the **old limit attributes**. The old limit attributes are discussed in section 5.15.1.15, "Old Limit Attributes: Server and Queue Resource Usage Limit Attributes Existing Before Version 10.1", on page 305. The set introduced in Version 10.1 is called simply the limit attributes, and they are discussed here.

You can use either the limit attributes or the old limit attributes for the server and queues, but not both. See section 5.15.1.13.v, "Do Not Mix Old And New Limits", on page 304.

The server and queues each have per-job limit attributes which operate independently of the limits discussed in this section. The resources_min.<resource name> and resources_max.<resource name> server and queue attributes are limits on what each individual job may use. See section 5.13, "Using Resources to Restrict Server or Queue Access", on page 256 and section 5.15.2, "Placing Resource Limits on Jobs", on page 307.

5.15.1.1 Examples of Managing Resource Usage at Server and Queues

You can limit resource usage and job count for specific projects, users and groups:

- UserA can use no more than 6 CPUs, and UserB can use no more than 4 CPUs, at one time anywhere in the PBS complex.
- The crashtest group can use no more than 16 CPUs at one time anywhere in the PBS complex.
- UserC accidentally submitted 200,000 jobs last week. UserC can now have no more than 25 jobs enqueued at one time.
- All jobs request the server-level custom resource nodehours, which is used for allocation. UserA cannot use more than 40 nodehours in the PBS complex. Once UserA reaches the nodehours limit, then all queued jobs owned by UserA are not eligible for execution.
- You wish to allow UserD to use 12 CPUs but limit all other users to 4 CPUs.
- Jobs belonging to Project A can use no more than 8 CPUs at Queue1.

You can limit the number of jobs a particular project, user or group runs in a particular queue:

- UserE can use no more than 2 CPUs at one time at Queue1, and 6 CPUs at one time at Queue2.
- You wish to limit UserF to 10 running jobs in queue Queue3, but allow all other users unlimited jobs running in the same queue.
- UserG is a member of Group1. You have a complex-wide limit of 5 running jobs for UserG. You have a limit at Queue1 of 10 running jobs for Group1. This way, up to 10 of the running jobs in Queue1 can belong to Group1, and 5 of these can belong to UserG.
- UserH is a member of Group1. You have a complex-wide limit of 5 running jobs for UserH. You have a limit at Queue1 of 10 running jobs for any group in Queue1. This way, no group in Queue1 can run more than 10 jobs total at one time, and 5 of these can belong to UserH.
- UserJ is a member of Group1. You have a complex-wide limit of 10 running jobs for UserJ. You also have a limit at Queue1 of 5 running jobs for Group1. This means that there may be up to 5 running jobs owned by users belonging to Group1 in Queue1, and up to 5 of these can be owned by UserJ. UserJ can also have another 5 running jobs owned by Group1 in any other queue, or owned by a different group in Queue1.
- No more than 12 jobs belonging to Project A can run at Queue1, and all other projects are limited to 8 jobs at Queue1.

You can ensure fairness in the use of resources:

- You have multiple departments which have shared the purchase of a large machine. Each department would like to ensure fairness in the use of the machine, by setting limits on individual users and groups.
- You have multiple departments, each of which purchases its own machines. Each department would like to limit the use of its machines so that all departmental users have specific limits. In addition, each department would like to allow non-departmental users to use its machines when they are under-utilized, while giving its own users priority on its machines. A non-departmental user can run jobs on a departmental machine, as long as no departmental users' jobs are waiting to run.

5.15.1.2 Glossary

Limit

The maximum amount of a resource that can be consumed at any time by running jobs or allocated to queued jobs, or the maximum number of jobs that can be running, or the maximum number of jobs that can be queued.

Overall limit

Limit on the total usage. In the context of server limits, this is the limit for usage at the PBS complex. In the context of queue limits, this is the limit for usage at the queue. An overall limit is applied to the total usage at the specified location. Separate overall limits can be specified at the server and each queue.

Generic user limit

Applies separately to users at the server or a queue. The limit for users who have no individual limit specified. A separate limit for generic users can be specified at the server and at each queue.

Generic group limit

Applies separately to groups at the server or a queue. The limit for groups which have no individual limit specified. A limit for generic groups is applied to the usage across the entire group. A separate limit can be specified at the server and each queue.

Generic project limit

Applies separately to projects at the server or a queue. The limit for projects which have no individual limit specified. A limit for generic projects is applied to the usage across the entire project. A separate limit can be specified at the server and each queue.

Individual user limit

Applies separately to users at the server or a queue. Limit for users who have their own individual limit specified. A limit for an individual user overrides the generic user limit, but only in the same context, for example, at a particular queue. A separate limit can be specified at the server and each queue.

Individual group limit

Applies separately to groups at the server or a queue. Limit for a group which has its own individual limit specified. An individual group limit overrides the generic group limit, but only in the same context, for example, at a particular queue. The limit is applied to the usage across the entire group. A separate limit can be specified at the server and each queue.

Individual project limit

Applies separately to projects at the server or a queue. Limit for a project which has its own individual limit specified. An individual project limit overrides the generic project limit, but only in the same context, for example, at a particular queue. The limit is applied to the usage across the entire project. A separate limit can be specified at the server and each queue.

User limit

A limit placed on one or more users, whether generic or individual.

Group limit

This is a limit applied to the total used by a group, whether the limit is a generic group limit or an individual group limit.

Project

In PBS, a project is a way to group jobs independently of users and groups. A project is a tag that identifies a set of jobs. Each job's project attribute specifies the job's project.

Project limit

This is a limit applied to the total used by a project, whether the limit is a generic project limit or an individual project limit.

Queued jobs

In a queue, queued jobs are the jobs that are waiting in that queue.

5.15.1.3 Difference Between PBS_ALL and PBS_GENERIC

Note the very important **difference** between the *overall limit* and a *generic* limit. We will describe how this works for users, but this applies to other entities as well. You set PBS_ALL for an overall limit on the total usage of that resource by all entities, whereas you set PBS_GENERIC for a limit for any single generic user.

Example 5-12: Difference between overall limit and generic user limit

Given the following:

- The overall server limit for running jobs is *100*
- The server limit for generic users is *10*
- The individual limit for User1 is 12 jobs

This means:

- Generic users (any single user except User1) can run no more than 10 jobs at this server
- User1 can run 12 jobs at this server
- At this server, no more than 100 jobs can be running at any time

5.15.1.4 Hard and Soft Limits

Hard limits are limits which cannot be exceeded. Soft limits are limits which mark the point where a project, user or group is using "extra, but acceptable" amounts of a resource. When this happens, the jobs belonging to that project, user or group are eligible for preemption. See section 4.9.33, “Using Preemption”, on page 182. Soft limits are discussed in section 4.9.33.7.i, “The Soft Limits Preemption Level”, on page 187.

5.15.1.5 Scope of Limits at Server and Queues

Each of the limits described above can be set separately at the server and at each queue. Each limit's scope is the PBS object where it is set. The individual and generic project, user and group limits that are set within one scope interact with each other only within that scope. For example, a limit set at one queue has no effect at another queue.

The scope of limits set at the server encompasses queues, so that the minimum, more restrictive limit of the two is applied. For precedence within a server or queue, see section 5.15.1.7, “Precedence of Limits at Server and Queues”, on page 296.

5.15.1.6 Ways To Limit Resource Usage at Server and Queues

You can create a complete set of limits at the server, and you can create another complete set of limits at each queue. You can set hard and soft limits. See section 4.9.33.7.i, "The Soft Limits Preemption Level", on page 187. You can limit resource usage at the server and the queue level for the following:

- Running jobs
  - Number of running jobs
  - Number of running jobs (soft limit)
  - Amount of each resource allocated for running jobs
  - Amount of each resource allocated for running jobs (soft limit)
- Queued jobs (this means jobs that are waiting to run from that queue)
  - Number of queued jobs
  - Amount of each resource allocated for queued jobs
- Queued and running jobs (this means both jobs that are waiting to run and jobs that are running from that queue)
  - Number of queued and running jobs
  - Amount of each resource allocated for queued and running jobs

These limits can be applied to the following:

- The total usage at the server
- The total usage at each queue
- Amount used by a single user
  - Generic users
  - Individual users
- Amount used by a single group
  - Generic groups
  - Individual groups
- Amount used by a single project
  - Generic projects
  - Individual projects

5.15.1.6.i Limits at Queues

You can limit the number of jobs that are queued at a queue, and running at a queue, and that are both queued and running at a queue.

You can limit the resources allocated to jobs that are queued at a queue, and running at a queue, and that are both queued and running at a queue.

Jobs queued at a queue are counted the same whether they were submitted to that queue via the `qsub` command or its equivalent API, moved to that queue via the `qmove` command or its equivalent API, or routed to that queue from another queue.

When PBS requeues a job, it does not take limits into account.

Routing queues do not run jobs, so you cannot set a limit for the number of running jobs, or the amount of resources being used by running jobs, at a routing queue.

5.15.1.6.ii Generic and Individual Limits

You can set a generic limit for groups, so that each group must obey the same limit. You can likewise set a generic limit for users and projects. Each generic limit can be set separately at the server and at each queue. For example, if you have two queues, the generic limit for the number of jobs a user can run be 4 at QueueA and 6 at QueueB.

You can set a different individual limit for each user, and you can set individual limits for groups and for projects. Each user, group, and project can have a different individual limit at the server and at each queue.

You can use a combination of generic and individual project, user or group limits, at the server and at each queue. Within the scope of the server or a queue, all projects, users or groups except the ones with the individual limits must obey the generic limit, and the individual limits override the generic limits.

Example 5-13: Generic and individual user limits on running jobs at QueueA and QueueB

At QueueA:

- At QueueA, the generic user limit is *5*
- At QueueA, Bob's individual limit is *8*
- Tom has no individual limit set at QueueA; the generic limit applies

At QueueB:

- At QueueB, the generic user limit is *2*
- At QueueB, Tom's individual limit is *1*
- Bob has no individual limit at QueueB; the generic limit applies

This means:

- Bob can run 8 jobs at QueueA
- Bob can run 2 jobs at QueueB
- Tom can run 5 jobs at QueueA
- Tom can run 1 job at QueueB

5.15.1.6.iii Overall Limits

The overall limit places a cap on the total amount of the resource that can be used within the scope in question (server or queue), regardless of whether project, user, or group limits have been reached. A project, user, or group at the server or a queue cannot use any more of a resource for which the overall limit has been reached, even if that project, user, or group limit has not been reached.

Example 5-14: Overall limit at server

Given the following:

- Overall server limit on running jobs is *100*
- Bob's user limit is *10* running jobs
- 98 jobs are already running
- Bob is running zero jobs

This means:

- Bob can start only 2 jobs

5.15.1.7 Precedence of Limits at Server and Queues

5.15.1.7.i Interactions Between Limits Within One Scope

Within the scope of a PBS object (server or queue), there is an order of precedence for limits when more than one applies to a job. The order of precedence for the limits at a queue is the same as the order at the server. The following table shows how limits interact within one scope:

Table 5-12: Limit Interaction Within One Scope

	Individual User	Generic User	Individual Group	Generic Group	Individual Project	Generic Project
Individual User	Individual user	Individual user	More restrictive	More restrictive	More restrictive	More restrictive
Generic User	Individual user	Generic user	More restrictive	More restrictive	More restrictive	More restrictive
Individual Group	More restrictive	More restrictive	Individual group	Individual group	More restrictive	More restrictive
Generic Group	More restrictive	More restrictive	Individual group	Generic group	More restrictive	More restrictive
Individual Project	More restrictive	More restrictive	More restrictive	More restrictive	Individual project	Individual project
Generic Project	More restrictive	More restrictive	More restrictive	More restrictive	Individual project	Generic project

An individual user limit overrides a generic user limit.

Example 5-15: Individual user limit overrides generic user limit

Given the following:

- Bob has a limit of 10 running jobs
- The generic limit is 5

This means:

- Bob can run 10 jobs

An individual group limit overrides a generic group limit in the same manner as for users.

If the limits for a user and the user's group are different, the more restrictive limit applies.

Example 5-16: More restrictive user or group limit applies

Given the following:

- Tom's user limit for running jobs is 8
- Tom's group limit is 7

This means:

- Tom can run only 7 jobs in that group

If a user belongs to more than one group, that user can run jobs up to the lesser of his user limit or the sum of the group limits.

Example 5-17: User can run jobs in more than one group

Given the following:

- Tom's user limit is *10* running jobs
- GroupA has a limit of *2* and GroupB has a limit of *4*
- Tom belongs to GroupA and GroupB

This means:

- Tom can run 6 jobs, 2 in GroupA and 4 in GroupB

An individual project limit overrides a generic project limit, similar to the way user and group limits work.

Project limits are applied independently of user and group limits.

Example 5-18: Project limits are applied without regard to user and group limits

Given the following:

- Project A has a limit of 2 jobs
- Bob has an individual limit of 4 jobs
- Bob's group has a limit of 6 jobs
- Bob is running 2 jobs, both in Project A

This means:

- Bob cannot run any more jobs in Project A

5.15.1.7.ii Interactions Between Queue and Server Limits

If the limits for a queue and the server are different, the more restrictive limit applies.

Example 5-19: More restrictive queue or server limit applies

Given the following:

- Server limit on running jobs for generic users is *10*
- Queue limit for running jobs from QueueA for generic users is *15*
- Queue limit for running jobs from QueueB for generic users is *5*

This means:

- Generic users at QueueA can run 10 jobs
- Generic users at QueueB can run 5 jobs

Example 5-20: More restrictive queue or server limit applies

Given the following:

- Bob's user limit on running jobs, set on the server, is *7*
- Bob's user limit on running jobs, set on QueueA, is *6*

This means:

- Bob can run 6 jobs from QueueA

5.15.1.8 Resource Usage Limit Attributes for Server and Queues

Each of the following attributes can be set at the server and each queue:

max_run

The maximum number of jobs that can be running.

max_run_soft

The soft limit on the maximum number of jobs that can be running.

max_run_res.<resource name>

The maximum amount of the specified resource that can be allocated to running jobs.

max_run_res_soft.<resource name>

The soft limit on the amount of the specified resource that can be allocated to running jobs.

max_queued

The maximum number of jobs that can be queued and running. At the server level, this includes all jobs in the complex. Queueing a job includes the `qsub` and `qmove` commands and the equivalent APIs.

max_queued_res.<resource name>

The maximum amount of the specified resource that can be allocated to queued and running jobs. At the server level, this includes all jobs in the complex. Queueing a job includes the `qsub` and `qmove` commands and the equivalent APIs.

queued_jobs_threshold

The maximum number of jobs that can be queued. At the server level, this includes all jobs in the complex. Queueing a job includes the `qsub` and `qmove` commands and the equivalent APIs.

queued_jobs_threshold_res.<resource name>

The maximum amount of the specified resource that can be allocated to queued jobs. At the server level, this includes all jobs in the complex. Queueing a job includes the `qsub` and `qmove` commands and the equivalent APIs.

Each attribute above can be used to specify all of the following:

- An overall limit (at the queue or server)
- A limit for generic users
- Individual limits for specific users
- A limit for generic projects
- Individual limits for specific projects
- A limit for generic groups
- Individual limits for specific groups

For example, you can specify the limits for the number of running jobs:

- In the complex:
    - The overall server limit (all usage in the entire complex) is *10,000*
    - The limit for generic users is *5*
    - The limit for Bob is *10*
    - The limit for generic groups is *50*
    - The limit for group GroupA is *75*
    - The limit for generic projects is *25*
    - The limit for Project A is *35*
- At QueueA:
    - The overall queue limit (all usage in QueueA) is *200*
    - The limit for generic users is *2*
    - The limit for Bob is *1*
    - The limit for generic groups is *3*
    - The limit for group GroupA is *7*
    - The limit for generic projects is *10*
    - The limit for Project A is *15*
- At QueueB:
    - The overall queue limit (all usage in QueueB) is *500*
    - The limit for generic users is *6*
    - The limit for Bob is *8*
    - The limit for generic groups is *15*
    - The limit for group GroupA is *11*
    - The limit for generic projects is *20*
    - The limit for Project A is *30*

5.15.1.9 How to Set Limits at Server and Queues

You can set, add, and remove limits by using the `qmgr` command to set limit attributes.

5.15.1.9.i Syntax

Format for setting a limit attribute:

set server <limit attribute> = "[limit-spec=<limit>], [limit-spec=<limit>],..."

set <queue> <queue name> <limit attribute> = "[limit-spec=<limit>], [limit-spec=<limit>],..."

Format for adding a limit to an attribute:

set server <limit attribute> += "[limit-spec=<limit>], [limit-spec=<limit>],..."

set <queue> <queue name> <limit attribute> += "[limit-spec=<limit>], [limit-spec=<limit>],..."

Format for removing a limit from an attribute; note that the value for <*limit*> need not be specified when removing a limit:

set server <limit attribute> -= "[limit-spec], [limit-spec],..."

set <queue> <queue name> <limit attribute> -= "[limit-spec], [limit-spec],..."

Alternate format for removing a limit from an attribute; note that the value of <*limit*> used when removing a limit must match the value of the limit:

set server <limit attribute> -= "[limit-spec=<limit>], [limit-spec=<limit>],..."

set <queue> <queue name> <limit attribute> -= "[limit-spec=<limit>], [limit-spec=<limit>],..."

where *limit-spec* specifies a user limit, a group limit, or an overall limit:

Table 5-13: Specifying Limits

Limit	limit-spec
Overall limit	*o:PBS_ALL*
Generic users	*u:PBS_GENERIC*
An individual user	*u:<username>*
Generic groups	*g:PBS_GENERIC*
An individual group	*g:<group name>*
Generic projects	p:PBS_GENERIC
An individual project	p:<project name>

The *limit-spec* can contain spaces anywhere except after the colon (":").

If there are comma-separated *limit-specs*, the entire string must be enclosed in double quotes.

A username, group name, or project name containing spaces must be enclosed in quotes.

If a username, group name, or project name is quoted using double quotes, and the entire string requires quotes, the outer enclosing quotes must be single quotes. Similarly, if the inner quotes are single quotes, the outer quotes must be double quotes.

PBS_ALL is a keyword which indicates that this limit applies to the usage total.

PBS_GENERIC is a keyword which indicates that this limit applies to generic users or groups.

When removing a limit, the limit value does not need to be specified.

PBS_ALL and *PBS_GENERIC* are case-sensitive.

5.15.1.9.ii Examples of Setting Server and Queue Limits

Example 5-21: To set the max_queued limit on QueueA to *5* for total usage, and to limit user bill to *3*:

```
Qmgr: s q QueueA max_queued = "[o:PBS_ALL=5], [u:bill =3]"
```

Example 5-22: On QueueA, set the maximum number of CPUs and the maximum amount of memory that user bill can request in his queued jobs:

```
Qmgr: s q QueueA max_queued_res.ncpus ="[u:bill=5]", max_queued_res.mem =
    "[u:bill=100mb]"
```

Example 5-23: To set a limit for a username with a space in it, and to set a limit for generic groups:

```
Qmgr: s q QueueA max_queued = '[u:"\PROG\Named User" = 1], [g:PBS_GENERIC=4]'
```

Example 5-24: To set a generic server limit for projects, and an individual server limit for Project A:

```
Qmgr: set server max_queued = '[p:PBS_GENERIC=6], [p:ProjectA=8]'
```

5.15.1.9.iii Examples of Adding Server and Queue Limits

Example 5-25: To add an overall limit for the maximum number of jobs that can be queued at QueueA to *10*:

```
Qmgr: s q QueueA max_queued += [o:PBS_ALL=10]
```

Example 5-26: To add an individual user limit, an individual group limit, and a generic group limit on queued jobs at QueueA:

```
Qmgr: s q QueueA max_queued += "[u:user1= 5], [g:GroupMath=5],[g:PBS_GENERIC=2]"
```

Example 5-27: To add a limit at QueueA on the number of CPUs allocated to queued jobs for an individual user, and a limit at QueueA on the amount of memory allocated to queued jobs for an individual user:

```
Qmgr: s q QueueA max_queued_res.ncpus += [u:tom=5], max_queued_res.mem += [u:tom=100mb]
```

Example 5-28: To add an individual server limit for Project B:

```
Qmgr: set server max_queued += [p:ProjectB=4]
```

5.15.1.9.iv Examples of Removing Server and Queue Limits

It is not necessary to specify the value of the limit when removing a limit, but you can specify the value of the limit.

Example 5-29: To remove the generic user limit at QueueA for queued jobs, use either of the following:

```
Qmgr: set queue QueueA max_queued -= [u:PBS_GENERIC]
Qmgr: set queue QueueA max_queued -= [u:PBS_GENERIC=2]
```

Example 5-30: To remove the limit on queued jobs at QueueA for *Named User*, use either of the following:

```
Qmgr: set queue QueueA max_queued -= [u:"\PROG\Named User"]
Qmgr: set queue QueueA max_queued -= [u:"\PROG\Named User"=1]
```

Example 5-31: To remove the limit at QueueA on the amount of memory allocated to an individual user, use either of the following:

```
Qmgr: set queue QueueA max_queued_res.mem -= [u:tom]
Qmgr: set queue QueueA max_queued_res.mem -= [u:tom=100mb]
```

To remove the limit on the number of CPUs allocated to queued jobs for user bill, use either of the following:

```
Qmgr: set queue QueueA max_queued_res.ncpus -= [u:bill]
Qmgr: set queue QueueA max_queued_res.ncpus -= [u:bill=5]
```

Example 5-32: To remove a generic user limit and an individual user limit, use either of the following:

```
Qmgr: set queue QueueA max_queued - -= "[u:user1], [u:PBS_GENERIC]"
Qmgr: set queue QueueA max_queued -= "[u:user1=2], [u:PBS_GENERIC=4]"
```

Example 5-33: To remove the individual server limit for Project B, use either of the following:

```
Qmgr: set server max_queued -=[p:ProjectB]
Qmgr: set server max_queued -=[p:ProjectB=4]
```

5.15.1.10 Who Can Set Limits at Server and Queues

As with other server and queue attributes, only PBS Managers and Operators can set limit attributes.

5.15.1.11 Viewing Server and Queue Limit Attributes

5.15.1.11.i Printing Server and Queue Limit Attributes

You can use the `qmgr` command to print the commands used to set the limit attributes at the server or queue.

Example 5-34: To print all the limit attributes for queue QueueA:

```
Qmgr: p q QueueA max_queued, max_queued_res
#
# Create queues and set their attributes.
#
# Create and define queue QueueA
#
create queue QueueA
set queue QueueA max_queued =  "[o:PBS_ALL=10]"
set queue QueueA max_queued += "[u:PBS_GENERIC=2]"
set queue QueueA max_queued += "[u:bill=3]"
set queue QueueA max_queued += "[u:tom=15]"
set queue QueueA max_queued += "[u:user1=3]"
set queue QueueA max_queued += '[u:"\PROG\Named User"=1]'
set queue QueueA max_queued += "[g:PBS_GENERIC=2] "
set queue QueueA max_queued += "[g:GroupMath=5]"
set queue QueueA max_queued_res.ncpus = "[u:bill=5]"
set queue QueueA max_queued_res.ncpus += "[u:tom=5]"
set queue QueueA max_queued_res.mem = "[u:bill=100mb]"
set queue QueueA max_queued_res.mem += "[u:tom=100mb]"
```

5.15.1.11.ii Listing Server and Queue Limit Attributes

You can use the `qmgr` command to list the limit attributes for the queue or server.

Example 5-35: To list the max_queued and max_queued_res attributes for QueueA:

```
Qmgr: l q QueueA max_queued, max_queued_res
Queue: QueueA
    max_queued = [o:PBS_ALL=10]
    max_queued = [g:PBS_GENERIC=2]
    max_queued = [g:GroupMath=5]
    max_queued = [u:PBS_GENERIC=2]
    max_queued = [u:bill=3]
    max_queued = [u:tom=15]
    max_queued = [u:user1=3]
    max_queued = [u:"\PROG\Named User"=1]
    max_queued_res.ncpus = [u:bill=5]
    max_queued_res.ncpus = [u:tom=5]
    max_queued_res.mem = [u:bill=5]
    max_queued_res.mem = [u:bill=100mb]
    max_queued_res.mem = [u:tom=100mb]
```

5.15.1.11.iii Using the `qstat` Command to View Queue Limit Attributes

You can use the `qstat` command to see the limit attribute settings for the queue or server.

Example 5-36: To see the settings for the max_queued and max_queued_res limit attributes for QueueA using the `qstat` command:

```
qstat -Qf QueueA
Queue: QueueA
        ...
    max_queued = [o:PBS_ALL=10]
    max_queued = [g:PBS_GENERIC=2]
    max_queued = [g:GroupMath=5]
    max_queued = [u:PBS_GENERIC=2]
    max_queued = [u:bill=3]
    max_queued = [u:tom=3]
    max_queued = [u:cs=3]
    max_queued = [u:"\PROG\Named User"=1]
    max_queued_res.ncpus = [u:bill=5]
    max_queued_res.ncpus = [u:tom=5]
    max_queued_res.mem = [u:bill=5]
    max_queued_res.mem =[u:bill=100mb]
    max_queued_res.mem =[u:tom=100mb]
```

5.15.1.12 How Server and Queue Limits Work

Affected jobs are jobs submitted by the user or group, or jobs belonging to a project, whose limit has been reached. The following table shows what happens when a given limit is reached:

Table 5-14: Actions Performed When Limits Are Reached

Limit	Action
Running jobs	No more affected jobs are run at this server or queue until the number of affected running jobs drops below the limit.
Queued jobs	The queue does not accept any more affected jobs until the number of affected queued jobs drops below the limit. Affected jobs submitted directly to the queue are rejected. Affected jobs in a routing queue whose destination is this queue remain in the routing queue. If a job is requeued, the limit is ignored.
Resources for running jobs	The queue does not run any more affected jobs until the limit would not be exceeded if the next affected job were to start.
Resources for queued jobs	The queue does not accept any more affected jobs until the limit would not be exceeded if the next affected job were to start. Affected jobs submitted directly to the queue are rejected. Affected jobs in a routing queue whose destination is this queue remain in the routing queue.

5.15.1.13 Caveats and Advice for Server and Queue Limits

5.15.1.13.i Avoiding Overflow

On PBS server platforms for which the native size of a long is less than 64 bits, you should refrain from defining a limit on a resource of type long whose cumulative sum over all queued jobs would exceed the storage capacity of the resource variable. For example, if each submitted job were to request 100 hours of the cput resource, overflow would occur on a 32-bit platform when 5965 jobs (which is $(2^{31} - 1)/360000$ seconds) were queued.

5.15.1.13.ii Ensuring That Limits Are Effective

In order for limits to be effective, each job must specify each limited resource. This can be accomplished using defaults; see section 5.9.3, “Specifying Job Default Resources”, on page 247. You can also use hooks; see the PBS Professional Hooks Guide.

5.15.1.13.iii Array Jobs

An array job with N subjobs is considered to consume N times the amount of resources requested when it was submitted. For example, if there is a server limit of 100 queued jobs, no user would be allowed to submit an array job with more than 100 subjobs.

5.15.1.13.iv Avoiding Job Rejection

Jobs are rejected when users, groups, or projects who have reached their limit submit a job in the following circumstances:

- The job is submitted to the execution queue where the limit has been reached
- The job is submitted to the complex, and the server limit has been reached

If you wish to avoid having jobs be rejected, you can set up a routing queue as the default queue. Set the server's default_queue attribute to the name of the routing queue. See section 2.3.6, “Routing Queues”, on page 27.

5.15.1.13.v Do Not Mix Old And New Limits

The new limit attributes are incompatible with the old limit attributes. See section 5.15.1.15, “Old Limit Attributes: Server and Queue Resource Usage Limit Attributes Existing Before Version 10.1”, on page 305. You cannot mix the use of old and new resource usage limit attributes. This means that:

- If any old limit attribute is set, and you try to set a new limit attribute, you will get error 15141.
- If any new limit attribute is set, and you try to set an old limit attribute, you will get error 15141.

You must unset all of one kind in order to set any of the other kind.

5.15.1.13.vi Do Not Limit Running Time

Beware creating limits such as max_run_res.walltime or max_run_res.max_walltime. The results probably will not be useful. You will be limiting the amount of walltime that can be requested by running jobs for a user, group, or project. For example, if you set a walltime limit of 10 hours for group A, then group A cannot run one job requesting 5 hours and another job requesting 6 hours.

5.15.1.14 Errors and Logging for Server and Queue Limits

5.15.1.14.i Error When Setting Limit Attributes

Attempting to set a new limit attribute while an old limit attribute is set:

```
"use new/old qmgr syntax, not both"
"Attribute name <new> not allowed.  Older name <old> already set'
```

Attempting to set an old limit attribute while a new limit attribute is set:

```
"use new/old qmgr syntax, not both"
"Attribute name <old> not allowed:  Newer name <new> already set''
```

5.15.1.14.ii Logging Events

Whenever a limit attribute is set or modified, the server logs the event, listing which attribute was modified and who modified it.

Whenever a limit is reached, and would be exceeded by a job, the scheduler logs the event, listing the limit attribute and the reason.

5.15.1.14.iii Queued Limit Error Messages

When a limit for queued jobs or resources allocated to queued jobs is reached, the command involved presents a message. This command can be `qsub`, `qmove` or `qalter`.

5.15.1.14.iv Run Limit Error Messages

See "Run Limit Error Messages" on page 389 of the PBS Professional Reference Guide for a list of run limit error messages.

5.15.1.15 Old Limit Attributes: Server and Queue Resource Usage Limit Attributes Existing Before Version 10.1

The old server and queue limit attributes discussed here existed in PBS Professional before Version 10.1. The old limit attributes continue to function as they did in PBS Professional 10.0. These attributes are incompatible with the limit attributes introduced in Version 10.1. See section 5.15.1.13.v, "Do Not Mix Old And New Limits", on page 304 and section 5.15.1.14.i, "Error When Setting Limit Attributes", on page 304.

The following table shows how the old limit attributes are used:

Table 5-15: Resource Usage Limits Existing Before Version 10.1

Limit	Overall Limit	Generic Users	Generic Groups	Indi-vidual Users	Indi-vidual Group
Maximum number of running jobs	max_running	max_user_run	max_group_run	N/A	N/A
Maximum number of running jobs (soft limit)	N/A	max_user_run_soft	max_group_run_soft	N/A	N/A
Maximum amount of specified resource allocated to running jobs	N/A	max_user_res	max_group_res	N/A	N/A
Maximum amount of specified resource allocated to running jobs (soft limit)	N/A	max_user_res_soft	max_group_res_soft	N/A	N/A
Maximum number of queued jobs	max_queuable	N/A	N/A	N/A	N/A
Maximum amount of specified resource allocated to queued jobs	N/A	N/A	N/A	N/A	N/A

5.15.1.15.i Precedence of Old Limits

If an old limit is defined at both the server and queue, the more restrictive limit applies.

5.15.1.15.ii Old Server Limits

For details of these limits, see "Server Attributes" on page 283 of the PBS Professional Reference Guide.

max_running

The maximum number of jobs allowed to be selected for execution at any given time.

max_group_res,
max_group_res_soft

The maximum amount of the specified resource that all members of the same Linux group may consume simultaneously.

max_group_run,
max_group_run_soft

The maximum number of jobs owned by a Linux group that are allowed to be running from this server at one time.

max_user_res,
max_user_res_soft

The maximum amount of the specified resource that any single user may consume.

max_user_run,
max_user_run_soft

The maximum number of jobs owned by a single user that are allowed to be running at one time.

5.15.1.15.iii Old Queue Limits

For details of these limits, see "Queue Attributes" on page 313 of the PBS Professional Reference Guide.

max_group_res,
max_group_res_soft

The maximum amount of the specified resource that all members of the same Linux group may consume simultaneously, in the specified queue.

max_group_run,
max_group_run_soft

The maximum number of jobs owned by a Linux group that are allowed to be running from this queue at one time

max_queuable

The maximum number of jobs allowed to reside in the queue at any given time. Once this limit is reached, no new jobs will be accepted into the queue.

max_user_res,
max_user_res_soft

The maximum amount of the specified resource that any single user may consume in submitting to this queue.

max_user_run,
max_user_run_soft

The maximum number of jobs owned by a single user that are allowed to be running at one time from this queue.

5.15.2 Placing Resource Limits on Jobs

Jobs are assigned limits on the amount of resources they can use. Each limit is set at the amount requested or allocated by default. These limits apply to how much the job can use on each vnode (per-chunk limit) and to how much the whole job can use (job-wide limit). Limits are derived from both requested resources and applied default resources. For information on default resources, see section 5.9.3, "Specifying Job Default Resources", on page 247.

Each chunk's per-chunk limits determine how much of any resource can be used in that chunk. Per-chunk resource usage limits are the amount of per-chunk resources requested, both from explicit requests and from defaults.

The consumable resources requested for chunks in the select specification are summed, and this sum makes a job-wide limit. Job resource limits from sums of all chunks override those from job-wide defaults and resource requests.

Job resource limits set a limit for per-job resource usage. Various limit checks are applied to jobs. If a job's job resource limit exceeds queue or server restrictions, it will not be put in the queue or accepted by the server. If, while running, a job exceeds its limit for a consumable or time-based resource, it will be terminated.

5.15.2.1 How Limits Are Derived

Job resource limits are derived in this order from the following:

1. Explicitly requested job-wide resources (e.g. `-l resource=value`)
2. The following built-in chunk-level resources in the job's select specification (e.g. `-l select =`...)

   accelerator_memory

   mem

   mpiprocs

   naccelerators

   ncpus

   nodect

   vmem
3. The server's default_qsub_arguments attribute
4. The queue's resources_default.<resource name>
5. The server's resources_default.<resource name>
6. The queue's resources_max.<resource name>
7. The server's resources_max.<resource name>

The server's default_chunk.<resource name> does **not** affect job-wide limits.

You can use a hook to set a per-chunk limit, using any hook that operates on jobs, such as a job submission hook, a modify job hook, etc.

5.15.2.2 Configuring Per-job Limits at Server and Queue

You can set per-job limits on the amount of each resource that any one job can use. You can set these limits at the server and at each queue. For example, you can specify the following limits:

- Jobs at the server can use no more than 48 hours of CPU time
- Jobs at QueueA can use no more than 12 hours of CPU time
- Jobs at QueueA must request more than 2 hours of CPU time

To set these limits, specify values for the server's resources_max.<resource name> attribute and each queue's resources_max.<resource name> and resources_min.<resource name> attributes. The server does not have a resources_min.<resource name> attribute. To set the maximum at the server, the format is:

Qmgr: set server resources_max.<resource name> = value

To set the maximum and minimum at the queue, the format is:

Qmgr: set queue <queue name> resources_max.<resource name> = value

Qmgr: set queue <queue name> resources_min.<resource name> = value

For example, to set the 48 hour CPU time limit:

```
    Qmgr: set server resources_max.cput = 48:00:00
```

5.15.2.2.i Running Time Limits at Server and Queues

For non-shrink-to-fit jobs, you can set limits on walltime at the server or queue. To set a walltime limit for non-shrink-to-fit jobs at the server or a queue, use resources_max.walltime and resources min.walltime.

For shrink-to-fit jobs, running time limits are applied to max_walltime and min_walltime, not walltime. To set a running time limit for shrink-to-fit jobs, you cannot use resources_max or resources_min for max_walltime or min_walltime. Instead, use resources_max.walltime and resources_min.walltime. See section 4.9.42.6, “Shrink-to-fit Jobs and Resource Limits”, on page 215.

5.15.2.3 Configuring Per-job Resource Limit Enforcement at Vnodes

For a job, enforcement of resource limits is per-MoM, not per-vnode. So if a job requests 3 chunks, each of which has 1MB of memory, and all chunks are placed on one host, the limit for that job for memory for that MoM is 3MB. Therefore one chunk can be using 2 MB and the other two using 0.5MB and the job can continue to run.

Job resource limits can be enforced for single-vnode jobs, or for multi-vnode jobs that are using a PBS-aware MPI. See the following table for an overview. Memory limits are handled differently depending on the operating system. See "Job Memory Limit Enforcement on Linux” on page 309. The ncpus limit can be adjusted in several ways. See "Job ncpus Limit Enforcement” on page 310 for a discussion. The following table summarizes how resource limits are enforced at vnodes:

Table 5-16: Resource Limit Enforcement at Vnodes

Limit	What Determines When Limit Is Enforced	Scope of Limit	Enforcement Method
file size	automatically	per-process	`setrlimit()`
vmem	If job requests or inherits vmem	job-wide	MoM poll
pvmem	If job requests or inherits pvmem	per-process	`setrlimit()`
pmem	If job requests or inherits pmem	per-process	`setrlimit()`
pcput	If job requests or inherits pcput	per-process	`setrlimit()`
cput	If job requests or inherits cput	job-wide	MoM poll
walltime	If job requests or inherits walltime	job-wide	MoM poll
mem	if $enforce mem in MoM's config	job-wide	MoM poll
ncpus	if $enforce cpuaverage, $enforce cpuburst, or both, in MoM's config. See "Job ncpus Limit Enforcement” on page 310.	job-wide	MoM poll

5.15.2.4 Job Memory Limit Enforcement

You may wish to prevent jobs from swapping memory. To prevent this, you can set limits on the amount of memory a job can use. Then the job must request an amount of memory equal to or smaller than the amount of physical memory available.

PBS measures and enforces memory limits in two ways:

- On each host, by setting OS-level limits, using the limit system calls
- By periodically summing the usage recorded in the `/proc` entries.

Enforcement of mem is dependent on the following:

- Adding $enforce mem to the MoM's `config` file
- The job requesting or inheriting a default value for mem

You can configure default `qsub` parameters in the default_qsub_arguments server attribute, or set memory defaults at the server or queue. See section 5.9.3, “Specifying Job Default Resources”, on page 247.

5.15.2.4.i Job Memory Limit Enforcement on Linux

By default, memory limits are not enforced. To enforce mem resource usage, put `$enforce mem` into MoM's `config` file, and set defaults for mem so that each job inherits a value if it does not request it.

The mem resource can be enforced at both the job level and the vnode level. The job-wide limit is the smaller of a job-wide resource request and the sum of that for all chunks. The vnode-level limit is the sum for all chunks on that host.

Job-wide limits are enforced by MoM polling the working set size of all processes in the job's session. Jobs that exceed their specified amount of physical memory are killed. A job may exceed its limit for the period between two polling cycles. See section 3.1.2, “Configuring MoM Polling Cycle”, on page 36.

Per-process limits are enforced by the operating system kernel. PBS calls the kernel call `setrlimit()` to set the limit for the top process (the shell), and any process started by the shell inherits those limits. PBS does not know whether the kernel kills a process for exceeding the limit.

If a user submits a job with a job limit, but not per-process limits (`qsub -l cput=10:00`) then PBS sets the per-process limit to the same value. If a user submits a job with both job and per-process limits, then the per-process limit is set to the lesser of the two values.

Example: a job is submitted with `qsub -lcput=10:00`

- There are two CPU-intensive processes which use 5:01 each. The job will be killed by PBS for exceeding the cput limit. 5:01 + 5:01 is greater than 10:00.
- There is one CPU-intensive process which uses 10:01. It is very likely that the kernel will detect it first.
- There is one process that uses 0:02 and another that uses 10:00. PBS may or may not catch it before the kernel does depending on exactly when the polling takes place.

If a job is submitted with a pmem limit, or without pmem but with a mem limit, PBS uses the `setrlimit(2)` call to set the limit. For most operating systems, `setrlimit()` is called with `RLIMIT_RSS` which limits the Resident Set (working set size). This is not a hard limit, but advice to the kernel. This process becomes a prime candidate to have memory pages reclaimed.

If vmem is specified and no single process exceeds that limit, but the total usage by all the processes in the job does, then PBS enforces the vmem limit, but not the pvmem limit, and logs a message. PBS uses MoM polling to enforce vmem.

The limit for pmem is enforced if the job specifies, or inherits a default value for, pmem. When pmem is enforced, the limit is set to the smaller of mem and pmem. Enforcement is done by the kernel, and applies to any single process in the job.

The limit for pvmem is enforced if the job specifies, or inherits a default value for, pvmem. When pvmem is enforced, the limit is set to the smaller of vmem and pvmem. Enforcement is done by the kernel, and applies to any single process in the job.

The following table shows which OS resource limits can be used by each operating system.

Table 5-17: RLIMIT Usage in PBS Professional

OS	file	mem/pmem	vmem/pvmem	cput/pcput
Linux	RLIMIT_FSIZE	RLIMIT_RSS	RLIMIT_AS	RLIMIT_CPU

Note that `RLIMIT_RSS`, `RLIMIT_UMEM`, and `RLIMIT_VMEM` are not standardized (i.e. do not appear in the Open Group Base Specifications Issue 6).

5.15.2.4.ii Memory Enforcement on cpusets

There should be no need to do so: either the vnode containing the memory in question has been allocated exclusively (in which case no other job will also be allocated this vnode, hence this memory) or the vnode is shareable (in which case using *mem_exclusive* would prevent two CPU sets from sharing the memory). Essentially, PBS enforces the equivalent of *mem_exclusive* by itself.

5.15.2.5 Job ncpus Limit Enforcement

Enforcement of the ncpus limit (number of CPUs used) is available on all platforms. The ncpus limit can be enforced using average CPU usage, burst CPU usage, or both. By default, enforcement of the ncpus limit is off. See "$enforce <limit>" on page 243 of the PBS Professional Reference Guide.

5.15.2.5.i Average CPU Usage Enforcement

Each MoM enforces cpuaverage independently, per MoM, not per vnode. To enforce average CPU usage, put `$enforce cpuaverage` in MoM's `config` file. You can set the values of three variables to control how the average is enforced. These are shown in the following table.

Table 5-18: Variables Used in Average CPU Usage

Variable	Type	Description	Default
cpuaverage	Boolean	If present (=*True*), MoM enforces ncpus when the average CPU usage over the job's lifetime usage is greater than the specified limit.	*False*
average_trialperiod	integer	Modifies cpuaverage. Minimum job walltime before enforcement begins. Seconds.	*120*
average_percent_over	integer	Modifies cpuaverage. Percentage by which the job may exceed ncpus limit.	*50*
average_cpufactor	float	Modifies cpuaverage. ncpus limit is multiplied by this factor to produce actual limit.	*1.025*

Enforcement of cpuaverage is based on the polled sum of CPU time for all processes in the job. The limit is checked each poll period. Enforcement begins after the job has had average_trialperiod seconds of walltime. Then, the job is killed if the following is true:

(cput / walltime) > (ncpus * average_cpufactor + average_percent_over / 100)

5.15.2.5.ii CPU Burst Usage Enforcement

To enforce burst CPU usage, put `$enforce cpuburst` in MoM's `config` file. You can set the values of four variables to control how the burst usage is enforced. These are shown in the following table.

Table 5-19: Variables Used in CPU Burst

Variable	Type	Description	Default
cpuburst	Boolean	If present (=*True*), MoM enforces ncpus when CPU burst usage exceeds specified limit.	*False*
delta_percent_over	integer	Modifies cpuburst. Percentage over limit to be allowed.	*50*
delta_cpufactor	float	Modifies cpuburst. ncpus limit is multiplied by this factor to produce actual limit.	*1.5*
delta_weightup	float	Modifies cpuburst. Weighting factor for smoothing burst usage when average is increasing.	*0.4*
delta_weightdown	float	Modifies cpuburst. Weighting factor for smoothing burst usage when average is decreasing.	*0.1*

MoM calculates an integer value called cpupercent each polling cycle. This is a moving weighted average of CPU usage for the cycle, given as the average percentage usage of one CPU. For example, a value of 50 means that during a certain period, the job used 50 percent of one CPU. A value of 300 means that during the period, the job used an average of three CPUs.

new_percent = *change_in_cpu_time**100 / *change_in_walltime*

weight = delta_weight[up|down] * walltime/*max_poll_period*

new_cpupercent = (*new_percent* * *weight*) + (*old_cpupercent* * (1-*weight*))

delta_weight_up is used if *new_percent* is higher than the old cpupercent value. delta_weight_down is used if *new_percent* is lower than the old cpupercent value. delta_weight_[up|down] controls the speed with which cpupercent changes. If delta_weight_[up|down] is 0.0, the value for cpupercent does not change over time. If it is 1.0, cpupercent will take the value of *new_percent* for the poll period. In this case cpupercent changes quickly.

However, cpupercent is controlled so that it stays at the greater of the average over the entire run or ncpus*100.

max_poll_period is the maximum time between samples, set in MoM's `config` file by $max_check_poll, with a default of 120 seconds.

The job is killed if the following is true:

new_cpupercent > ((ncpus * 100 * delta_cpufactor) + delta_percent_over)

The following entries in MoM's `config` file turn on enforcement of both average and burst with the default values:

```
$enforce cpuaverage
$enforce cpuburst
$enforce delta_percent_over 50
$enforce delta_cpufactor 1.05
$enforce delta_weightup 0.4
$enforce delta_weightdown 0.1
$enforce average_percent_over 50
$enforce average_cpufactor 1.025
$enforce average_trialperiod 120
```

The cpuburst and cpuaverage information show up in MoM's log file, whether or not they have been configured in `mom_priv/config`. This is so a site can test different parameters for cpuburst/cpuaverage before enabling enforcement. You can see the effect of any change to the parameters on your job mix before "going live".

Note that if the job creates a child process whose usage is not tracked by MoM during its lifetime, CPU usage can appear to jump dramatically when the child process exits. This is because the CPU time for the child process is assigned to its parent when the child process exits. MoM may see a big jump in cpupercent, and kill the job.

5.15.2.5.iii Job Memory Limit Restrictions

Enforcement of mem resource usage is available on all Linux platforms, but not Windows.

5.15.2.6 Changing Job Limits

The `qalter` command is used to change job limits, with these restrictions:

- A non-privileged user may only lower the limits for job resources
- A Manager or Operator may lower or raise requested resource limits, except for per-process limits such as pcput and pmem, because these are set when the process starts, and enforced by the kernel.
- When you lengthen the walltime of a running job, make sure that the new walltime will not interfere with any existing reservations etc.

See “qalter” on page 128 of the PBS Professional Reference Guide.

5.15.3 Limiting the Number of Jobs in Queues

If you limit the number of jobs in execution queues, you can speed up the scheduling cycle. You can set an individual limit on the number of jobs in each queue, or a limit at the server, and you can apply these limits to generic and individual users, groups, and projects, and to overall usage. You specify this limit by setting the queued_jobs_threshold queue or server attribute. See section 5.15.1.9, “How to Set Limits at Server and Queues”, on page 299.

If you set a limit on the number of jobs that can be queued in execution queues, we recommend that you have users submit jobs to a routing queue only, and route jobs to the execution queue as space becomes available. See section 4.9.39, “Routing Jobs”, on page 207.

5.16 Where Resource Information Is Kept

Definitions and values for PBS resources are kept in the following files, attributes, and parameters. Attributes specifying resource limits are not listed here. They are listed in section 5.15.1.8, “Resource Usage Limit Attributes for Server and Queues”, on page 297 and section 5.15.1.15, “Old Limit Attributes: Server and Queue Resource Usage Limit Attributes Existing Before Version 10.1”, on page 305.

5.16.1 Files

`<sched_priv directory>/sched_config`

`resources:` line

In order for scheduler to be able to schedule using a resource, the resource must be listed in the `resources:` line. Format:

resources: "<resource name>, [<resource name>, ...]"

Example:

```
resources: "ncpus, mem, arch, [...], LocalScratch, FloatLicense, SharedScratch"
```

The only exception is host-level Boolean resources, which do not need to appear in the `resources:` line.

`server_dyn_res:` line

Each dynamic server resource must be listed in its own `server_dyn_res:` line. Format:

server_dyn_res: "<resource name> !<path to script/command>"

Example:

```
server_dyn_res: "SharedScratch !/usr/local/bin/serverdynscratch.pl"
```

`mom_resources:` line (**deprecated** as of 18.2.1)

Dynamic host resources must be listed in the `mom_resources:` line. Format:

mom_resources: "<resource name>"

Example:

```
mom_resources: "LocalScratch"
```

`PBS_HOME/mom_priv/config`

Contains MoM configuration parameters and any local resources. Format:

<resource name> !<path to script/command>

Example:

```
LocalScratch !/usr/local/bin/localscratch.pl
```

See “MoM Parameters” on page 241 of the PBS Professional Reference Guide.

`Version 2 Configuration Files`

Contain vnode information. See section 3.4.3, “Version 2 Vnode Configuration Files”, on page 44.

5.16.2 MoM Configuration Parameters

$cputmult <factor>

This sets a factor used to adjust CPU time used by each job. This allows adjustment of time charged and limits enforced where jobs run on a system with different CPU performance. If MoM's system is faster than the reference system, set factor to a decimal value greater than 1.0. For example:

```
$cputmult 1.5
```

If MoM's system is slower, set factor to a value between *1.0* and *0.0*. For example:

```
$cputmult 0.75
```

$wallmult <factor>

Each job's walltime usage is multiplied by this factor. For example:

```
$wallmult 1.5
```

5.16.3 Attributes

Resources are tracked in the following attributes:

Table 5-20: Attributes Where Resources Are Tracked

Resource Being Tracked	Attribute Name			
	Server and Queue	Vnode	Job	Reservation
Amount of each resource available for use at the object (server, queue, vnode)	resources_available.<resource name>	resources_available.<resource name>		
Amount of each resource allocated to jobs running and exiting at the object (server, queue, vnode)	resources_assigned.<resource name>	resources_assigned.<resource name>		
Amount of each resource used by the job			resources_used.<resource name>	
Amount of each job-wide resource that is assigned to any job that does not explicitly request the resource	resources_default.<resource name>			
Amount of each host-level resource that is assigned to each chunk of any job where that does not explicitly request the resource	default_chunk.<resource name>			
List of resources requested by the object (job or reservation)			Resource_List.<resource name>	Resource_List.<resource name>
List of chunks for the job. Each chunk shows the name of the vnode from which it is taken along with the host-level, consumable resources allocated from that vnode.			exec_vnode	
List of vnodes and resources allocated to them to satisfy the chunks requested for this reservation or occurrence				resv_nodes

5.17 Viewing Resource Information

You can see attribute values of resources for the server, queues, and vnodes using the `qmgr` or `pbsnodes` commands. The value in the server, queue, or vnode resources_assigned attribute is the amount explicitly requested by running and exiting jobs and, at the server and vnodes, started reservations.

You can see job attribute values using the `qstat` command. The value in the job's Resource_List attribute is the amount explicitly requested by the job. See "Resources Requested by Job" on page 247 in the PBS Professional Administrator's Guide.

The following table summarizes how to find resource information:

Table 5-21: How to View Resource Information

Location	Item to View	Command
server	default_chunk, default_qsub_arguments, resources_available, resources_assigned, resources_default	`qmgr`, `qstat`, `pbsnodes`
scheduler	`sched_config file`	Favorite editor or viewer
queues	default_chunk, resources_available, resources_assigned, resources_default	`qmgr`, `qstat`
MoM and vnodes	resources_available, sharing, pcpus, resources_assigned	`qmgr`, `pbsnodes`
	`mom_config file`	Favorite editor or viewer
job	Resource_List	`qstat`
reservation	Resource_List	pbs_rstat -f
accounting	`resources_assigned` entry in accounting log	Favorite editor or viewer

Every consumable resource, for example mem, can appear in four PBS attributes. These attributes are used in the following elements of PBS:

Table 5-22: Values Associated with Consumable Resources

Attribute	Vnode	Queue	Server	Accounting Log	Job	Scheduler
resources_available	Yes	Yes	Yes			Yes
resources_assigned	Yes	Yes	Yes	Yes		
resources_used				Yes	Yes	Yes
Resource_List					Yes	Yes

5.17.1 Resource Information in Accounting Logs

For a complete description of the resource information in the PBS accounting logs, see Chapter 19, "Accounting", on page 635.

5.17.2 Resource Information in Daemon Logs

At the end of each job, the server logs the values in the job's resources_used attribute, at event class 0x0010.

Upon startup, MoM logs the number of CPUs reported by the OS, at event class 0x0002.

At the end of each job, the MoM logs cput and mem used by each job, and cput used by each job task, at event class 0x0100.

5.17.3 Finding Current Value

You can find the current value of a resource by subtracting the amount being used from the amount that is defined.

Use the `qstat -Bf` command, and grep for resources_available.<resource name> and resources_used.<resource name>. To find the current amount not being used, subtract resources_used.<resource name> from resources_available.<resource name>.

5.17.4 Restrictions on Viewing Resources

- Dynamic resources shown in `qstat` do not display the current value, they display the most recent retrieval. Dynamic resources have no resources_available.<resource name> representation anywhere in PBS.
- Local static host-level resources cannot be viewed via `qstat` or managed via `qmgr`.

5.18 Resource Recommendations and Caveats

- It is not recommended to set the value for resources_available.ncpus. The exception is when you want to oversubscribe CPUs. See section 9.6.5.1.iii, "How To Share CPUs", on page 448.
- It is not recommended to change the value of ncpus at vnodes on a multi-vnoded machine.
- If you want to limit how many jobs are run, or how much of each resource is used, use the new limits. See section 5.15, "Managing Resource Usage", on page 290.
- It is not recommended to create local host-level resources by defining them in the MoM configuration file.
- Do not attempt to set values for resources_available.<resource name> for dynamic resources.
- Externally-managed application licenses may not be available when PBS thinks they are. PBS doesn't actually check out externally-managed licenses; the application being run inside the job's session does that. Between the time that the scheduler queries for licenses, and the time the application checks them out, another application may take the licenses. In addition, some applications request varying amounts of tokens during a job run.
- Jobs may be placed on different vnodes from those where they would have run in earlier versions of PBS. This is because a job's resource request will no longer match the same resources on the server, queues and vnodes.
- While users cannot request custom resources that are created with the `r` flag, jobs can inherit these as defaults from the server or queue resources_default.<resource name> attribute.
- A `qsub` or `pbs_rsub` hook does not have resources inherited from the server or queue resources_default or default_chunk as an input argument.
- Resources assigned from the default_qsub_arguments server attribute are treated as if the user requested them. A job will be rejected if it requests a resource that has a resource permission flag, whether that resource was requested by the user or came from default_qsub_arguments. Be aware that creating custom resources with permission flags and then using these in the default_qsub_arguments server attribute can cause jobs to be rejected. See section 5.14.2.3.vi, "Resource Permission Flags", on page 262.
- Numeric dynamic resources cannot have the q or n flags set. This would cause these resources to be underused. These resources are tracked automatically by scheduler.
- The behavior of several command-line interfaces is dependent on resource permission flags. These interfaces are those which view or request resources or modify resource requests:

  `pbsnodes`

  Users cannot view restricted host-level custom resources.

  `pbs_rstat`

  Users cannot view restricted reservation resources.

`pbs_rsub`

Users cannot request restricted custom resources for reservations.

`qalter`

Users cannot alter a restricted resource.

`qmgr`

Users cannot print or list a restricted resource.

`qselect`

Users cannot specify restricted resources via -l Resource_List.

`qsub`

Users cannot request a restricted resource.

`qstat`

Users cannot view a restricted resource.

- Do not set values for any resources, except those such as shared scratch space or floating application licenses, at the server or a queue, because the scheduler will not allocate more than the specified value. For example, if you set resources_available.walltime at the server to *10:00:00*, and one job requests 5 hours and one job requests 6 hours, only one job will be allowed to run at a time, regardless of other idle resources.
- If a job is submitted without a request for a particular resource, and no defaults for that resource are set at the server or queue, and either the server or queue has resources_max.<resource name> set, the job inherits that maximum value. If the queue has resources_max.<resource name> set, the job inherits the queue value, and if not, the job inherits the server value.
- When setting global static vnode resources on multi-vnode machines, follow the rules in section 3.4.5, "Configuring Vnode Resources", on page 49.
- Do not create custom resources with the same names or prefixes that PBS uses when you create custom resources for specific systems.
- Do not set resources_available.place for a vnode.
- Using dynamic host-level resources can slow the scheduler down, because the scheduler must wait for each resource-query script to run.
- On the parent vnode, all values for resources_available.<resource name> should be *zero* (*0*), unless the resource is being shared among child vnodes via indirection.
- Default `qsub` arguments and server and queue defaults are applied to jobs at a coarse level. Each job is examined to see whether it requests a select and a place. This means that if you specify a default placement, such as *excl*, with `-lplace=excl`, and the user specifies an arrangement, such as *pack*, with `-lplace=pack`, the result is that the job ends up with `-lplace=pack`, NOT `-lplace=pack:excl`. The same is true for select; if you specify a default of `-lselect=2:ncpus=1`, and the user specifies `-lselect=mem=2GB`, the job ends up with `-lse-lect=mem=2GB`.

6 Managing Power Usage

6.1 Monitoring and Controlling Job Power Usage

6.1.1 Power Provisioning: Monitoring and Controlling Job Power Usage

PBS Professional can control and monitor job power usage. PBS can assign a power profile for each job at submission time to control the job's power draw, and jobs can request power profiles.

PBS collects energy consumption information and records it in each job's resources_used.energy value. PBS provides information about job energy usage in the output of the `qstat` command, and records energy usage in the accounting logs.

For each job or power profile change, PBS provisions each vnode with the required power profile. The eoe resource represents one or more power profiles on each vnode. Each vnode's current_eoe attribute shows its current power profile.

Jobs can request a power profile, by requesting a value for the eoe resource, or PBS can set each job's eoe request. When a job requests a power profile, it is sent to vnodes that have this profile available, and when the job runs, the vnodes where the job runs are set to the power profile requested by the job.

The default power setting for a node is no power capping. If a job runs on a node, the node uses the requested power profile, but when the job finishes, the node goes back to the default setting.

6.1.1.1 Monitoring Power Use by Jobs

To see the power used by a job, you can use `qstat` to examine the job's resources_used.energy.

6.1.2 Platforms Supporting Power Provisioning

Power provisioning is supported on Cray XC machines and HPE 8600 machines with HPE Performance Cluster Manager (HPCM).

6.1.3 Power Provisioning on Cray XC

On Cray XC systems, you use the PBS_power hook to provision vnodes with the power requested by jobs, and to monitor job power usage. This is the same hook used for powering nodes up and down and limiting ramp rate. See section 6.2.1, “Managing Node Power on Cray XC with PBS”, on page 323 and section 6.2.2, “Limiting Ramp Rate for Node Power on Cray XC”, on page 324.

6.1.3.1 Overview of Power Provisioning on Cray

- You find out what power settings each vnode can support.
- You choose what power settings will make up each vnode power profile.
- You set the values for resources_available.eoe on vnodes.
- You enable the power provisioning hook.
- You enable power provisioning at specific vnodes.
- Each job requests or is assigned a power profile.
- PBS provisions each vnode with the requested power settings.

6.1.3.2 Selecting Power Profiles

You get the supported power capabilities of each compute node by running the `capmc` tool with the argument `"get_power_cap_capabilities"`. Each node reports ranges for its pstate, pgov, pcap_node, and pcap_accelerator power settings.

You choose the power profiles you want, by selecting values for the pstate, pgov, pcap_node, and pcap_accelerator attributes for each power profile. Note that some settings for pcap_node may cause pstate to be ignored.

6.1.3.3 Setting Vnode Power Resources and Attributes

You specify the desired power profiles for each vnode by setting the vnode's resources_available.eoe to the list of profiles available at that vnode. For example:

```
Qmgr: set node compute_node1 resources_available.eoe="low,med"
Qmgr: set node compute_node2 resources_available.eoe="med,high"
```

Once a job is submitted and the hook sets the job's attributes, the process of setting power profile attributes on vnodes is handled automatically by PBS when PBS provisions each vnode with the requested values for the power attributes. PBS tells the Cray what settings to use on each vnode.

6.1.3.4 Setting Job Power Resource Requests

Each job can request or be assigned one of the power profiles you have defined.

You write a queuejob hook that sets each job's power attributes to the correct values for the requested profile. The hook maps each profile to a value for each of the power attributes. For example, if a compute node supports the following settings:

pstate range = 100-300

pgov range = 50-150

pcap_node range = 250-500

pcap_accelerator range = 500-1000

and you want to have profiles named "low", "med", and "high", the following table shows sample power profile settings:

Table 6-1: Sample Power Profile Settings

Power Profile	pstate	pgov	pcap_node	pcap_accelerator
low	100	50	250	500
med	200	100	350	700
high	300	150	500	1000

6.1.3.4.i Writing Power Profile Hook for Cray

Create a queuejob hook that sets each job's attributes to reflect its requested profile. Set each job's desired power profile by setting any of the following job attributes in the hook:

- Set the pcap_node job attribute to the value corresponding to the Cray `capmc set_power_cap --node` setting
- Set the pstate job attribute to the corresponding Cray ALPS p-state setting. Note that pcap_node takes precedence, and some settings for pcap_node can result in pstate being ignored.
- Set the pcap_accelerator job attribute to the value corresponding to the Cray `capmc set_power_cap --accel` setting
- Set the pgov job attribute for CPU throttling to the corresponding setting for p-governor

Example 6-1: We will use three profiles called "low", "med", and "high", and we will set pcap_node and pstate for each job requesting a profile:

```
import pbs

e = pbs.event()
j = e.job

profile = j.Resource_List['eoe']
if profile is None:
    res = j.Resource_List['select']
    if res is not None:
        for s in str(res).split('+')[0].split(':'):
            if s[:4] == 'eoe=':
                profile = s.partition('=')[2]
                break

pbs.logmsg(pbs.LOG_DEBUG, "got profile '%s'" % str(profile))
if profile == "low":
    j.Resource_List["pstate"] = "1900000"
    j.Resource_List["pcap_node"] = 100
    pbs.logmsg(pbs.LOG_DEBUG, "set low")
elif profile == "med":
    j.Resource_List["pstate"] = "220000"
    j.Resource_List["pcap_node"] = 200
    pbs.logmsg(pbs.LOG_DEBUG, "set med")
elif profile == "high":
    j.Resource_List["pstate"] = "240000"
    pbs.logmsg(pbs.LOG_DEBUG, "set high")
else:
    pbs.logmsg(pbs.LOG_DEBUG, "unhandled profile '%s'" % str(profile))

e.accept()
```

6.1.3.5 Enabling Power Provisioning on Cray

Enable power provisioning:

1. On each vnode where you want power provisioning enabled, set the power_provisioning vnode attribute to *True*:
   ```
   Qmgr: set node <node name> power_provisioning=true
   ```
2. Enable the PBS_power hook:
   ```
   Qmgr: set pbshook PBS_power enabled=true
   ```

6.1.3.6 Reporting Energy Usage on Cray

On Cray, PBS collects energy consumption information using `capmc` or `RUR`.

If `RUR` is configured and the energy reported by `RUR` is different from what is reported by `capmc`, PBS reports the larger value for the job.

Using `RUR` is optional. If you want PBS to collect energy information from `RUR`, enable `RUR` using the PBS output plugin. You must modify the `RUR` configuration file to use the PBS output plugin. This plugin is located in `/opt/pbs/lib/cray/pbs_output.py`

See the Cray instructions for this procedure in *XC™ System Administration Guide (S-2393)* at https://pubs.cray.com/bundle/XC_Series_System_Administration_Guide_CLE70UP02_S-2393_XC_Admin_Guide_final/page/cray/About_XC_Series_System_Administration_Guide_S-2393.html.

See especially *6.22 Resource Utilization Reporting.*

6.1.3.7 Caveats for Power Provisioning on Cray

Note that pcap_node takes precedence, and some settings for pcap_node can result in pstate being ignored.

6.1.4 Power Provisioning on HPE

6.1.4.1 Overview of Power Provisioning on HPE

On HPE, PBS uses the power API for HPE Performance Cluster Manager (HPCM). PBS handles querying for available power profiles and setting the eoe resource to the available power profiles. You enable power provisioning at the server and vnodes.

6.1.4.2 Setting Power Profiles on HPE

On each vnode, PBS queries the HPE Performance Cluster Manager (HPCM) for available power profiles, and sets the vnode's resources_available.eoe to the power profiles available on that vnode.

6.1.4.3 Enabling Power Provisioning on HPE

To enable power provisioning:

1. On each vnode where you want power provisioning enabled, set the power_provisioning vnode attribute to *True*:
   ```
   Qmgr: set node <node name> power_provisioning=true
   ```
2. Enable the PBS_power hook:
   ```
   Qmgr: set pbshook PBS_power enabled=true
   ```
3. HUP each MoM. If the vnode does not report resources_available.eoe, HUP the MoM again.

6.1.5 Terminology for Power Provisioning

Activate a power profile

To set a power profile on a node, for example, to set a node's power profile to match the specifications for "low".

Deactivate a power profile

To reset the power profile of the node to its default setting, which is no power capping.

6.1.6 Caveats and Restrictions for Using Power Profiles

- Make sure that your power provisioning queuejob hook takes into account your desired order of precedence for an explicit request for pcap_node and/or pstate versus a request for a profile. You may want users to be able to override power profile settings for pcap_node and/or pstate, or you may want profiles to override explicit requests.
- You cannot use power profiles on any hosts where the PBS server and/or scheduler are running.
- You cannot suspend jobs on vnodes that are using power profiles, meaning that you cannot use preemption via suspension on vnodes that are using power profiles.
- If you disable the PBS_power hook while a job is running, the vnodes where the job runs do not have their profile deactivated when the job finishes, and the job's resources_used.energy value is not set at the end of the job.
- A prologue script will not run when the PBS_power hook is enabled. Any prologue script must be converted to an execjob_prologue hook.
- If a job does not request a value for eoe, there is no activation of a power profile on a node, but the job's resources_used.energy is still calculated.
- If a job requests values for both aoe and eoe, PBS addresses the aoe request first.
- There is no PBS interface to `RUR` that can be used by administrators or job submitters.
- If `pbs.conf` is not in /etc on a host, add PBS_CONF_FILE to the `PBS_HOME/pbs_environment` file for that host, and set it to the path to `pbs.conf` on the host. For example, if `/var/pbs.conf` is the location of the `pbs.conf` file, add the following line to `PBS_HOME/pbs_environment`:

  ```
  PBS_CONF_FILE=/var/pbs.conf
  ```
- PBS does not automatically set resources_available.eoe on machines that host the PBS server/scheduler.
- PBS can provide precise power consumption accounting only where jobs are allocated exclusively. Vnodes must have the sharing attribute set so that jobs get exclusive use of the vnode, or jobs must request exclusive use of vnodes.

6.2 Managing Node Power on Cray XC

You can manage node power and limit the ramp rate on Cray XC* systems running CLE 6.0 and later. You can use the *PBS_power* hook to manage node power and to limit ramp rate on Cray XC systems. This is the same hook used on Cray XC for provisioning vnodes with the power requested by jobs and monitoring job power usage. See section 6.1.3, "Power Provisioning on Cray XC", on page 319. PBS_power is a built-in periodic server hook. It takes a list of nodes to power up and manages power ramp rate, and communicates with vendor power APIs through a generic PMI interface. This hook powers up or down no more than max_concurrent_nodes nodes at once. When this hook is enabled, PBS sets the power_provisioning server attribute to *True*.

6.2.1 Managing Node Power on Cray XC with PBS

This version of PBS Professional allows you to automatically power down nodes that are not being used, and then power them up again only when they are needed for a job or reservation.

PBS periodically checks to see which nodes should be powered down, and if a node has been idle for the minimum specified amount of time, PBS powers down the node. You can specify the amount of node idle time that triggers powering down a node. PBS also periodically checks to see which nodes should be powered up so that a job or reservation can use them.

You can specify which nodes are eligible for power management by PBS, and the maximum number of nodes to power down or up at one time.

In addition, PBS minimizes the number of power cycles experienced by nodes, because power cycling a node puts a strain on the hardware. To do this, PBS avoids powering up nodes that have just been powered down.

6.2.1.1 Using the PBS_power hook for Managing Node Power on Cray

PBS manages node power through the *PBS_power* hook. The hook takes a list of nodes and communicates with vendor power APIs through a generic PMI interface to manage node power.

You configure node power management via server and vnode attributes. To enable this feature, enable the PBS_power hook.

You specify which nodes are eligible for power management by PBS via the power_provisioning vnode attribute.

You set the minimum amount of idle time for a node to be powered down in the node_idle_limit hook configuration parameter. Set the limit on the number of nodes that can be powered up or down at one time in the max_concurrent_nodes hook configuration parameter. Specify the minimum amount of time a node is powered down in the min_node_down_delay hook configuration parameter.

PBS records the time when a node is powered off in the last_state_change_time vnode attribute, and tracks the node's idle time by updating the last_used_time vnode attribute at the end of any job or reservation involving the node.

When a job or reservation is scheduled on a vnode, PBS sets the the job's estimated.start_time attribute. The hook calculates how much time it needs to power up all the nodes required. Using the Cray rules for powering a node up, PBS gives a node 600 seconds to power up. The PBS_power hook powers up nodes in batches of max_concurrent_nodes, with 600 seconds between each batch.

6.2.2 Limiting Ramp Rate for Node Power on Cray XC

PBS allows you to limit the ramp rate for the Cray system, by communicating with the `capmc` utility. The PBS_power power management hook controls the number of nodes whose C-state can be changed.

When ramping nodes up or down, the hook steps through sleep states.

6.2.2.1 Using the PBS_power for Managing Ramp Rate on Cray

You can manage the ramp rate behavior of the power management hook by setting parameters in the PBS_power hook configuration file. The hook configuration file contains parameters the hook uses as guides for its behavior, and parameters that the hook uses when it communicates with `capmc`. This file must conform to JSON syntax.

We show a sample file in section 6.2.2.2, “Sample Power Management Configuration File”, on page 325.

You can also export and look at the installed PBS power management hook configuration file:

```
qmgr -c "export pbshook PBS_power application/x-config default" > PBS_power.json
```

You can edit this file and change its parameters, then read it back in:

```
qmgr -c "import pbshook PBS_power application/x-config default PBS_power.json"
```

6.2.2.2 Sample Power Management Configuration File

Here is a sample configuration file, showing the ramp rate parameters:

```
{
"power_ramp_rate_enable": "True",
"power_on_off_enable": "False",
"node_idle_limit": "1000",
"min_node_down_delay": "600",
"max_jobs_analyze_limit": "80",
"max_concurrent_nodes": "5"
}
```

6.2.3 Power Management Hook Configuration Parameters

Table 6-2: Hook Configuration Parameters

Configuration File Parameter	Default Value	Description
power_ramp_rate_enable	*False*	Enables ramp rate limiting for the system. Nodes can be ramped up to sleep state C1 and ramped down to sleep state C6.
power_on_off_enable	*False*	Enables powering nodes on and off for nodes where the poweroff_eligible vnode attribute is *True*.
node_idle_limit	*1800*	Length of time in seconds for a node to be left idle before it is considered for powering down or ramping down.
min_node_down_delay	*1800*	Length of time in seconds for a node that is powered off to remain so until it is considered for powering up or ramping up.
max_jobs_analyze_limit	*100*	The maximum number of jobs that are analyzed for power-on or ramp-up. The jobs considered here are those which have a current estimated.start_time and exec_vnode. For these attributes to be current, set the strict_ordering scheduler parameter to *True*, and make sure jobs are submitted with a specification for walltime.
max_concurrent_nodes	*5*	Limit on number of nodes that can be powered on or off or ramped up or down at a time.

6.3 Power Management Attributes, Resources, Etc.

energy

Resource. Consumable. PBS records the job's energy usage in the job's resources_used.energy.

Format: *float*

Units: *kWh*

eoe

Resource. Stands for "Energy Operational Environment". Non-consumable. When set on a vnode in resources_available.eoe, contains the list of available power profiles. When set for a job in Resource_List.eoe, can contain at most one power profile. (A job can request only one power profile.) Automatically added to `resources:` line in `sched_config`.

Default value for resources_available.eoe: *unset*

Format: *string_array*

current_eoe

Vnode attribute. Shows the current value of eoe on the vnode.

Visible to all. Settable by manager. We do not recommend setting this attribute manually.

Format: *string*

Default: *unset*

last_state_change_time

Vnode attribute. Records the most recent time that this node changed state.

Set by PBS. Readable by Manger and Operator.

Format: integer seconds since epoch

Default: no default

last_used_time

Vnode attribute. Records the most recent time that this node finished being used for a job or reservation.

Set at creation or reboot time. Updated when node is released early from a running job. Reset when node is ramped up.

Set by PBS. Readable by Manger and Operator.

Format: integer seconds since epoch

Default: no default

max_concurrent_nodes

Hook configuration parameter. Specifies the maximum number of nodes that can be powered up or down at one time. Enabled when the the PBS_power hook is enabled. Used by the PBS_power hook.

set by Manager and Operator. Readable by all.

Format: positive integer

Default: *5*

min_node_down_delay

Hook configuration parameter. Specifies the minimum time a node is powered down before it can be powered back up. Enabled when the the PBS_power hook is enabled.

set by Manager and Operator. Readable by all.

Format: integer seconds

Default: *1800 seconds*

node_idle_limit

Hook configuration parameter. Specifies the minimum idle time for a node to be considered for powering down. Enabled when the the PBS_power hook is enabled.

set by Manager and Operator. Readable by all.

Format: integer seconds

Default: *1800 seconds*

pstate

Job attribute. Cray ALPS reservation setting for CPU frequency corresponding to p-state. See BASIL 1.4 documentation.

Settable by and visible to all PBS users.

Units: *hertz*

Format: *string*

Default: *unset*

Example: *pstate = 2200000*

pgov

Job attribute. Cray ALPS reservation setting for CPU throttling corresponding to p-governor. See BASIL 1.4 documentation. We do not recommend using this attribute.

Visible to all. Settable by all.

Format: *string*

Default: *unset*

pcap_node

Job attribute. Power cap for a node. Corresponds to Cray `capmc set_power_cap --node` setting. See `capmc` documentation.

Visible to and settable by all.

Units: *watts*

Format: *int*

Default: *unset*

pcap_accelerator

Job attribute. Power cap for an accelerator. Corresponds to Cray `capmc set_power_cap --accel` setting. See `capmc` documentation.

Visible to and settable by all.

Units: *watts*

Format: *int*

Default: *unset*

poweroff_eligible

Vnode attribute. Specifies whether this node is eligible to have its power managed by PBS.

set by Manager. Readable by all.

Format: Boolean

Default: False (not eligible)

power_provisioning

Server attribute. Reflects use of power profiles and managing node power via PBS. Set by PBS to *True* when the PBS_power hook is enabled.

Set by PBS. Read-only.

Format: Boolean

Default: *unset*, which behaves like *False* (not enabled)

power_provisioning

Vnode attribute. Specifies whether this node is eligible to have its power managed by PBS, including whether it can use power profiles.

set by Manager. Readable by all.

Format: Boolean

Default: *False* (not eligible)

sleep

Vnode state. Indicates that this vnode was ramped down or powered off via PBS power management. This tells the scheduler that it can schedule jobs on this vnode; in that case PBS powers the vnode back up.

6.4 Caveats and Restrictions for Power Management

- If a reservation is created with a start time coming up soon, where the reservation requires nodes that are currently powered off, the reservation may start in degraded mode until all of the nodes can be powered up.
- Do not set resources_available.eoe on vnodes. This is handled by PBS.

7 Provisioning

PBS provides automatic provisioning of an OS or application on vnodes that are configured to be provisioned. When a job requires an OS that is available but not running, or an application that is not installed, PBS provisions the vnode with that OS or application.

7.1 Introduction

You can configure vnodes so that PBS will automatically install the OS or application that jobs need in order to run on those vnodes. For example, you can configure a vnode that is usually running RHEL to run SLES instead whenever the Physics group runs a job requiring SLES. If a job requires an application that is not usually installed, PBS can install the application in order for the job to run.

You can use provisioning for booting multi-boot systems into the desired OS, downloading an OS to and rebooting a diskless system, downloading an OS to and rebooting from disk, instantiating a virtual machine, etc. You can also use provisioning to run a configuration script or install an application.

7.2 Definitions

AOE

The environment on a vnode. This may be one that results from provisioning that vnode, or one that is already in place

Master Provisioning Script, Master Script

The script that makes up the provisioning hook

Provision

To install an OS or application, or to run a script which performs installation and/or setup

Provisioning Hook

The hook which performs the provisioning, either by calling other scripts or running commands

Provisioning Tool

A tool that performs the actual provisioning, e.g. HPE Performance Cluster Manager (HPCM)

Provisioned Vnode

A vnode which, through the process of provisioning, has an OS or application that was installed, or which has had a script run on it

7.3 How Provisioning Can Be Used

- Each application requires specific version of OS

The site runs multiple applications, and each application may be certified to run on a specific OS. In this situation, a job that will run an application requiring a specific OS requests the OS, and PBS provisions the required OS.

- The site needs differently configured images of the same OS to be loaded at different times

  The site has multiple projects, and each project requires the OS to be configured in a different way on a group of hosts. In this situation, PBS provisions groups of hosts with the correct OS image, for the time period needed by each project. The OS image is configured and supplied by the site administrator.

- The entire site needs different OSes at different times of day

  The entire site runs one OS during certain hours, and a different OS at other times.

- A user reserves multiple vnodes running the same version of an OS

  A user may need a specific version of an OS for a period of time. For example, a user needs 5 nodes running a specific version of RHEL from 5pm Friday until 5am Monday.

- The administrator wants to limit the number of hosts that are being provisioned at any one time, for any of the following reasons:
  - The network can become overwhelmed transferring OS images to execution nodes
  - The hosts can draw excessive power if many are powering up at the same time
  - Some sites notify the administrator whenever an execution node goes down, and when several vnodes are provisioned, the administrator is paged repeatedly

7.4 How Provisioning Works

7.4.1 Overview of Provisioning

PBS allows you to create a provisioning hook, which is a hook that is triggered by a provisioning event. When this hook is triggered, it manages the required provisioning on the vnodes to be provisioned. The hook calls a provisioning mechanism such as HPE Performance Cluster Manager to accomplish the provisioning.

Provisioning can be the following:

- Directly installing an OS or application
- Running a script which may perform setup or installation

PBS allows you to configure each vnode with a list of available AOEs. This list is specified in the vnode's resources_available.aoe resource. Each vnode's current_aoe attribute shows that vnode's current AOE. The scheduler queries each vnode's aoe resource and current_aoe attribute in order to determine which vnodes to provision for each job.

When users submit jobs, they can request a specific AOE for each job. When the scheduler runs each job, it either finds the vnodes that satisfy the job's requirements, or provisions the required vnodes.

Users can create reservations that request AOEs. Each reservation can have at most one AOE specified for it. Any jobs that run in that reservation must not request a different AOE.

7.4.1.1 Rebooting When Provisioning

When provisioning a vnode with some AOEs, the vnode must be rebooted as part of the provisioning process. Some OS installations, for example, require rebooting. In this case, the provisioning script must cause the vnode to be rebooted.

When the installation does not require a reboot, the provisioning script does not need to cause the vnode to be rebooted. For example, provisioning with some applications does not require a reboot.

7.4.2 How Vnodes Are Selected for Provisioning

Each job can request at most one AOE. When scheduling the job, PBS looks for vnodes with the requested AOE, as with any other resource. If there are not enough vnodes with the requested AOE, PBS tries to provision vnodes in order to satisfy the job's requirements.

7.4.2.1 Provisioning Policy

PBS allows a choice of provisioning policies. You set the scheduler's provision_policy configuration parameter to be either "*avoid_provision*" or "*aggressive_provision*". The default provisioning policy is "*aggressive_provision*".

avoid_provision

PBS first tries to satisfy the job's request from free vnodes that already have the requested AOE instantiated. PBS uses node_sort_key to sort these vnodes.

If it cannot satisfy the job's request using vnodes that already have the requested AOE instantiated, it does the following:

- PBS uses node_sort_key to select the free vnodes that must be provisioned in order to run the job, choosing from vnodes that are free, provisionable, and offer the requested AOE, regardless of which AOE is instantiated on them.
- Of the selected vnodes, PBS provisions any that do not have the requested AOE instantiated on them.

aggressive_provision

PBS selects vnodes to be provisioned without considering which AOE is currently instantiated.

PBS uses node_sort_key to select the vnodes on which to run the job, choosing from vnodes that are free, provisionable, and offer the requested AOE, regardless of which AOE is instantiated on them. Of the selected vnodes, PBS provisions any that do not have the requested AOE instantiated on them.

7.4.2.2 Examples of Vnode Selection

The following examples show how provisioning policy can affect which vnodes are selected for provisioning.

Example 7-1: 3 vnodes

In `sched_config`:

```
node_sort_key: "ncpus HIGH"
```

We have 3 nodes as described in the following table:

Table 7-1: Example Configuration

Vnode/Host	Number of CPUs	Current AOE	State
host1	1	aoe1	*free*
host2	2	unset	*free*
host3	3	aoe2	*free*

No jobs are running on any of the vnodes.

Case 1: aggressive provisioning

```
provision_policy: "aggressive_provision"
```

Job submitted with -lselect=ncpus=1:aoe=aoe1

In this case, host3 is used to run the job and host3 is provisioned.

Case 2: avoiding provisioning

`provision_policy: "avoid_provision"`

Job submitted with -lselect=ncpus=1:aoe=aoe1

In this case, host1 is used to run the job and host1 is not provisioned.

Example 7-2: 5 vnodes

The following table shows the example configuration:

Table 7-2: Example Configuration

Vnode/Host	AOE Available	Current AOE	State
N1	aoe1, aoe2	aoe1	*busy*
N2	aoe1, aoe2	aoe2	*free*
N3	aoe1, aoe2	NULL	*free*
N4	aoe1, aoe2	aoe1	*free*
N5	aoe1, aoe2	aoe1	*free*

The vnodes are sorted in the order N1, N2, N3, N4, N5.

A job is submitted with:

```
qsub -lselect=3:ncpus=1:aoe=aoe1 -lplace=scatter
```

The job needs three vnodes with aoe1. Assume that all other requests except that for the AOE can be satisfied by any vnode.

Case 1: aggressive provisioning

The scheduler selects N2, N3 and N4. It has not considered the AOE instantiated on these vnodes. It then provisions N2 and N3 since N2 has a different AOE instantiated on it and N3 is not provisioned yet. N4 is not provisioned, because it has the requested AOE already instantiated.

Case 2: avoiding provisioning

First, the scheduler selects N4 and N5. It does not choose N2 since it has a different AOE instantiated, and it does not choose N3 since it does not have any AOE instantiated. But N4 and N5 together do not satisfy the job's requirement of 3 vnodes.

Second, the scheduler seeks vnodes that if provisioned can satisfy the job's request. N2 and N3 can each satisfy the job's request, so it chooses N2, because it comes first in sorted order.

The job runs on N4, N5 and N2. N2 is provisioned.

7.4.2.3 Rules for Vnode Selection for Provisioning

A vnode is not selected for provisioning for the following reasons:

- It does not have the requested AOE available in its list
- It does not have provisioning enabled on it
- It has other running or suspended jobs
- It already has the requested AOE

7.4.2.4 Triggering Provisioning

When a job requires a vnode, and the vnode's current_aoe attribute is unset, or is set to a different AOE from the one requested, the vnode is provisioned.

7.4.3 Provisioning And Reservations

7.4.3.1 Creating Reservations that Request AOEs

A reservation can request at most one AOE.

When a user creates a reservation that requests an AOE, the scheduler searches for vnodes that can satisfy the reservation. When searching, the scheduler follows the rule specified in the provision_policy scheduling parameter in `<sched_priv directory>/sched_config`. See the `pbs_sched(8B)` manual page.

The vnodes allocated to a reservation that requests an AOE are put in the resv-exclusive state when the reservation runs. These vnodes are not shared with other reservations or with jobs outside the reservation.

7.4.3.2 Submitting Jobs to a Reservation

If a job that requests an AOE is submitted to a reservation, the reservation must request the same AOE.

7.4.3.3 Running a Job in a Reservation Having a Requested AOE

A job can run in a reservation that has requested an AOE, as long as the job fits the following criteria:

- It requests the same AOE as the reservation

If the job has requested no AOE, or an AOE different from that of the reservation, the job is rejected.

7.4.4 How Provisioning Affects Jobs

7.4.4.1 Preemption and Provisioning

A job that has requested an AOE will not preempt another job, regardless of whether the job's requested AOE matches an instantiated AOE. Running jobs are not preempted by jobs requesting AOEs.

7.4.4.2 Backfilling and Provisioning

If the job being backfilled around or the job doing the backfilling share a vnode, a job that has requested an AOE will not play any part in backfilling:

- It will not be backfilled around by smaller jobs.
- It will not be used as the job that backfills around another job.

7.4.4.3 Walltime and Provisioning

A job's walltime clock is started after provisioning is over.

7.4.4.4 Using `qrun`

When a job requesting an AOE is run via `qrun -H`, the following happens:

- If the requested AOE is available on the specified vnodes, those vnodes are provisioned with the requested AOE
- If the requested AOE is not available on the specified vnodes, the job is held

7.4.5 Vnode States and Provisioning

7.4.5.1 States Associated With Provisioning

The following vnode states are associated with provisioning:

provisioning

A vnode is in the provisioning state while it is in the process of being provisioned. No jobs are run on vnodes in the provisioning state.

wait-provision

There is a limit on the maximum number of vnodes that can be in the provisioning state. This limit is specified in the server's max_concurrent_provision attribute. If a vnode is to be provisioned, but cannot because the number of concurrently provisioning vnodes has reached the specified maximum, the vnode goes into the *wait-provisioning* state. No jobs are run on vnodes in the *wait-provisioning* state.

resv-exclusive

The vnodes allocated to a reservation that requests an AOE are put in the resv-exclusive state when the reservation runs. These vnodes are not shared with other reservations or with jobs outside the reservation.

7.4.5.2 Provisioning Process

The following table describes how provisioning and vnode state transitions interact:

Table 7-3: Vnode State Transitions and Provisioning

Event	Starting Vnode State	Ending Vnode State
Vnode is selected for provisioning	*free*	*provisioning*
Provisioning on vnode finishes	*provisioning*	*free*
1. Job running on this vnode leaving some resources available 2. No job running on this vnode	*free*	*free*
Job running on this vnode, using all resources	*free*	*job-busy*
Vnode is selected for provisioning, but other vnodes being provisioned have already reached maximum allowed number of concurrently provisioning vnodes	*free*	*wait-provisioning*
This vnode is waiting to be provisioned for a multi-vnode job, and provisioning fails for another of the job's vnodes	*wait-provisioning*	*free*
Provisioning fails for this vnode	*provisioning*	*offline*
This vnode is waiting to be provisioned, and another vnode finishes provisioning, bringing the total number of provisioning vnodes below the limit specified in max_concurrent_provision	*wait-provisioning*	*provisioning*

7.4.5.3 Vnode State When Provisioning Fails

If provisioning fails on a vnode, that vnode is put into the *offline* state.

If provisioning for a multi-vnode job fails on one vnode, any vnodes in the *wait-provisioning* state are put into the *free* state.

7.4.5.4 Using the `qmgr` Command on Vnodes In Process of Provisioning

The following changes cannot be made to a provisioning vnode (a vnode in the *provisioning* state):

- Changing value of current_aoe vnode attribute
- Modifying resource resources_available.aoe
- Changing the state of the vnode. The `qmgr` command returns an error if this is attempted.
- Deleting the vnode from the server. The `qmgr` command returns an error if this is attempted.

The following can be modified while a vnode is provisioning:

- The server's max_concurrent_provision attribute
- A provisioning vnode's provision_enable attribute

The following cannot be set on the server host:

- current_aoe vnode attribute
- provision_enable vnode attribute
- The resources_available.aoe resource

7.4.6 Attributes, Resources, and Parameters Affecting Provisioning

7.4.6.1 Host-level Resources

aoe

The built-in aoe resource is a list of AOEs available on a vnode. Case-sensitive. You specify the list of AOEs that can be requested on a vnode by setting the value of resources_available.aoe to that list. Each job can request at most one AOE.

Automatically added to the `"resources"` line in `<sched_priv directory>/sched_config`.

Cannot be modified while a vnode is provisioning.

Non-consumable. Cannot be set on the server host. Can be set only by a Manager.

Format: string_array.

Default: unset.

Python attribute value type: str

7.4.6.2 Vnode Attributes

current_aoe

The current_aoe vnode attribute shows which AOE is currently instantiated on a vnode. Case-sensitive.

At startup, each vnode's current_aoe attribute is unset. You must set the attribute to the currently instantiated AOE if you want the scheduler to be able to choose vnodes efficiently.

The value of this attribute is set automatically after a vnode is provisioned.

This attribute cannot be modified while a vnode is provisioning.

Cannot be set on the server host. Settable by Manager only; visible to all.

Format: String.

Default: Unset.

provision_enable

This attribute controls whether the vnode can be provisioned. If set to *True*, the vnode can be provisioned.

Cannot be set on the server host.

Settable by Manager only; visible to all.

Format: Boolean

Default: Unset

7.4.6.3 Server Attributes

max_concurrent_provision

The maximum number of vnodes allowed to be in the process of being provisioned. Settable by Manager only; readable by all. When unset, default value is used. Cannot be set to zero; previous value is retained.

Format: Integer

Default: *5*

Python attribute value type: *int*

7.4.6.4 Hook Attributes

All attributes of the provisioning hook affect provisioning. See "Hook Attributes" on page 352 of the PBS Professional Reference Guide.

7.4.6.5 Scheduler Configuration Parameters

provision_policy

Specifies the provisioning policy to be used. Valid values: *avoid_provision*, *aggressive_provision*.

avoid_provision

PBS first tries to satisfy the job's request from free vnodes that already have the requested AOE instantiated. PBS uses node_sort_key to sort these vnodes.

If it cannot satisfy the job's request using vnodes that already have the requested AOE instantiated, it does the following:

PBS uses node_sort_key to select the free vnodes that must be provisioned in order to run the job, choosing from vnodes that are free, provisionable, and offer the requested AOE, regardless of which AOE is instantiated on them.

Of the selected vnodes, PBS provisions any that do not have the requested AOE instantiated on them.

aggressive_provision

PBS selects vnodes to be provisioned without considering which AOE is currently instantiated.

PBS uses node_sort_key to select the vnodes on which to run the job, choosing from vnodes that are free, provisionable, and offer the requested AOE, regardless of which AOE is instantiated on them. Of the selected vnodes, PBS provisions any that do not have the requested AOE instantiated on them.

Default: "*aggressive_provision*".

7.5 Configuring Provisioning

7.5.1 Overview of Configuring Provisioning

The administrator configures provisioning attributes, provides a provisioning tool, and writes a provisioning hook. The administrator configures each vnode to be provisioned with a list of AOE resources, where each resource is an AOE that is available to be run on that vnode. These resources are tags that tell the scheduler what can be run on that vnode. The administrator should also inform the scheduler about the current environment on each vnode, by setting the vnode's current_aoe attribute. It is also necessary to enable provisioning on each vnode to be provisioned and to set provisioning policy at the server and scheduler.

7.5.1.1 Steps in Configuring Provisioning

These are the steps that the administrator must take:

1. Provide a provisioning tool such as HPE Performance Cluster Manager (HPCM). See section 7.5.2, “Provide a Provisioning Tool”, on page 337.
2. Prepare each OS, application, or script that is to be used in provisioning. See section 7.5.3, “Prepare Images”, on page 338.
3. Configure each vnode to be provisioned with the appropriate resources. See section 7.5.4, “Define aoe Resources”, on page 338.
4. Optional: publish each vnode's current AOE. See section 7.5.5, “Inform Scheduler of Current AOE”, on page 338.
5. Write the provisioning hook's script. See section 7.5.6, “Write the Provisioning Script”, on page 339.
6. Create the empty provisioning hook, import the script, and configure the hook. See section 7.5.7, “Create and Configure the Provisioning Hook”, on page 340.
7. Configure provisioning policy. See section 7.5.8, “Configure Provisioning Policy”, on page 341.
8. Enable provisioning on vnodes. See section 7.5.9, “Enable Provisioning on Vnodes”, on page 342.
9. Enable the provisioning hook. See section 7.5.10, “Enable Provisioning Hook”, on page 342.

7.5.2 Provide a Provisioning Tool

For each vnode you wish to provision, there must be a provisioning tool that can be used on that vnode. This provisioning tool can either be written into the provisioning hook script, or be a separate script that is called by the provisioning hook script. You can write the provisioning tool yourself, or you can use something like the HPE Performance Cluster Manager (HPCM) cluster management tool. Your provisioning tool may be able to employ network-accessible power control units.

7.5.3 Prepare Images

You must prepare each image, application, or script you will use. Make sure that each is available to the target vnode. For example, if you use a diskless node server, put your images on the diskless node server.

The values for the ncpus and mem resources must be the same for all OS images that may be instantiated on a given vnode.

7.5.4 Define aoe Resources

The aoe resource is of type string_array, and is used to hold the names of the AOEs available at each vnode. This resource is not consumable. This resource is unset by default, and by default is added to the `resources` line in `<sched_priv directory>/sched_config`. See "Resources Built Into PBS" on page 267 of the PBS Professional Reference Guide. The aoe resource is visible to all, but settable by the PBS Manager and Operator only.

The scheduler must be able to find out which AOEs can be run on which vnodes. To tag each vnode with the AOEs that can run on it, set that vnode's resources_available.aoe attribute to the list of available AOEs. For example, if vnode V1 is to run RHEL and SLES, and the hook script will recognize *rhel* and *sles*, set the vnode's resources_available.aoe attribute to show this:

```
Qmgr: set node V1 resources_available.aoe = "rhel, sles"
```

It is recommended that you make a list of all of the AOEs that may be used in provisioning in your PBS complex. The list is to facilitate script writing and resource configuration. Each entry in this list should contain at least the following information:

- Full description of the AOE
- Resource name of the AOE
- Vnodes that are to run the AOE
- Location where script should look for the AOE

For example, the list might look like the following table:

Table 7-4: Example AOE List

Description	Resource Name	Vnodes	Location
SuSE SLES 12 64-bit	*sles12*	mars, jupiter, neptune, pluto	`imageserver.example.com:/images/sles12-image`
SuSE SLES 15 64-bit	*sles15*	mars, jupiter, pluto	`imageserver.example.com:/images/sles15-image`
Red Hat Enterprise Linux 8 64-bit	*rhel7*	luna, aitne, io	`imageserver.example.com:/images/rhel8-image`
Windows Server 2016 64-bit	*winsrv16*	luna, aitne, io	`\\WinServer\ C:\images\winsrv16`

7.5.5 Inform Scheduler of Current AOE

Each vnode has an attribute called current_aoe which is used to tell the scheduler what the vnode's current AOE is. This attribute is unset by default. The attribute is of type string. It is visible to all, but settable by the PBS Manager only.

You can set this attribute on each vnode that will be used in provisioning. Set it to the value of the AOE that is currently instantiated on the vnode. So for example, using the table in section 7.5.4, "Define aoe Resources", on page 338, if vnode pluto is running 64-bit SuSE SLES 15, set current_aoe to *sles15*:

```
Qmgr: set node pluto current_aoe = sles15
```

When PBS provisions a vnode with a new AOE, the PBS server sets the value of current_aoe to the new AOE.

If PBS cannot provision a vnode with the desired AOE, it marks the vnode *offline* and unsets the value of current_aoe.

7.5.6 Write the Provisioning Script

You create the provisioning hook using a provisioning script which must manage all provisioning, either directly, or indirectly by calling other scripts. The script in the hook is the master provisioning script.

The script that does the provisioning must have the logic needed to provision the specified vnode with the specified AOE.

There are two types of provisioning. One is when the vnode is rebooted after installing/uninstalling the OS/application or running the script. The other is when the vnode is not rebooted after installing/uninstalling the OS/application or running the script.

The master provisioning script must meet the following requirements:

- Written in Python
- Arguments to the script are the vnode name and the AOE name
- If the vnode must be rebooted for provisioning, the provisioning script must cause the target vnode to be rebooted
- Must indicate success using the correct return value:
  - Return pbs.event.accept(0) if provisioning is successful and the vnode is rebooted
  - Return pbs.event.accept(1) if provisioning is successful and the vnode is not rebooted
- Must indicate failure to PBS by using pbs.event.reject()
- If the master provisioning script calls other scripts, it must wait for them to finish before returning success or failure to PBS

7.5.6.1 Arguments to Master Script

The arguments to the master script are the following:

- Name of vnode to be provisioned

  Supplied to the hook via the PBS provision event object, as pbs.event.vnode
- Name of AOE to be instantiated on the target vnode

  Supplied to the hook via the PBS provision event object, as pbs.event.aoe

These values can be passed to scripts that are called by the master script.

7.5.6.2 Return Values

The master script must indicate to PBS whether it succeeded or failed in a way that PBS can understand.

7.5.6.2.i Success

By default, pbs.event.accept() returns zero. The script must return different values for successful provisioning, depending on whether the vnode is rebooted:

- If provisioning is successful and the vnode is rebooted, the script must return *0* (zero) to PBS via pbs.event.accept(0).
- If provisioning is successful and the vnode is not rebooted, the script must return *1* (one) to PBS via pbs.event.accept(1).

7.5.6.2.ii Failure

If provisioning fails, the script must use pbs.event.reject() to indicate failure. By default, pbs.event.reject() returns *255*. To return another failure code, use the following:

```
pbs.event.reject(error message, error code)
```

where error code is any number between *2* and *255*. Returning an error code in pbs.event.reject() is optional.

7.5.6.3 Master Script Calls Subscript

Often, the master script (the hook script) calls another script, depending on the provisioning required. The subscript does the actual provisioning of the target vnode with the requested AOE. In this case, the master script must wait for the subscript to return and indicate success or failure. The master script then propagates the result to PBS.

Example of a fragment of a master script calling a subscript:

```
return_value = os.system("/var/vendor/vendor_prov.sh " <arguments to vendor_prov.sh>)
```

7.5.7 Create and Configure the Provisioning Hook

The provisioning hook causes any provisioning to happen. The provisioning hook is a Python script which either does the provisioning directly or calls other scripts or tools. Typically the provisioning hook calls other scripts, which do the actual work of provisioning. For complete information on writing hooks, see the PBS Professional Hooks Guide.

You can have at most one provisioning hook. Do not attempt to create more than one provisioning hook.

In the steps that follow, we use as examples a provisioning hook named "Provision_Hook", and an ASCII script named "`master_provision.py`".

7.5.7.1 Create the Hook

To create the provisioning hook:

```
Qmgr: create hook <hook name>
```

For example, to create a provisioning hook called Provision_Hook:

```
Qmgr: create hook Provision_Hook
```

7.5.7.2 Import the Hook Script

If the hook script is called "`master_provision.py`", and it is ASCII, and it is located in `/root/data/`, importing the hook script looks like this:

```
Qmgr: import hook Provision_Hook application/x-python default
    /root/data/master_provision.py
```

See "Importing Hooks" on page 34 in the PBS Professional Hooks Guide for more about importing hooks.

7.5.7.3 Configure the Hook Script

7.5.7.3.i Set Event Type

The event type for the provisioning hook is called "*provision*". To set the event type:

```
Qmgr: set hook Provision_Hook event = provision
```

Do not try to assign more than one event type to the provisioning hook.

7.5.7.3.ii Set Alarm Time

The default alarm time for hooks is *30 seconds*. This may be too short for a provisioning hook. You should set the alarm time to a value that is slightly more than the longest time required for provisioning. Test provisioning each AOE, and find the longest time required, then add a small amount of extra time. To set the alarm time:

```
Qmgr: set hook Provision_Hook alarm = <number of seconds required>
```

7.5.8 Configure Provisioning Policy

7.5.8.1 Set Maximum Number of Concurrently Provisioning Vnodes

The value of the server's max_concurrent_provision attribute specifies the largest number of vnodes that can be in the process of provisioning at any time. The default value of this attribute is *5*. Set the value of this attribute to the largest number of vnodes you wish to have concurrently provisioning. See section 7.4.6.3, “Server Attributes”, on page 336 for more information on the attribute.

7.5.8.1.i Considerations

You may wish to limit the number of hosts that can be in the process of provisioning at the same time:

- So that the network isn't overwhelmed transferring OS images to execution nodes
- So the hosts won't draw excessive power when powering up at the same time

Many sites have tools that notify them when an execution node goes down. You may want to avoid being paged every time an execution node is provisioned with a new AOE.

7.5.8.2 Set Scheduling Policy

When a job is scheduled to be run, and the job requests an AOE, PBS can either try to fit the job on vnodes that already have that AOE instantiated, or it can choose the vnodes regardless of AOE. Choosing regardless of AOE is the default behavior; the assumption is that the chances of finding free vnodes that match all the requirements including that of the requested AOE are not very high.

Provisioning policy is controlled by the provision_policy scheduling parameter in `<sched_priv directory>/sched_config`. This parameter is a string which can take one of two values: *avoid_provision* or *aggressive_provision*. If you want PBS to try first to use vnodes whose AOEs already match the requested AOE, set provision_policy to *avoid_provision*. If you want PBS to choose vnodes regardless of instantiated AOE, set it to *aggressive_provision*.

For details about the provision_policy parameter, see section 7.4.2.1, “Provisioning Policy”, on page 331.

For jobs that do not request an AOE, node_sort_key is used to choose vnodes.

7.5.9 Enable Provisioning on Vnodes

PBS will provision only those vnodes that have provisioning enabled. Provisioning on each vnode is controlled by its provision_enable attribute. This attribute is Boolean, with a default value of *False*. You enable provisioning on a vnode by setting its provision_enable attribute to *True*.

This attribute cannot be set to *True* on the server host.

See section 7.4.6.2, "Vnode Attributes", on page 336 for details about the provision_enable vnode attribute.

7.5.10 Enable Provisioning Hook

The last step in configuring provisioning is enabling the provisioning hook. The provisioning hook is enabled when its enabled attribute is set to *True*. To set the enabled attribute to *True* for the provisioning hook named Provision_Hook:

```
Qmgr: set hook Provision_Hook enabled = True
```

7.6 Viewing Provisioning Information

7.6.1 Viewing Provisioning Hook Contents

To see the contents of the provisioning hook, export them:

qmgr -c "export hook <hook name> application/x-python default" > <output-path>/<output-filename>

For example, if the provisioning hook is named Provision_Hook, and you wish to export the contents to `/usr/user1/hook_contents`:

```
qmgr -c "export hook Provision_Hook application/x-python default" > /usr/user1/hook_contents
```

7.6.2 Viewing Provisioning Hook Attributes

To view the provisioning hook's attributes, use the list hook option to the `qmgr` command:

```
qmgr -c "list hook <hook name>"
```

7.6.3 Printing Provisioning Hook Creation Commands

To print the provisioning hook's creation commands, use the print hook option to the `qmgr` command:

```
qmgr -c "p hook"
#
# Create hooks and set their properties.
#
#
# Create and define hook my_prov_hook
#
create hook my_prov_hook
set hook my_prov_hook type = site
set hook my_prov_hook enabled = True
set hook my_prov_hook event = provision
set hook my_prov_hook user = pbsadmin
set hook my_prov_hook alarm = 30
set hook my_prov_hook order = 1
import hook my_prov_hook application/x-python base64 -
c2xzbGwK
```

7.6.4 Viewing Attributes and Resources Affecting Provisioning

7.6.4.1 Server Attributes

To see the server attributes affecting provisioning, print the server's information using the `qmgr` command:

```
qmgr -c "print server"
```

You will see output similar to the following:

```
# qmgr
Max open servers: 49
Qmgr: p s
#
# Create queues and set their attributes.
#
#
# Create and define queue workq
#
create queue workq
set queue workq queue_type = Execution
set queue workq enabled = True
set queue workq started = True
#
# Set server attributes.
#
set server scheduling = True
set server default_queue = workq
set server log_events = 511
set server mail_from = adm
set server resv_enable = True
set server node_fail_requeue = 310
set server pbs_license_min = 0
set server pbs_license_max = 2147483647
set server pbs_license_linger_time = 31536000
set server license_count = "Avail_Global:0 Avail_Local:256 Used:0 High_Use:0"
set server max_concurrent_provision = 5
```

7.6.4.2 Viewing Vnode Attributes and Resources

To see vnode attributes and resources affecting provisioning, use the `-a` option to the `pbsnodes` command:

```
pbsnodes -a
host1
     Mom = host1
     ntype = PBS
     state = free
     pcpus = 2
     resources_available.aoe = osimage1, osimage2
     resources_available.arch = linux
     resources_available.host = host1
     resources_available.mem = 2056160kb
     resources_available.ncpus = 2
     resources_available.vnode = host1
     resources_assigned.mem = 0kb
     resources_assigned.ncpus = 0
     resources_assigned.vmem = 0kb
     resv_enable = True
     sharing = default_shared
     provision_enable = True
     current_aoe = osimage2
```

7.7 Requirements and Restrictions

7.7.1 Site Requirements

7.7.1.1 Single-vnode Hosts Only

PBS will provision only single-vnode hosts. Do not attempt to use provisioning on hosts that have more than one vnode.

7.7.1.2 Provisioning Tool Required

For each vnode you wish to provision, there must be a provisioning tool that can be used on that vnode. Examples of provisioning tools are the following:

- The HPE Performance Cluster Manager (HPCM) cluster management tool
- Dual boot system
- Network-accessible power control units

7.7.1.3 Single Provisioning Hook Allowed

The PBS server allows only one provisioning hook. If you have an existing provisioning hook and you import a provisioning script, that script will become the contents of the hook, whether or not the hook already has a script. The new script will overwrite the existing provisioning hook script.

7.7.1.4 Provisioning Hook Cannot Have Multiple Event Types

The provisioning hook cannot have more than one event type.

7.7.1.5 AOE Names Consistent Across Complex

Make AOE names consistent across the complex. The same AOE should have the same name everywhere.

7.7.2 Usage Requirements

7.7.2.1 Restriction on Concurrent AOEs on Vnode

Only one AOE can be instantiated at a time on a vnode.

Only one kind of aoe resource can be requested in a job. For example, an acceptable job could make the following request:

```
-l select=1:ncpus=1:aoe=suse+1:ncpus=2:aoe=suse
```

7.7.2.2 Vnode Job Restrictions

A vnode with any of the following jobs will not be selected for provisioning:

- One or more running jobs
- A suspended job
- A job being backfilled around

7.7.2.3 Vnode Reservation Restrictions

A vnode will not be selected for provisioning for job MyJob if the vnode has a confirmed reservation, and the start time of the reservation is before job MyJob will end.

A vnode will not be selected for provisioning for a job in reservation R1 if the vnode has a confirmed reservation R2, and an occurrence of R1 and an occurrence of R2 overlap in time and share a vnode for which different AOEs are requested by the two occurrences.

7.7.2.4 Hook Script and AOE Must Be Compatible

The requested AOE must be available to the vnode to be provisioned. The following must be *True*:

- The AOE must be in the list of available AOEs for the vnode
- Each AOE listed on a vnode must be recognized by the provisioning hook script.
- The vnode must have provisioning enabled

7.7.2.5 Provisioning Hook Must Be Ready

- The provisioning hook must obey the following rules:
    - It must exist
    - It must have a Python script imported
    - It must be enabled
    - It must be designed to invoke an external script or command for AOEs that are to be used

7.7.2.6 Server Host Cannot Be Provisioned

The server host cannot be provisioned: a MoM can run on the server host, but that MoM's vnode cannot be provisioned. The provision_enable vnode attribute, resources_available.aoe, and current_aoe cannot be set on the server host.

7.7.2.7 PBS Attributes Not Available to Provisioning Hook

The provisioning hook cannot operate on PBS attributes except for the following:

- The name of the vnode to be provisioned: pbs.event.vnode
- The AOE to be instantiated: pbs.event.aoe

7.7.2.8 avoid_provision Incompatible with smp_cluster_dist

The avoid_provision provisioning policy is incompatible with the smp_cluster_dist scheduling scheduler configuration parameter. If a job requests an AOE, the avoid_provision policy overrides the behavior of smp_cluster_dist.

7.8 Defaults and Backward Compatibility

By default, PBS does not provide provisioning. You must configure PBS to provide provisioning.

7.9 Example Scripts

7.9.1 Sample Master Provisioning Hook Script With Explanation

We show a sample provisioning hook script, and an explanation of what the script does. For readability, the sample script is a master script calling two subscripts.

This provisioning hook allows two kinds of provisioning request:

- For the application AOE named "App1", via the script `app_prov.sh`

  The `app_prov.sh` script does not reboot the vnode
- For other provisioning, via the vendor-provided provisioning shell script `vendorprov.sh`

  The `vendorprov.sh` script reboots the vnode

7.9.1.1 Sample Master Provisioning Hook Script

```
import pbs                                              (1)
import os                                               (2)

e = pbs.event()                                         (3)
vnode = e.vnode                                         (4)
aoe = e.aoe                                             (5)

if (aoe == "App1"):                                     (6)
    appret = os.system("/var/user/app_prov.sh
   " + vnode + " " + aoe )                              (7)
    if appret != 1:                                      (8)
        e.reject("Provisioning without reboot
          failed", 210)                                 (9)
    else:
        e.accept(1)                                      (10)

ret = os.system("/var/vendor/vendorprov.sh
    " + vnode + " " + aoe )                            (11)

if ret != 0:                                           (12)
    e.reject("Provisioning with reboot
          failed", 211)                                (13)
else:
    e.accept(0)                                         (14)
```

7.9.1.2 Explanation of Sample Provisioning Hook Script

- Lines 1 and 2 import the pbs and os modules.
- Line 3 puts the PBS provisioning event into the local variable named "e".
- Lines 4 and 5 store the target vnode name and the name of the AOE to be instantiated on the target vnode in local variables.
- Line 6 checks whether provisioning of the application AOE named "App1" is requested.
- Line 7 is where the actual code to do non-rebooting provisioning could go. In this example, we call a subscript, passing the name of the target vnode and the requested AOE, and storing the return value in "appret".

  The non-rebooting provisioning subscript should return *1* on success.
- Line 8 checks whether non-rebooting provisioning via `app_prov.sh` succeeded.
- Line 9 returns the error code *210* and an error message to PBS if `app_prov.sh` failed.
- Line 10 returns *1* via pbs.event.accept(1) if non-rebooting provisioning succeeded.
- Line 11 calls the vendor-supplied script that is responsible for doing rebooting provisioning whenever "App1" is not the AOE.

  The name of the target vnode and the requested AOE are passed to this script.

The vendor-supplied script should expect these two arguments. The return value from this script is stored in the variable named "ret".

- Line 12 checks whether rebooting provisioning via the vendor-supplied script `vendorprov.sh` was successful.
- Line 13: If the return value is anything but *zero* (success), the provisioning hook script passes the error code *211* back to PBS, along with an error message.
- Line 14 returns success to PBS via pbs.event.accept(0) and the master script exits.

7.9.2 Sample Master Provisioning Hook Script Calling Performance Cluster Manager

The following is a master provisioning hook script that calls HPE Performance Cluster Manager (HPCM):

```
# -*- coding: utf-8 -*-
import pbs
import os

e = pbs.event()
vnode = e.vnode
aoe = e.aoe

if (aoe=="App1"):
    ret = os.system("/root/osprov/application.sh " + vnode + " " + aoe)
    if ret != 0:
        e.reject("Non-reboot provisioning failed",ret)
    else:
        e.accept(1)

ret = os.system("/root/osprov/sgi_provision.sh " + vnode + " " + aoe)
if ret != 0:
    e.reject("Reboot provisioning failed",ret)
else:
    e.accept(0)
```

7.9.3 Sample Script Set

This is a set of example Linux scripts designed to work together. They are the following:

`provision_hook.py`

This is the script for the provisioning hook. It calls the master provisioning script.

`provision_master.py:`

This is the master provisioning script. It is responsible for rebooting the machine being provisioned. It calls `update_grub.sh` to update the current AOE.

`update_grub.sh`

This shell script updates the linux `grub.conf` file and sets the value for current_aoe after the reboot.

The `update_grub.sh` script must be modified according to the `grub` configuration of the system in question before being run.

7.9.3.1 Provisioning Hook Script

`provision_hook.py:`

```
import pbs
import os

e = pbs.event()
vnode = e.vnode
aoe = e.aoe
#print "vnode:" + vnode
#print "AOE:" + aoe

if (aoe=="App1"):
    print "Provisioning an application"
    e.accept(1)

ret = os.system("python /root/provision_master.py " + vnode + " " + aoe + " " + "lin")
#print "Python top level script returned " + str(ret)
if ret != 0:
    e.reject("Provisioning failed",ret)
else:
    e.accept(0)
```

7.9.3.2 Master Provisioning Script

provision_master.py:

```
#!/usr/bin/python

#--------------------
# success : 0
# failure : 1
#--------------------
# win_or_lin == 1 : windows
# win_or_lin == 0 : linux
#--------------------
# 1 is TRUE
# 0 is FALSE
#--------------------

import sys
import os

vnode = sys.argv[1]
aoe = sys.argv[2]
win_or_lin = sys.argv[3]

print vnode, aoe

if not aoe.find('win'):
    print "aoe is win"
    isvnodewin = 1
else:
    print "aoe is *nix"
    isvnodewin = 0

print "win_or_lin = [", win_or_lin, "]"

if (win_or_lin == "win"):
    print "entering window server"
    if isvnodewin:
#------------ WINDOWS -> WINDOWS
        ret = os.system("pbs-sleep 05")
#------------ WINDOWS -> WINDOWS

    else:
#------------ WINDOWS -> LINUX
        ret = os.system("pbs-sleep 05")
#------------ WINDOWS -> LINUX
```

```
        ret = os.system("pbs-sleep 45")
        print "Pinging machine until it is up..."
        timeout = 120
        ticks = 0

        while 1:
            ret = os.system("ping -c 1 -i 5 " + vnode + " -w 10 > /dev/null 2>&1")
            if not ret:
                print "that machine is now up"
                exit(0)

            ticks = ticks + 1
            print "ticks = ", ticks
            if ticks > timeout:
                print "exit ticks = ", ticks
                print "that machine didn't come up after 2 mins,FAIL"
                exit(1)

    else:
        print "entering linux server"
        if isvnodewin:
    #------------ LINUX -> WINDOWS
            ret = os.system("sleep 05")
    #------------ LINUX -> WINDOWS

        else:
    #------------ LINUX -> LINUX

            ret = os.system("scp -o StrictHostKeyChecking=no /root/update_grub.sh " + vnode + ":/root
        > /dev/null 2>&1")
            if ret != 0:
                print "scp failed to copy"
                exit(1)

            ret = os.system("/usr/bin/ssh -o StrictHostKeyChecking=no " + vnode + "
        \"/root/update_grub.sh " + vnode + " " + aoe + " 1 " + " \" > /dev/null 2>&1")
            if ret != 0:
                print "failed to run script"
                exit(1)

            ret = os.system("/usr/bin/ssh -o StrictHostKeyChecking=no " + vnode + " \"reboot\"" + " >
        /dev/null 2>&1")
            if ret != 0:
                print "failed to reboot that machine"
                exit(1)

    #------------ LINUX -> LINUX
```

```
ret = os.system("sleep 45")
print "Pinging machine until it is up..."
timeout = 120
ticks = 0

while 1:
    ret = os.system("ping -c 1 -i 5 " + vnode + " -w 10 > /dev/null 2>&1")
    if not ret:
        print "that machine is now up"
        exit(0)

    print "ticks = ", ticks
    ticks = ticks + 1
    if ticks > timeout:
        print "That machine didn't come up after 2 mins. FAIL"
        exit(1)
```

7.9.3.3 Grub Update Shell Script

update_grub.sh:

```
#! /bin/sh

if [ $# -lt 2 ]; then
    echo "syntax: $0 <machine ip> <aoe name>"
    exit 1
fi

machine=$1
aoe_name=$2

menufile="/boot/grub/grub.conf"
if [ ! -f "$menufile" ]; then
    echo "grub.conf file not found. $machine using grub bootloader?"
    exit 1
fi

link=`ls -l $menufile | cut -c1`
if [ "$link" = "l" ]; then
    menufile=`ls -l $menufile | awk -F"-> " '{print $2}'`
    echo "Found link file, original file is $menufile"
fi

titles=`cat $menufile | grep title | awk -F"title" '{print $2}' | sed 's/^[ \t]//g'`
lines=`echo -e "$titles" | wc -l`

found_aoe_index=-1
count=0
while [ $count -lt $lines ]
do
    lineno=`expr $count + 1`
    title=`echo -e "$titles" | head -n $lineno | tail -n 1`
    if [ "$aoe_name" = "$title" ]; then
        found_aoe_index=$count
    fi
    count=`expr $count + 1`
done

if [ $found_aoe_index = -1 ]; then
    echo "Requested AOE $aoe_name is not found on machine $machine"
    exit 2
fi

new_def_line="default=$found_aoe_index"
```

```
def_line=`cat $menufile | grep "^default="`

echo "new_def_line=$new_def_line"
echo "def_line=$def_line"
echo "menufile=$menufile"

cp $menufile /boot/grub/grub.conf.backup
cat $menufile | sed "s/^$def_line/$new_def_line/g" > grub.out
if [ -s grub.out ]; then
    mv grub.out $menufile
else
    exit 1
fi

service pbs stop

exit 0
```

7.10 Advice and Caveats

7.10.1 Using Provisioning Wisely

It is recommended that when using provisioning, you set PBS up so as to prevent things such as the following:

- User jobs not running because vnodes used in a reservation have been provisioned, and provisioning for the reservation job will take too long
- Excessive amounts of time being taken up by provisioning from one AOE to another and back again

In order to avoid problems like the above, you can do the following to keep specific AOE requests together:

- For each AOE, associate a set of vnodes with a queue. Use a hook to move jobs into the right queues.
- Create a reservation requesting each AOE, then use a hook to move jobs requesting AOEs into the correct reservation.

7.10.1.1 Preventing Provisioning

You may need to prevent specific users or groups from using provisioning. You can use a job submission, job modification, or reservation creation hook to prevent provisioning. For more about hooks, see the PBS Professional Hooks Guide. The following is an example of a hook script to prevent USER1 from provisioning:

```
import pbs
import re

#--- deny user access to provisioning

e = pbs.event()
j = e.job   #--- Use e.resv to restrict provisioning in reservation
who = e.requestor

unallow_ulist = ["USER1"]

if who not in unallow_ulist
    e.accept(0)

#User request AOE in select?
if j.Resource_List["select"] != None:
    s = repr(j.Resource_List["select"])
    if re.search("aoe=", s) != None:
        pbs.logmsg(pbs.LOG_DEBUG, "User %s not allowed to
        provision" % (who))
        e.reject("User not allowed to provision")

#User request AOE?
if j.Resource_List["aoe"] != None:
    pbs.logmsg(pbs.LOG_DEBUG, "User %s not allowed to
    provision" % (who))
    e.reject("User not allowed to provision")

e.accept(0)
```

7.10.2 Allow Enough Time in Reservations

If a job is submitted to a reservation with a duration close to the walltime of the job, provisioning could cause the job to be terminated before it finishes running, or to be prevented from starting. If a reservation is designed to take jobs requesting an AOE, leave enough extra time in the reservation for provisioning.

7.11 Errors and Logging

7.11.1 Errors

7.11.1.1 Errors Resulting in Marking Vnodes Offline

A vnode is marked *offline* if:

- Provisioning fails for the vnode
- The AOE reported by the vnode does not match the requested AOE after the provisioning script finishes

A vnode is not marked *offline* if provisioning fails to start due to internal errors in the script.

7.11.1.2 Errors Resulting in Requeueing Job

Before provisioning a vnode with a requested OS, the server checks to see whether MoM's hook files are synced. If not, the server creates a timed task to check again. If the server fails to create the timed task, it requeues the job, and logs following error messages at log level 0x0001:

```
"Resource temporarily unavailable (11) in prov_startjob, Unable to set task for prov_startjob;
   requeueing the job"
"Cannot allocate memory (12) in prov_startjob, Unable to set task for prov_startjob; requeuing the
   job"
"Cannot allocate memory (12) in check_and_run_jobs, Unable to set task for prov_startjob;
   requeueing the job"
```

7.11.2 Logging

7.11.2.1 Accounting Logs

For each job and reservation, an accounting log entry is made whenever provisioning starts and provisioning ends. Each such log entry contains a list of the vnodes that were provisioned, the AOE that was provisioned on these vnodes, and the start and end time of provisioning.

The accounting log entry for the start of provisioning is identified by the header "*P*", and the entry for the end of provisioning is identified by the header "*p*".

Example:

Printed when job starts provisioning:

```
"01/15/2009 12:34:15;P;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=START start_time=1231928746"
```

Printed when job stops provisioning:

```
"01/15/2009 12:34:15;p;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=END status=SUCCESS
   end_time=1231928812"
```

Printed when provisioning for job failed:

```
"01/15/2009 12:34:15;p;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=END status=FAILURE
   end_time=1231928812"
```

7.11.2.2 Server Logs

7.11.2.2.i Messages Printed at Log Level 0x0080

```
"vnode <vnode name>: Vnode offlined since it failed provisioning"
"vnode <vnode name>: Vnode offlined since server went down during provisioning"
"Provisioning for Job <job id> succeeded, running job"
"Job failed to start provisioning"
"Provisioning for Job <job id> failed, job held"
"Provisioning for Job <job id> failed, job queued"
```

7.11.2.2.ii Messages Printed at Log Level 0x0100

```
"Provisioning of Vnode <vnode name> successful"
"Provisioning of <vnode name> with <AOE name> for <job ID> failed, provisioning exit
   status=<number>"
"Provisioning of <vnode name> with <aoe name> for <job id> timed out"
"Provisioning vnode <vnode> with AOE <AOE> started successfully"
"provisioning error: AOE mis-match"
"provisioning error: vnode offline"
```

7.11.2.2.iii Messages Printed at Log Level 0x0002

```
"Provisioning hook not found"
```

7.11.2.2.iv Messages Printed at Log Level 0x0001

```
"Provisioning script recompilation failed"
"Resource temporarily unavailable (11) in prov_startjob, Unable to set task for prov_startjob;
   requeueing the job"
"Cannot allocate memory (12) in prov_startjob, Unable to set task for prov_startjob; requeueing
   the job"
"Cannot allocate memory (12) in check_and_run_jobs, Unable to set task for prov_startjob;
   requeueing the job"
```

7.11.2.3 Scheduler Logs

7.11.2.3.i Messages Printed at Log Level 0x0400

Printed when vnode cannot be selected for provisioning because requested AOE is not available on vnode:

```
"Cannot provision, requested AOE <aoe-name> not available on vnode"
```

Printed when vnode cannot be selected for provisioning because vnode has running or suspended jobs, or the reservation or job would conflict with an existing reservation:

```
"Provision conflict with existing job/reservation"
```

Printed when vnode cannot be selected for provisioning because provision_enable is unset or set *False* on vnode:

```
"Cannot provision, provisioning disabled on vnode"
```

Printed when job cannot run because server is not configured for provisioning:

```
"Cannot provision, provisioning disabled on server"
```

Printed when multiple vnodes are running on the host:

```
"Cannot provision, host has multiple vnodes"
```

Printed when vnodes are sorted according to avoid_provision policy:

```
"Re-sorted the nodes on aoe <aoe name>, since aoe was requested"
```

7.11.2.3.ii Messages Printed at Log Level 0x0100

Printed when a vnode is selected for provisioning by a job:

```
"Vnode <vnode name> selected for provisioning with <AOE name>"
```

7.11.3 Error Messages

Printed when vnode is provisioning and current_aoe is set or unset or resources_available.aoe is modified via `qmgr`:

```
"Cannot modify attribute while vnode is provisioning"
```

Printed when `qmgr` is used to change state of vnode which is currently provisioning:

```
"Cannot change state of provisioning vnode"
```

Printed when vnode is deleted via '`qmgr > delete node <name>`' while it is currently provisioning:

```
"Cannot delete vnode if vnode is provisioning"
```

Printed when provision_enable, current_aoe or resources_available.aoe are set on host running PBS server, scheduler, and communication daemons:

```
"Cannot set provisioning attribute on host running PBS server and scheduler"
```

Printed when current_aoe is set to an AOE name that is not listed in resources_available.aoe of the vnode:

```
"Current AOE does not match with resources_available.aoe"
```

Printed when an event of a hook is set to '*provision*' and there exists another hook that has event '*provision*':

```
"Another hook already has event 'provision', only one 'provision' hook allowed"
```

Printed when `qsub` has *-laoe* and *-lselect=ao*e:

```
"-lresource= cannot be used with "select" or "place", resource is: aoe"
```

Job comment printed when job fails to start provisioning:

```
"job held, provisioning failed to start"
```

Printed when job is submitted or altered so that it does not meet the requirements that all chunks must request same AOE, and this AOE must match that of any reservation to which the job is submitted:

```
"Invalid provisioning request in chunk(s)"
```

8 Security

This chapter describes the security features of PBS. These instructions are for the PBS administrator and Manager.

8.1 Configurable Features

This section gives an overview of the configurable security mechanisms provided by PBS, and gives links to information on how to configure each mechanism.

The following table lists configurable PBS security mechanisms and their configuration procedures.

Table 8-1: Security Mechanisms and their Configuration Procedures

Security Mechanism	Configuration Procedure
Authentication with daemons and users	"Authentication for Daemons & Users" on page 380
Encrypting communication	"Encrypting PBS Communication" on page 389
Access control for server, queues, reservations	"Using Access Control Lists" on page 364
Event logging for server, scheduler, MoMs	"Event Logging" on page 548
File copy mechanism	"Setting File Transfer Mechanism" on page 561
Levels of privilege (user roles)	"User Roles and Required Privilege" on page 361
Restricting access to execution hosts via $restrict_user	"Restricting Execution Host Access" on page 393

8.2 User Roles and Required Privilege

8.2.1 Root Privilege

Root privilege is required to perform some operations in PBS involving writing to the server's private, protected data. Root privilege is required in order to do the following:

- Create hooks
- Alter MoM and scheduler configuration files
- Set scheduler priority formula
- Run certain commands, including the following:
    - `pbs_probe`
    - `pbs_mom`
    - `pbs_sched`
    - `pbs_server`
    - `pbsfs`
- Use the `tracejob` command to view accounting log information

There are some operations that root privilege alone does not allow. These operations require Manager privilege but not root privilege. Manager privilege, but not root privilege, is required in order to do the following:

- Set attributes
- Create or delete vnodes using the `qmgr` command

8.2.2 User Roles

PBS allows certain privileges based on what role a person has, and whether that person has root privilege. PBS recognizes only three roles, and all those using PBS must be assigned one of these roles. These roles are *Manager*, *Operator*, and *user*. Roles are assigned by PBS Managers only. No roles can be added, and roles cannot be modified; the function of roles is hardcoded in the server.

In addition to these roles, PBS requires a PBS Administrator to perform some downloading, installation, upgrading, configuration, and management functions. PBS does not recognize *PBS Administrator* as a PBS role; this term is used in PBS documentation to mean the person who performs these tasks.

PBS roles and PBS Administrators are described in the following sections:

8.2.2.1 User

8.2.2.1.i Definition of User

Users are those who submit jobs to PBS.

Users have the lowest level of privilege. Users are referred to in the PBS documentation as "users". By default, users may operate only on their own jobs. They can do the following:

- Submit jobs
- Alter, delete, and hold their own jobs
- Status their own jobs, and those of others if permission has been given via the query_other_jobs server attribute. The query_other_jobs server attribute controls whether unprivileged users are allowed to select or query the status of jobs owned by other users.
- List and print some but not all server, queue, vnode, scheduler, and reservation attributes

8.2.2.1.ii Defining List of Users

PBS allows you to define a list of users allowed or denied access to the PBS server, however this is done using the PBS access control list mechanism. Access control is described in section 8.3, “Using Access Control Lists”, on page 364.

8.2.2.2 Operator

8.2.2.2.i Definition of Operator

A PBS Operator is a person who has an account that has been granted Operator privilege.

Operators have more privilege than users, and less privilege than Managers.

Operators can manage the non-security-related attributes of PBS such as setting and unsetting non-security attributes of vnodes, queues, and the server. Operators can also set queue ACLs.

Operators can do the following:

- All operations that users can perform
- Set non-security-related server, queue, and vnode attributes (Operators are not permitted to set server ACLs)
- Alter some job attributes
- Set or alter most resources on the server, queues, and vnodes
- Rerun, requeue, delete, and hold all jobs
- Run any command to act on a job

8.2.2.2.ii Defining List of Operators

To define the list of Operators at a PBS complex, set the server's operators attribute to a list of usernames, where each username should be an Operator. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

It is important to grant Operator privilege to appropriate persons only, since Operators can control how user jobs run.

8.2.2.3 Manager

8.2.2.3.i Definition of Manager

A Manager is a person who has an account that has been granted PBS Manager privilege.

Managers have more privilege than Operators. Managers can manage the security aspects of PBS such as server ACLs and assignment of User Roles.

Managers can do the following:

- All operations that Operators can perform
- Create or delete queues or vnodes
- Set all server, queue, and vnode attributes, including server ACLs

8.2.2.3.ii Defining List of Managers

To define the list of Managers at a PBS complex, set the server's managers attribute to a list of usernames, where each username should be a Manager. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

If the server's managers attribute is not set or is unset, root on the server host is given Manager privilege.

It is important to grant Manager privilege to appropriate persons only, since Managers control much of PBS.

8.2.2.4 PBS Administrator

8.2.2.4.i Definition of PBS Administrator

Linux: person with Manager privilege and root access.

Windows: person with Manager privilege who is a member of the local Administrators group.

A person who administers PBS, performing functions such as downloading, installing, upgrading, configuring, or managing PBS. PBS Administrators perform all the functions requiring root privilege, as described in section 8.2.1, "Root Privilege", on page 361.

PBS Administrator is distinguished from "site administrator", although often these are the same person.

8.3 Using Access Control Lists

8.3.1 Access Definitions

In this section we describe the meaning of access for each entity and object where the access of the entity to the object has an access control mechanism.

8.3.1.1 Access to a PBS Object

Below are the definitions of what access to each of the following PBS objects means:

Access to the server

Being able to run PBS commands to submit jobs and perform operations on them such as altering, selecting, and querying status. It also means being able to get the status of the server and queues.

Access to a queue

Being able to submit jobs to the queue, move jobs into the queue, being able to perform operations on jobs in the queue, and being able to get the status of the queue.

Access to a reservation

Being able to place jobs in the reservation, whether by submitting jobs to the reservation or moving jobs into the reservation. It also means being able to delete the reservation, and being able to operate on the jobs in the reservation.

8.3.1.2 Access by a PBS Entity

Access can be granted at the server, queues, and reservations for each of the following entities:

User access

The specified user is allowed access.

Group access

A user in the specified group is allowed access

Host access

A user is allowed access from the specified host

8.3.2 Requirement for Access

In order to have access to a PBS object such as the server or a queue, a user must pass all enabled access control tests: the user must be allowed access, the user's group must be allowed access, and the host where the user is working must be allowed access.

In some cases, Manager or Operator privilege overrides access controls. For some kinds of access, there are no controls. See section 8.3.10, “Operations Controlled by ACLs”, on page 376.

8.3.3 Managing Access via Lists

PBS uses access control lists (ACLs) to manage access to the server, queues, and reservations. There is a separate set of ACLs for the server, each queue, and each reservation. The server enforces the access control policy for User Roles supported by PBS. The policy is hardcoded within the server. ACLs can specify which entities are allowed access and which entities are denied access.

Each server and queue ACL can be individually enabled or disabled by a Manager. If an ACL is enabled, access is allowed or denied based on the contents of the ACL. If the ACL is disabled, access is allowed to all. The contents of each server or queue ACL can be set or altered by a Manager.

Reservation ACLs are enabled only by the reservation creator or the PBS Administrator. The server's resv_enable attribute controls whether reservations can be created. When this attribute is set to *False*, reservations cannot be created.

No default ACLs are shipped.

8.3.4 ACLs

An ACL, or Access Control List, is a list of zero or more entities (users, groups, or hosts from which users or groups may be attempting to gain access) allowed or denied access to parts of PBS such as the server, queues, or reservations. A server ACL applies to access to the server, and therefore all of PBS. A queue's ACL applies only to that particular queue. A reservation's ACL applies only to that particular reservation. The server, each queue, and each reservation has its own set of ACLs.

8.3.4.1 Format of ACLs

Entity access is controlled according to the list of entities allowed or denied access as specified in the object's *acl_<entity>* attribute. The object's access control attribute contains a list of entity names, where each entity name is marked with a plus sign ("+") if the entity is allowed access, and with a minus sign ("-") if the entity is denied access. For example, to allow User1@host1.example.com, and deny User2@host1.example.com:

```
+User1@host1.example.com, -User2@host1.example.com
```

8.3.4.2 Default ACL Behavior

If an entity name is included without either a plus or a minus sign, it is treated as if it has a plus sign, and allowed access.

If an entity name is not in the list, the default behavior is to deny access to the entity. Therefore, if the list is empty but enabled because the object's acl_<entity>_enable attribute is set to *True* (see section 8.3.5, “Enabling Access Control”, on page 367), all entities are denied access.

8.3.4.3 Modifying ACL Behavior

You can specify how an ACL treats an unmatched entity by including special flags in the ACL itself. These are the plus and minus signs.

To allow access for all unmatched entities (the reverse of the default behavior), put a plus sign ("+") anywhere by itself in the list. For example:

```
+User1@host1.example.com, +, -User2@host1.example.com
```

To deny access for all unmatched entities (the default behavior), put a minus sign ("-") anywhere by itself in the list. For example:

```
+User1@host1.example.com, -, -User2@host1.example.com
```

If there are entries for both a plus and a minus sign, the last entry in the list (closest to the rightmost side of the list) will control the behavior of the ACL.

8.3.4.4 Contents of User ACLs

User ACLs contain a username and hostname combination.The subject's username and hostname combination is compared to the entries in the user ACL. Usernames take this form:

User1@host.domain.com

User1@host.subdomain.domain.com

User names can be wildcarded. See section 8.3.4.7, "Wildcards In ACLs", on page 366.

8.3.4.5 Contents of Group ACLs

Group ACLs contain names based on the user's groups, as defined by the operating system where the server is executing. All of the user's groups are included. The subject's group names on the server are compared to the entries in the Group ACL. Group names cannot be wildcarded.

8.3.4.6 Contents of Host ACLs

Host ACLs contain fully-qualified hostnames. The subject's host name is compared to the entries in the host ACL. To find the fully-qualified name of a host, use the `pbs_hostn` command. See "pbs_hostn" on page 64 of the PBS Professional Reference Guide.

Hostnames can be wildcarded. See the following section.

8.3.4.7 Wildcards In ACLs

Usernames and hostnames can be wildcarded. The hostname portion of the username is wildcarded exactly the same way a hostname is wildcarded. The non-hostname portion of a username cannot be wildcarded.

The only character that can be used to wildcard entity names is the asterisk ("*"). Wildcarding must follow these rules:

- The asterisk must be to the right of the at sign ("@")
- There can be at most one asterisk per entity name
- The asterisk must be the leftmost label after the at sign

The following table shows how hostnames are wildcarded:

Table 8-2: How Hostnames Are Wildcarded

Wildcard Use	Meaning
`*.test.example.com`	Any host in the test subdomain in example.com
`*.example.com`	Any host in example.com
`*.com`	Any host in .com
`*`	Any host

The following examples show how wildcarding works in host ACLs:

Example 8-1: To limit host access to host myhost.test.example.com only:

```
myhost.test.example.com
```

Example 8-2: To limit host access to any host in the test.example.com subdomain:

```
*.test.example.com
```

Example 8-3: To limit host access to any host in example.com:

```
*.example.com
```

Example 8-4: To allow host access for all hosts:

```
*
```

The following examples show how wildcarding works in user ACLs:

Example 8-5: To limit user access to UserA requesting from host myhost.test.example.com only:

```
UserA@myhost.test.example.com
```

Example 8-6: To limit user access to UserA on any host in the test.example.com subdomain:

```
UserA@*.test.example.com
```

Example 8-7: To limit user access to UserA on any host in example.com:

```
UserA@*.example.com
```

Example 8-8: To limit user access to UserA from anywhere:

```
UserA@*
```

or

```
UserA
```

Listing a username without specifying the host or domain is the equivalent of listing the username followed by "@*". This means that

```
User1
```

is the same as

```
User1@*
```

8.3.4.8 Restrictions on ACL Contents

All access control lists are traversed from left to right, and the first match found is used. It is important to make sure that entries appear in the correct order.

To single out a few, specify those few first, to the left of the other entries.

Example 8-9: To allow all users in your domain except User1 access, the list should look like this:

```
-User1@example.com, +*@example.com
```

Example 8-10: To deny access to all users in your domain except User1, the list should look like this:

```
+User1@example.com, -*@example.com
```

8.3.5 Enabling Access Control

Each server and queue ACL is controlled by a Boolean switch whose default value is *False*, meaning that access control is turned off. When access control is turned off, all entities have access to the server and to each queue. When access control is turned on, access is allowed only to those entities specifically granted access.

To use access control, first set the contents of the ACL, then enable it by setting its switch to *True*.

Reservation ACLs are enabled when the reservation creator sets their contents. Reservation ACLs do not have switches. Reservations use queues, which are regular queues whose ACL values have been copied from the reservation. These queues are not intended to be operated on directly. See section 8.3.8, “Reservation Access”, on page 373.

8.3.5.1 Table of ACLs and Switches

The following table lists the ACLs and their switches, with defaults, for the server, queues, and reservations.

Table 8-3: ACLs and Their Switches

		User (Default Value)	Group (Default Value)	Host (Default Value)
Server	Switch	acl_user_enable (*False*)	None	acl_host_enable (*False*)
	List	acl_users (all users allowed)	None	acl_hosts (all hosts allowed)
Queue	Switch	acl_user_enable (*False*)	acl_group_enable (*False*)	acl_host_enable (*False*)
	List	acl_users (all users allowed)	acl_groups (all groups allowed)	acl_hosts (all hosts allowed)
Reservation	Switch	None	None	None
	List	Authorized_Users (creator only)	Authorized_Groups (creator's group only)	Authorized_Hosts (all hosts allowed)
Reservation queue	Switch	acl_user_enable (*True*)	acl_group_enable (*False*)	acl_host_enable (*False*)
	List	acl_users (creator only)	acl_groups (all groups allowed)	acl_hosts (all hosts allowed)

8.3.6 Creating and Modifying ACLs

Server and queue ACLs follow the same rules for creation and modification. Reservation queue ACLs behave the same way regular queue ACLs do. Reservation ACLs can only be created and modified by the reservation creator and the administrator. See section 8.3.8, “Reservation Access”, on page 373.

8.3.6.1 Rules for Creating and Modifying Server and Queue ACLs

- Server and queue ACLs are created and modified using the `qmgr` command.
- An ACL is a list of entries. When you operate on the list, the first match found, searching from left to right, is used. If there is more than one match for the entity you wish to control, ensure that the first match gives the behavior you want.
- When you create or add to an ACL, you can use the + or - operators to specify whether or not an entity is allowed access. Omitting the operator is equivalent to adding a + operator.
- When you re-create an existing ACL, this is equivalent to unsetting the old ACL and creating a new one.
- When you add to an ACL, the new entry is appended to the end of the ACL, on the right-hand side.
- When you remove an entity from an ACL, you cannot use + or - operators to specify which entity to remove, even if there are multiple entries for an entity and each entry has a different operator preceding it, for example `"-bob, +bob"`.
- When you remove an entity, only the first match found is removed.

8.3.6.2 Examples of Creating and Modifying Server and Queue ACLs

The following examples show the server's user ACL being set. Queue ACLs work the same way as server ACLs, and the equivalent `qmgr` command can be used for queues. So, where we use the following for the server:

```
Qmgr: set server acl_users ...
```

the same effect can be achieved at the queue using this:

```
Qmgr: set queue <queue name> acl_users ...
```

If the queue name is Q1, the qmgr command looks like this:

```
Qmgr: set queue Q1 acl_users ...
```

Example 8-11: To create a server or queue ACL:

```
Qmgr: set <object> <ACL> = <entity list>
```

Example:

```
Qmgr: set server acl_users ="-User1@*.example.com,+User2@*.example.com"
```

ACL looks like this:

```
-User1@*.example.com, +User2@*.example.com
```

Example 8-12: To add to a server or queue ACL:

```
Qmgr: set <object> <ACL> += <entity list>
```

Example:

```
Qmgr: set server acl_users += -User3@*.example.com
```

ACL looks like this:

```
-User1@*.example.com, +User2@*.example.com, -User3@example.com
```

Example 8-13: To remove an entry from an ACL:

```
Qmgr: set <object> <ACL> -= <entity>
```

Example:

```
Qmgr: set server acl_users -= User2@*.example.com
```

ACL looks like this:

```
-User1@*.example.com, -User3@*.example.com
```

Example 8-14: To remove two entries for the same entity from an ACL:

```
Qmgr: set <object> <ACL> -= <entity1, entity1>
```

Example: If ACL contains +A, +B, -C, -A, +D, +A

```
Qmgr: set server acl_users -= "A, A"
```

ACL looks like this:

```
+B, -C, +D, +A
```

Example 8-15: To remove multiple entities from an ACL:

```
Qmgr: set <object> <ACL> -= <entity list>
```

Example: If ACL contains +B, -C, +D, +A

```
Qmgr: set server acl_users -= "B, D"
```

ACL looks like this:

```
-C, +A
```

8.3.6.3 Who Can Create, Modify, Enable, or Disable ACLs

The following table summarizes who can create, modify, enable, or disable ACLs and their associated switches:

Table 8-4: Who Can Create, Modify, Enable, Disable ACLs

ACLs and Switches		Manager	Operator	User
Server ACLs and Switches	Create	Yes	No	No
	Modify	Yes	No	No
	Enable	Yes	No	No
	Disable	Yes	No	No
Queue ACLs and Switches	Create	Yes	Yes	No
	Modify	Yes	Yes	No
	Enable	Yes	Yes	No
	Disable	Yes	Yes	No
Reservation ACLs	Create	Only if reservation creator	Only if reservation creator	When creating reservation
	Modify	Yes, if administrator	No	Yes
	Enable	Creator and administrator	No	When creating reservation
	Disable	No	No	No

Table 8-4: Who Can Create, Modify, Enable, Disable ACLs

ACLs and Switches		Manager	Operator	User
Reservation Queue ACLs and Switches	Create	Yes	Yes	Indirectly when creating reservation
	Modify	Yes	Yes	No
	Enable	Yes	Yes	Indirectly when creating reservation
	Disable	Yes	Yes	Group and host ACLs can be indirectly disabled by user during reservation creation. User ACL cannot be disabled by user.

8.3.6.4 Who Can Operate on Server ACLs

PBS Managers only can create or modify server ACLs and the Boolean switches that enable them.

8.3.6.5 Who Can Operate on Queue ACLs

PBS Managers and Operators, but not users, can create and modify queue ACLs and their Boolean switches.

8.3.6.6 Who Can Operate on Reservation ACLs

When creating a reservation, the reservation creator cannot disable the user ACL, but can choose to enable or disable the group and host ACLs implicitly via the command line, and can specify the contents of all three ACLs. Reservation ACLs can be modified via pbs_ralter or disabled.

8.3.6.7 Who Can Operate on Reservation Queue ACLs

Unprivileged users cannot directly create, modify, enable, or disable reservation queue ACLs or the associated switches. The reservation creator can indirectly create and enable the reservation queue's ACLs during reservation creation. If a user wants to modify a reservation queue's ACLs, they can do so indirectly by deleting the reservation and creating a new one with the desired ACLs.

PBS Managers and Operators can modify, enable, or disable a reservation queue's ACLs.

A reservation queue's user ACL is always enabled unless explicitly disabled after creation by a Manager or Operator.

8.3.7 Server and Queue ACLs

Access control for an entity such as a user, group, or host is enabled by setting the attribute enabling that entity's ACL to *True*. When this attribute is *True*, entity access is controlled according to the list of entities allowed or denied access as specified in the ACL for that entity. The default value for each ACL's switch attribute is *False*, meaning that entity access is not controlled.

8.3.7.1 Server ACLs

The server has a host ACL and a user ACL.

Server access is controlled by these attributes:

- User access: acl_user_enable and acl_users
- Host access: acl_host_enable and acl_hosts

8.3.7.2 Queue ACLs

Each queue has three ACLs: a host ACL, a user ACL, and a group ACL.

Queue access is controlled by these attributes:

- User access: acl_user_enable and acl_users
- Group access (queue only): acl_group_enable and acl_groups
- Host access: acl_host_enable and acl_hosts

8.3.7.3 Access to Server for MoMs

You can specify whether all MoMs should have the same privilege when contacting the server as hosts listed in the acl_hosts server attribute using the acl_host_moms_enable server attribute. If you set this to *True*, all MoMs are allowed privileged access to the server, and you don't need to explicitly add their hosts to the ACL. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

8.3.7.4 Examples of Setting Server and Queue Access

To restrict access to the server or queue, first set the contents of the ACL, then enable the ACL by setting its switch to *True*.

Example 8-16: To allow server access for all users in your domain except User1, and to allow server access for User2 in another domain:

Set the server's acl_users attribute:

```
Qmgr: set server acl_users = "-User1@example.com, +*@example.com,
   +User2@otherdomain.com"
```

Enable user access control by setting the server's acl_user_enable attribute to *True*:

```
Qmgr: set server acl_user_enable = True
```

Example 8-17: To require that users of a queue be in Group1 only:

Set the queue's acl_groups attribute:

```
Qmgr: set queue Queue1 acl_groups = +Group1
```

Enable group access control by setting the queue's acl_group_enable attribute to *True*:

```
Qmgr: set queue Queue1 acl_group_enable = True
```

Example 8-18: To allow access to Queue1 from Host1 only:

Set the queue's acl_hosts attribute:

```
Qmgr: set q Queue1 acl_hosts = +Host1@example.com
```

Enable host access control by setting the queue's acl_host_enable attribute to *True*:

```
Qmgr: set q Queue1 acl_host_enable = True
```

8.3.8 Reservation Access

Advance, job-specific, and standing reservations are intended to be created by job submitters, although managers and operators can create them as well. Maintenance reservations can be created only by managers and operators. The administrator controls whether reservations can be created via the server's resv_enable attribute. When this attribute is set to *True*, reservations can be created.

Reservation ACLs allow or deny access based on group names, usernames, and hostnames. Each reservation has its own access control attributes that can be used to specify which users and groups have access to the reservation, and the hosts from which these users and groups are allowed access. The creator of the reservation sets the lists of users, groups and hosts that have access to the reservation (the reservation ACLs). This is done while creating the reservation, using options to the `pbs_rsub` command.

When you create a reservation ACL, it is automatically enabled; you do not have to explicitly enable it. The reservation's list of authorized users is always enabled during reservation creation. The reservation's lists of authorized groups and authorized hosts are only enabled if explicitly set by the reservation creator. PBS checks for membership in authorized lists only when that ACL is enabled. So for example, if you create a reservation and do not specify a list of authorized groups, no groups are added to the reservation's ACL, but you can submit jobs to the reservation because PBS does not check for group membership.

While you will see that each reservation has its own queue, do not attempt to manipulate reservation queue attributes directly. You operate on the reservation attributes, and PBS manages the queue's attributes, making them mirror those of the reservation. Set or modify reservation attributes using pbs_rsub and pbs_ralter.

8.3.8.1 Meaning of Reservation Access

Access to a reservation via the reservation's ACLs is required for the following actions:

- Submitting a job into the reservation
- Moving a job into the reservation

A job owner can perform the following actions on their own jobs, regardless of ACLs:

- Delete their job
- Hold their job
- Move their job out of the reservation

For example, if an Operator qmoves User1's job into a reservation to which User1 is denied access, User1 can still perform operations on the job such as deleting or holding the job, and User1 can `qmove` the job out of the reservation.

8.3.8.2 Reservation Access Attributes

Reservation access is controlled by the following reservation attributes:

- User access: Authorized_Users
  - Default: the reservation creator only is allowed access
  - This ACL is always enabled
- Group access: Authorized_Groups
  - Default: no groups are allowed access
  - This ACL is enabled only when you specify a list of groups
- Host access: Authorized_Hosts
  - Default: all hosts are allowed access
  - This ACL is enabled only when you specify a list of hosts

8.3.8.3 Setting and Changing Reservation Access

The reservation creator uses options to the pbs_rsub command to set reservation access attributes:

-U <authorized user list>

Comma-separated list of users who are and are not allowed to submit jobs to this reservation. Sets reservation's Authorized_Users attribute to *auth user list*.

This list becomes the acl_users attribute for the reservation's queue.

More specific entries should be listed before more general, because the list is read left-to-right, and the first match determines access. The reservation creator's username is automatically added to this list, whether or not the reservation creator specifies this list.

If both the Authorized_Users and Authorized_Groups reservation attributes are set, a user must belong to both in order to be able to submit jobs to this reservation.

See the Authorized_Users reservation attribute in section 6.8, "Reservation Attributes", on page 305.

Syntax:

[+|-]<username>[@<hostname>][,[+|-]<username>[@<hostname>]...]

Default: Job owner only

-G <authorized group list>

Comma-separated list of names of groups who can or cannot submit jobs to this reservation. Sets reservation's Authorized_Groups attribute to *auth group list*.

This list becomes the acl_groups list for the reservation's queue.

More specific entries should be listed before more general, because the list is read left-to-right, and the first match determines access.

If both the Authorized_Users and Authorized_Groups reservation attributes are set, a user must belong to both in order to be able to submit jobs to this reservation.

Group names are interpreted in the context of the server host, not the context of the host from which the job is submitted.

See the Authorized_Groups reservation attribute in section 6.8, "Reservation Attributes", on page 305.

Syntax:

[+|-]<group name>[,[+|-]<group name> ...]

Default: No groups are authorized to submit jobs

-H <authorized host list>

Comma-separated list of hosts from which jobs can and cannot be submitted to this reservation. This list becomes the acl_hosts list for the reservation's queue. More specific entries should be listed before more general, because the list is read left-to-right, and the first match determines access. If the reservation creator specifies this list, the creator's host is not automatically added to the list.

See the Authorized_Hosts reservation attribute in section 6.8, "Reservation Attributes", on page 305.

Format: *[+|-]<hostname>[,[+|-]<hostname> ...]*

Default: All hosts are authorized to submit jobs

Use the pbs_ralter command to modify existing advance, job-specific, or standing reservations:

-U <authorized user list>

Comma-separated list of users who are and are not allowed to submit jobs to this reservation. Sets reservation's Authorized_Users attribute to *auth user list*.

This list becomes the acl_users attribute for the reservation's queue.

More specific entries should be listed before more general, because the list is read left-to-right, and the first match determines access. The reservation creator's username is automatically added to this list, whether or not the reservation creator specifies this list.

If both the Authorized_Users and Authorized_Groups reservation attributes are set, a user must belong to both in order to be able to submit jobs to this reservation.

See the Authorized_Users reservation attribute in section 6.8, "Reservation Attributes", on page 305.

Syntax:

[+|-]<username>[@<hostname>][,[+|-]<username>[@<hostname>]...]

-G <authorized group list>

Comma-separated list of names of groups who can or cannot submit jobs to this reservation. Sets reservation's Authorized_Groups attribute to *auth group list*.

This list becomes the acl_groups list for the reservation's queue.

More specific entries should be listed before more general, because the list is read left-to-right, and the first match determines access.

If both the Authorized_Users and Authorized_Groups reservation attributes are set, a user must belong to both in order to be able to submit jobs to this reservation.

Group names are interpreted in the context of the server host, not the context of the host from which the job is submitted.

See the Authorized_Groups reservation attribute in section 6.8, "Reservation Attributes", on page 305.

Syntax:

[+|-]<group name>[,[+|-]<group name> ...]

Default: no default

8.3.8.3.i Examples of Setting and Changing Reservation Access

Example 8-19: To disallow access for User1 and allow access for all other users at your domain:

Set reservation's Authorized_Users attribute using the -U option to `pbs_rsub`:

```
pbs_rsub ... -U "-User1@example.com, +*@example.com"
```

Example 8-20: To allow access for Group1 and Group2 only:

Set reservation's Authorized_Groups attribute using the -G option to `pbs_rsub`:

```
pbs_rsub ... -G "+Group1, +Group2"
```

Note that any users in Group1 and Group2 to whom you wish to grant access must be explicitly granted access in the Authorized_Users list.

Example 8-21: To allow access from Host1 and Host2 only:

Set reservation's Authorized_Hosts attribute using the -H option to `pbs_rsub`:

```
pbs_rsub ... -H "+Host1.example.com, +Host2.example.com, -*.example.com"
```

Example 8-22: To allow User2 and User3 access to the the reservation:

Use `pbs_ralter -U` to add User2 and User3 to the the reservation's Authorized_Users attribute:

```
pbs_ralter ... -U "+User2@example.com,+User3@example.com"
```

Example 8-23: To disallow Group3 access to the the reservation:

Use `pbs_ralter -G` to remove Group3 from the the reservation's Authorized_Groups attribute:

```
pbs_ralter ... -G "-Group3@example.com"
```

8.3.8.4 Reservation Queues

While you will see that each reservation has its own queue, do not attempt to manipulate reservation queue attributes directly. You operate on the reservation attributes, and PBS manages the queue's attributes, making them mirror those of the reservation. Set or modify reservation attributes using pbs_rsub and pbs_ralter.

You can move jobs into or out of reservation queues.

8.3.8.4.i Reservation Queue ACLs

If the group or host reservation ACL is specified by the reservation creator, the associated Boolean switch for the reservation queue ACL is set to *True*.

Authorized_Users is always set to the creator and copied to the queue's acl_users attribute, and acl_user_enable is always set to *True*.

If Authorized_Groups is specified by the creator, it is copied to the queue's acl_groups attribute and acl_group_enable is set to *True*. If the reservation creator does not specify a value for Authorized_Groups, nothing is copied to the queue's acl_groups, and acl_group_enable remains at its default value of *False*.

If Authorized_Hosts is specified by the creator, it is copied to the queue's acl_hosts attribute and acl_host_enable is set to *True*. If the reservation creator does not specify a value for Authorized_Hosts, nothing is copied to the queue's acl_hosts, and acl_host_enable remains at its default value of *False*.

The following table shows the relationships between reservation ACLs and reservation queue ACLs:

Table 8-5: Relationship Between Reservation ACLs and Reservation Queue ACLs

Entity	Reservation ACL	Reservation Queue ACL	Reservation Queue ACL Switch
Users	Authorized_Users	acl_users	acl_user_enable
Groups	Authorized_Groups	acl_groups	acl_group_enable
Hosts	Authorized_Hosts	acl_hosts	acl_host_enable

8.3.9 Scope of Access Control

Queue-level ACLs provide different security functionality from that provided by server-level ACLs. Access to PBS commands is controlled by server-level ACLs. For example, access to the `qstat` and `qselect` operations are controlled only at the server level. For unprivileged users, access to a specific queue is controlled through that queue's ACLs.

The users allowed access to a queue or reservation are a subset of the users allowed access to the server. Therefore, if you wish to allow a user access to a queue, that user must also be allowed access to the server. The hosts from which a user may run commands at a queue are a subset of the hosts from which a user may run commands at the server. See "Server Attributes" on page 283 of the PBS Professional Reference Guide, "Queue Attributes" on page 313 of the PBS Professional Reference Guide, and "Reservation Attributes" on page 305 of the PBS Professional Reference Guide.

8.3.10 Operations Controlled by ACLs

ACLs control some operations in PBS, but not others. Manager and Operator privileges override some ACL restrictions.

8.3.10.1 Server Operations Controlled by ACLs

8.3.10.1.i Server Host ACL

If it is enabled, the server host ACL is checked for and controls all server operations, and is honored regardless of privilege. Any request coming from a disallowed host is denied.

8.3.10.1.ii Server User ACL

If it is enabled, the server's user ACL is checked for and controls all server operations, but is overridden by Manager or Operator privilege. This means that the server's user ACL applies only to users, not to Managers or Operators. Even if explicitly denied access in the server's user ACL, a PBS Manager or Operator is allowed access to the server. Note that queue access is controlled separately by queue ACLs; even if Managers or Operators are explicitly denied access in the server's user ACL, if a queue's ACLs are not enabled, Managers and Operators have access to the queue. The same is true for reservations.

8.3.10.2 Queue Operations Controlled by ACLs

If enabled, queue ACLs are applied only when an entity is attempting to enqueue a job. Enqueueing a job can happen in any of three ways:

- Moving a job into the queue
- Submitting a job to the queue
- Routing a job into the queue

Queue ACLs are not applied for non-enqueueing operations, for example:

- Moving a job out of the queue
- Holding a job
- Deleting a job
- Signaling a job
- Getting job status

8.3.10.2.i Queue Host ACL

If a queue's host ACL is enabled, it is checked when an entity attempts to enqueue a job. The host ACL is always honored, regardless of privilege.

8.3.10.2.ii Queue User and Group ACLs

If a queue's user or group ACL is enabled, it is applied when an entity attempts to enqueue a job. Manager and Operator privileges override queue user and group ACLs when an entity attempts to move a job into a queue. This means that a PBS Manager or Operator who is explicitly denied access by the user or group ACL for queue Q1 can still use the qmove command to move a job into Q1, as long as other ACLs allow the operation (the server's user and host ACLs must both allow this).

A queue user or group ACL is applied in the following way:

Table 8-6: How Queue User and Group ACLs Are Applied

Operation	Applied to Users	Applied to Managers/Operators
Moving a job into the queue	Yes	No
Submitting a job to the queue	Yes	Yes
Having a job routed into the queue	Yes	Yes

8.3.10.3 Reservation Operations Controlled by ACLs

Access to a reservation's queue is controlled through its queue's ACLs. A reservation's queue behaves exactly the same way as a regular queue.

8.3.10.4 Table of Operations Controlled by ACLs and Overrides

The following table lists which operations are and are not controlled by server and queue ACLs, and which controls are overridden.

Table 8-7: Operations Controlled by ACLs, and ACL Overrides

Operation	Server ACLs						Queue ACLs								
	Host			User			Host			User			Group		
	Applied	Manager Override	Operator Override	Applied	Manager Override	Operator Override	Applied	Manager Override	Operator Override	Applied	Manager Override	Operator Override	Applied	Manager Override	Operator Override
Move job into queue	Y	N	N	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y
Move job out of queue	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Submit job to queue	Y	N	N	Y	Y	Y	Y	N	N	Y	N	N	Y	N	N
Have job routed into queue	Y	N	N	Y	Y	Y	Y	N	N	Y	N	N	Y	N	N
Delete job	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Hold job	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Release job	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Signal job	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Status job	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Status server	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-
Status queue	Y	N	N	Y	Y	Y	N	-	-	N	-	-	N	-	-

8.3.11 Avoiding Problems

8.3.11.1 Using Group Lists

When a user specifies a group list, each and every group in which that user might execute a job must have a group name and an entry in the groups database, for example, `/etc/group`.

8.3.12 Flatuid and Access

The server's flatuid attribute affects both when users can operate on jobs and whether users without accounts on the server host can submit jobs.

8.3.12.1 How flatuid Controls When Users Can Operate On Jobs

This section describes how the server's flatuid attribute affects the circumstances under which users can operate on jobs.

This attribute specifies whether, for each user, the username at the submission host must be the same as the one at the server host. The username at the server host must always be the same as the username at the execution host. When flatuid is set to *True*, the server assumes that UserA@host1 is the same as UserA@host2. Therefore, if flatuid is *True*, UserA@host2 can operate on UserA@host1's job.

The value of flatuid also affects whether `.rhosts` and `hosts.equiv` are checked. If flatuid is *True*, `.rhosts` and `hosts.equiv` are not queried, and for any users at host2, only UserA is treated as UserA@host1. If flatuid is *False*, `.rhosts` and `hosts.equiv` are queried.

That is, when flatuid is *True*, even if UserB@host2 is in UserA@host1's `.rhosts`, UserB@host2 cannot operate on UserA's job(s). If flatuid is *False*, and UserB@host2 is in UserA@host1's `.rhosts`, UserB@host2 is allowed to operate on UserA's job(s).

Example:

UserA@host1 has a job

UserB@host2 is in UserA@host1's `.rhosts`

a. flatuid = *True*: UserB@host2 cannot operate on UserA's job

b. flatuid = *False*: UserB@host2 can operate on UserA's job

The following table shows how access is affected by both the value of the server's flatuid attribute and whether UserB@host2 is in UserA@host1's `.rhosts`:

Table 8-8: Effect of flatuid Value on Access

	flatuid = *True*		**flatuid = *False***	
UserB@host2 in UserA@host1's `.rhosts`	**Yes**	**No**	**Yes**	**No**
Is UserA@host1 treated as UserA@host2?	Yes	Yes	No	No
`Is .rhosts` queried?	No	No	Yes	Yes
Can UserB operate on UserA's jobs?	No	No	Yes	No

8.3.12.2 How flatuid Affects Users Without Server Accounts

This section describes how the server's flatuid attribute affects users who have no account on the server host.

8.3.12.2.i Linux and flatuid

- If flatuid is set to *False*, users who have no account at the server host cannot submit jobs to PBS.
- If flatuid is set to *True*, these users can submit jobs. However, the job will only run if it is sent to execution hosts where the user does have an account. If the job is sent to execution hosts where the user does not have an account, the job will not run, and the MoM will log an error message.

8.3.12.2.ii Windows and flatuid

Regardless of the value of flatuid , users who have no account at the server host cannot submit jobs to PBS. Users must have an account at the server, and it must have the same password.

8.4 Authentication for Daemons & Users

PBS uses a client-server model for authentication. Note that communication between MoM and comm or PBS server and comm is initiated by MoM or PBS server, not comm. The following table shows the authentication method used for each communication pair:

Table 8-9: Authentication Method Selection

Sender	Recipient	Authentication Method Specified At...
PBS server	Comm	Server (in this case, PBS server)
MoM	Comm	Client (in this case, MoM)
Comm A	Comm B	Client (in this case, comm A)
PBS commands, e.g. `qsub`, `qstat`	PBS server	Client (in this case, the command)

By default, PBS on Linux uses reserved ports for authentication of daemons and users. On Windows, PBS uses `pwd`. You can use other methods such as MUNGE. We use MUNGE for mixed-mode operation.

Authentication is independent of encryption. For encryption, see section 8.5, “Encrypting PBS Communication”, on page 389.

For server-to-scheduler communication, PBS always uses reserved ports for authentication; this is not configurable.

8.4.1 Specifying Allowed Authentication Methods

PBS can use more than one authentication method at the same time. You specify which authentication methods are to be allowed by listing them in the PBS_SUPPORTED_AUTH_METHODS parameter in `pbs.conf` on all PBS hosts. If you leave this field blank, it defaults to "resvport" (reserved ports). If you specify any value, for example "munge", that is the only allowed method. So if you want both reserved ports and MUNGE, use "munge,resvport" (without quotes). This value is used only by the authenticating server, and is ignored by the client.

8.4.1.1 Supported Authentication Methods

You can use any of the following authentication methods/libraries:

MUNGE

resvport (reserved port)

pwd (password, used on Windows)

If you do not configure a method, PBS uses resvport.

8.4.2 Specifying Authentication Method Used by Authentication Client

To specify the default method to be used by an authentication client at a given host, set the PBS_AUTH_METHOD parameter in `pbs.conf` on that host to the desired library/method, for example, "munge". This parameter is case-insensitive.

Make sure that the authentication method you choose for the authentication client is listed in the PBS_SUPPORTED_AUTH_METHODS parameter in `pbs.conf` on the server host. This parameter is also case-insensitive.

The `pbs.conf` parameter is used only by the authentication client.

To override this value, set the authentication method in the PBS_AUTH_METHOD environment variable. Job submitters can set this in their profiles.

Job submitters can use multiple authentication methods. For example, a job submitter in a mixed Linux-Windows complex can submit a Linux job using MUNGE, then set their authentication method to "pwd" and submit a Windows job.

8.4.3 Authentication via Reserved Ports

PBS commands and daemons can call the `pbs_iff` command to authenticate a user or daemon. The `pbs_iff` command runs as a privileged user, binds to a reserved port, and sends a request from the client to the server.

8.4.4 Authentication via MUNGE

You can use the MUNGE authentication daemon to create and validate credentials within a PBS complex. Using MUNGE, the hosts in the PBS complex form a security realm and share a cryptographic key. PBS processes can use MUNGE to authenticate the UID and GID of other processes on hosts in a PBS complex. The client machines in the complex can create and validate credentials without using root privilege, reserved ports, or methods requiring a specific platform.

PBS Professional uses the MUNGE authentication service to authenticate the UID and GID of PBS processes, and to create and validate credentials. Once MUNGE is integrated, communication for PBS commands and daemons is validated via MUNGE. All PBS daemons are authenticated via MUNGE when they try to connect to `pbs_comm`.

The MUNGE key is in `/etc/munge/munge.key.`

8.4.4.1 Steps to Integrate MUNGE with PBS

1. Download and install a supported version of MUNGE on all machines in the PBS complex This includes server, execution, and submission hosts. You can get MUNGE either via your Linux distribution package repositories or from the MUNGE project directly; see https://dun.github.io/munge/.
2. Start MUNGE.
3. Integrate MUNGE with PBS Professional on the PBS server, client, and execution hosts, using either of the following methods:
    a. Edit the PBS configuration file (`/etc/pbs.conf`) and add this line:
    ```
    PBS_AUTH_METHOD=MUNGE
    ```
    The value specified in the PBS_AUTH_METHOD parameter is case-insensitive.
    b. Export the PBS_AUTH_METHOD environment variable:
    ```
    $ export PBS_AUTH_METHOD=MUNGE
    ```
4. Restart the PBS daemons.

8.4.5 Configuring SSSD

8.4.5.1 Configuring SSSD on RHEL 7 and CentOS 7

We show an example of configuring SSSD on RHEL 7 and CentOS 7, using the following steps:

1. Install the required packages:
   a. Install required packages for `sssd`:
   ```
   yum install realmd oddjob oddjob-mkhomedir sssd adcli openldap-clients policycoreutils-python
       samba-common samba-common-tools krb5-workstation
   ```
   b. Check whether `libpam` is already installed on the system. If not, install `libpam`.
   c. The `pam` library name may be `libpam.so.<version>`. If so, you may need to create a soft link:
   ```
   ln -s /usr/lib64/libpam.so.0.83.1 /usr/lib64/libpam.so
   ```
2. Find out whether we are in a domain:
   ```
   realm list
   ```
3. Discover the Active Directory domain for your Windows hosts:
   ```
   realm discover <domain controller hostname>.<domain to join>.com
   <domain to join>.com
   type: kerberos
   realm-name: <domain to join>.COM
   domain-name: <domain to join>.com
   configured: no
   server-software: active-directory
   client-software: sssd
   required-package: oddjob
   required-package: oddjob-mkhomedir
   required-package: sssd
   required-package: adcli
   required-package: samba-common-tools
   ```
4. Add the Linux host to Active Directory:
   ```
   realm join --user=Administrator@<domain to join>.com <domain controller hostname>.<domain to
       join>.com
   ```
5. If no errors are encountered, users should be able to see the domain information:
   ```
   realm list
   type: kerberos
   realm-name: <domain to join>.COM
   domain-name: <domain to join>.com
   configured: kerberos-member
   server-software: active-directory
   client-software: sssd
   required-package: oddjob
   required-package: oddjob-mkhomedir
   required-package: sssd
   required-package: adcli
   ```

```
required-package: samba-common-tools
login-formats: %U@<domain to join>.com
login-policy: allow-realm-logins
```

6. Verify that the Kerberos configuration file `/etc/krb5.conf` and `sssd` configuration file `/etc/sssd/sssd.conf` have the correct domain name specified where required.

7. Set the appropriate permissions for `sssd.conf`:

```
chown root:root /etc/sssd/sssd.conf
chmod 0600 /etc/sssd/sssd.conf
restorecon /etc/sssd/sssd.conf
authconfig --enablesssd --enablesssdauth --enablemkhomedir --update
systemctl start sssd
```

8. In the file `/etc/sssd/sssd.conf`, set use_fully_qualified_names to *False*:

```
use_fully_qualified_names = False
```

9. Restart the `sssd` service:

```
systemctl restart sssd
```

8.4.5.2 Configuring SSSD on RHEL8

Example 8-24: Configuring SSSD on RHEL8:

1. Follow the steps in section 8.4.5.1, “Configuring SSSD on RHEL 7 and CentOS 7”, on page 382
2. Make sure that the following lines are in the `/etc/pam.d/passwd` file; add them if necessary:

```
auth     include  system-auth
account  include  system-auth
```

3. Add the following line to `/etc/sssd/sssd.conf`:

```
access_provider = permit
```

8.4.5.3 Configuring SSSD on Ubuntu 16

Example 8-25: Configuring SSSD on Ubuntu 16:

1. Follow the steps in section 8.4.5.1, “Configuring SSSD on RHEL 7 and CentOS 7”, on page 382
2. Make sure that the following lines are in the `/etc/pam.d/passwd` file; add them if necessary:

```
auth     include  common-auth
account  include  common-auth
```

3. Add the following line to `/etc/sssd/sssd.conf`:

```
access_provider = permit
```

8.4.5.4 Configuring SSSD on Ubuntu 18

Configuring SSSD on Ubuntu 16:

1. Update and install:
   ```
   sudo apt -y update
   sudo apt-get install -y packagekit
   sudo apt install sssd-ad sssd-tools realmd adcli
   ```
2. In `/etc/hosts`, add an entry for the host where AD is configured
3. Discover and join the domain:
   ```
   sudo realm -v discover ad1.example.com
   sudo realm join --user <administrator>@<domain to join>.COM <domain controller hostname>.<domain
       to join>.com
   ```
4. List the newly joined domain:
   ```
   realm list
   sudo pam-auth-update --enable mkhomedir
   ```
5. In the `/etc/sssd/sssd.conf` file, set the following:
   ```
   use_fully_qualified_names = False
   ```
6. Restart `sssd`:
   ```
   service sssd restart
   ```
7. Check whether `sssd` works:
   ```
   id <username>
   su - <username>
   ```

For more information, see https://ubuntu.com/server/docs/service-sssd.

8.4.5.5 Configuring SSSD on SUSE 15

Example 8-26: Configuring SSSD on SUSE 15 in order to connect to a Windows server host:

We use these settings for our example:

- Windows Domain = WINAUTHTEST.COM
- Windows Server Name = advmsetup
- Windows Server IP Address = 10.79.102.6
- AD Administrator user = loginuser
- Test User on AD = servacc

1. Install required packages and their dependencies:

```
zypper ref
zypper in krb5-client samba-client sssd sssd-ad
```

2. Edit /etc/krb5.conf so that it contains the following:

```
includedir /etc/krb5.conf.d
[libdefaults]
# "dns_canonicalize_hostname" and "rdns" are better set to false for improved security.
# If set to true, the canonicalization mechanism performed by Kerberos client may
# allow service impersonification, the consequence is similar to conducting TLS certificate
# verification without checking host name.
# If left unspecified, the two parameters will have default value true, which is less secure.
dns_canonicalize_hostname = false
rdns = false
default_realm = WINAUTHTEST.COM
dns_lookup_realm = false

[realms]
WINAUTHTEST.COM = {
    kdc = advmsetup.winauthtest.com
    master_kdc = advmsetup.winauthtest.com
    admin_server = advmsetup.winauthtest.com
}

[logging]
kdc = FILE:/var/log/krb5/krb5kdc.log
admin_server = FILE:/var/log/krb5/kadmind.log
default = SYSLOG:NOTICE:DAEMON

[domain_realm]
.winauthtest.com = WINAUTHTEST.COM
winauthtest.com = WINAUTHTEST.COM
```

3. Edit /etc/samba/smb.conf. Add the following lines to the global section:

```
[global]
workgroup = WINAUTHTEST
passdb backend = tdbsam
```

```
printing = cups
printcap name = cups
printcap cache time = 750
cups options = raw
map to guest = Bad User
logon path = \\%L\profiles\.msprofile
logon home = \\%L\%U\.9xprofile
logon drive = P:
usershare allow guests = Yes
realm = WINAUTHTEST.COM
security = ADS
template shell = /bin/bash
winbind refresh tickets = yes
winbind use default domain = yes
kerberos method = secrets and keytab
client signing = yes
client use spnego = yes
```

4. Edit /etc/hosts. Add the Windows server IP address and hostname:

```
10.79.102.6 advmsetup.winauthtest.com advmsetup winauthtest.com
10.79.102.22 sles15server2 sles15server2.winauthtest.com
```

5. Add the SLES 15 server to the AD domain:
   a. Run the `kinit` command as administrator:

   ```
   pbsadmin@sles15server:~> kinit loginuser
   Password for loginuser@WINAUTHTEST.COM:
   Warning: Your password will expire in 3 days on Sunday 14 June 2020 02:16:13 PM UTC
   ```

   b. Join the AD domain:

   ```
   pbsadmin@sles15server:~> sudo net ads join -U loginuser -S advmsetup.winauthtest.com
   Enter loginuser's password:
   Using short domain name -- WINAUTHTEST
   Joined 'SLES15SERVER' to dns domain 'winauthtest.com'
   No DNS domain configured for sles15server. Unable to perform DNS Update.
   DNS update failed: NT_STATUS_INVALID_PARAMETER
   ```

   (Ignore the warning you get here for DNS.)

6. Verify that the user is authenticated to the SLES server using `ldapsearch`. This gives the AD attributes:

```
pbsadmin@sles15server:~> /usr/bin/ldapsearch -H ldap://advmsetup.winauthtest.com/ -Y GSSAPI -N -b
    "dc=winauthtest,dc=com" "(&(objectClass=user)(sAMAccountName=servacc))"
SASL/GSSAPI authentication started
SASL username: loginuser@WINAUTHTEST.COM
SASL SSF: 56
SASL data security layer installed.
# extended LDIF
#
# LDAPv3
# base <dc=winauthtest,dc=com> with scope subtree
```

```
# filter: (&(objectClass=user)(sAMAccountName=servacc))
# requesting: ALL
#

# servacc, Users, winauthtest.com
dn: CN=servacc,CN=Users,DC=winauthtest,DC=com
objectClass: top
objectClass: person
objectClass: organizationalPerson
objectClass: user
cn: servacc
givenName: servacc
distinguishedName: CN=servacc,CN=Users,DC=winauthtest,DC=com
instanceType: 4
whenCreated: 20200403032934.0Z
whenChanged: 20200608034248.0Z
displayName: servacc
uSNCreated: 69750
uSNChanged: 335995
name: servacc
objectGUID:: micBdtED4UKRiEl4r2bFCg==
userAccountControl: 66048
badPwdCount: 0
codePage: 0
countryCode: 0
badPasswordTime: 132361895928844770
lastLogoff: 0
lastLogon: 132363412329813043
pwdLastSet: 132325361902386414
primaryGroupID: 513
objectSid:: AQUAAAAAAAUVAAAAcGLL19eyqDlLBPfLvhsAAA==
accountExpires: 9223372036854775807
logonCount: 6695
sAMAccountName: servacc
sAMAccountType: 805306368
userPrincipalName: servacc@winauthtest.com
objectCategory: CN=Person,CN=Schema,CN=Configuration,DC=winauthtest,DC=com
dSCorePropagationData: 20200403033300.0Z
dSCorePropagationData: 16010101000001.0Z
lastLogonTimestamp: 132360613688616817

# search reference
ref: ldap://ForestDnsZones.winauthtest.com/DC=ForestDnsZones,DC=winauthtest,DC
=com

# search reference
```

```
ref: ldap://DomainDnsZones.winauthtest.com/DC=DomainDnsZones,DC=winauthtest,DC
=com

# search reference
ref: ldap://winauthtest.com/CN=Configuration,DC=winauthtest,DC=com

# search result
search: 4
result: 0 Success

# numResponses: 5
# numEntries: 1
# numReferences: 3
```

7. Edit `/etc/sssd/sssd.conf`. You add the domain in the *domain* section. Add the following lines in the *sssd*, *nss*, and *domain* sections:

```
[sssd]
config_file_version = 2
services = nss, pam
# SSSD will not start if you do not configure any domains.
# Add new domain configurations as [domain/<NAME>] sections, and
# then add the list of domains (in the order you want them to be
# queried) to the "domains" attribute below and uncomment it.
; domains = LDAP
domains = winauthtest.com

[nss]

filter_users = root
filter_groups = root
[pam]

[domain/winauthtest.com]
debug_level = 6
id_provider = ad
auth_provider = ad
ad_domain = winauthtest.com
ad_server = advmsetup.winauthtest.com
ad_hostname = advmsetup.winauthtest.com
ldap_id_mapping = True
override_homedir = /home/%u
ldap_schema = ad
default_shell = /bin/bash
use_fully_qualified_names = False
```

8. Edit `/etc/nsswitch.conf`. NSS is used for name resolution. Since we are adding another service to resolve names, that service needs to be added to `/etc/nsswitch.conf`. Add 'sss' to the *passwd* and *group* fields:

```
sles15server:/home/pbsadmin # vi /etc/nsswitch.conf

passwd: compat sss
group: compat   sss
shadow: compat
```

9. Edit /etc/nscd.conf.

   Prevent ncsd from caching so that it doesn't interfere with the sssd password and group caching. If both nscd and sss are caching passwords and groups, the daemons could conflict and AD users would not be resolved. Find the enable-cache option for the password and group and set it to '*no*':

   ```
   enable-cache passwd no
   enable-cache group no
   ```

10. Restart the nscd service:

    ```
    sudo systemctl restart nscd
    ```

11. Start the sssd service:

    ```
    sudo systemctl start sssd
    ```

    You can verify whether sssd is started:

    ```
    ps -eaf | grep sssd ]
    ```

12. Enable authentication through SSSD to AD. Add the sss pam module:

    ```
    pam-config --add --sss
    pam-config --add --mkhomedir
    ```

13. Test user resolution and authentication.

    a. Run the id command to check user name resolution:

       ```
       id servacc
       ```

    b. Switch user to see whether the home directory is created:

       ```
       su - servacc
       ```

For more information on configuring sssd, see https://www.suse.com/support/kb/doc/?id=000019039.

8.5 Encrypting PBS Communication

PBS can encrypt communication sent via commands and between daemons, providing end-to-end encryption. To encrypt your PBS communication, provide the encryption mechanism, and set the PBS_ENCRYPT_METHOD parameter in pbs.conf on all PBS hosts to the method that clients will use. For end-to-end encryption, set it on all PBS hosts.

You may want to use encryption especially for cloud hosts.

TLS encryption is required on Windows.

8.5.1 Supported Encryption Methods

PBS supports TLS for encryption.

8.5.2 Using Transport Layer Security (TLS) for Client-Server Communication

You can use transport layer security (TLS) encryption for a PBS complex that has both Windows and Linux execution hosts, or when you want an extra layer of security. TLS encryption will provide greater security for your client-server connections when one PBS daemon sends a request to another daemon.

Encryption is independent of authentication. For authentication information, see section 8.4, "Authentication for Daemons & Users", on page 380.

8.5.2.1 Overview of Configuring PBS for TLS Encryption

We walk you through the steps to configure PBS for TLS encryption, and we provide example steps here. To summarize:

1. Get or create a CA certificate (the public certificate)
2. Get or create a self-signed TLS certificate
3. Copy the TLS certificate into the appropriate location
4. Generate a private key
5. Edit `pbs.conf` and set TLS as your encryption method
6. Restart PBS

For additional information, see https://www.openssl.org/docs/man1.1.1/man1/openssl-ca-html.

8.5.2.2 Example of Configuring PBS for TLS Encryption

The following steps show an example of configuring PBS for TLS encryption.

1. Log in as root or administrator.

   Perform all of the following steps as root on Linux or Administrator on Windows.
2. Create a configuration file for a certificate using X509v3 extensions.

For this step, make sure you choose options and configuration parameters that meet your requirements. See the OpenSSL documentation for help. In our example, the file is named "my.conf" and the current working directory is `/root/certs`. Contents of `my.conf`:

```
[ cacert ]
subjectKeyIdentifier = hash
authorityKeyIdentifier = keyid:always,issuer
basicConstraints = critical, CA:TRUE
keyUsage = critical, digitalSignature, cRLSign, keyCertSign, keyEncipherment
extendedKeyUsage = clientAuth, serverAuth, emailProtection
nsCertType = server, client, email
nsComment = "CA Certificate Generated By OpenSSL for PBSPro"

[ usrcert ]
subjectKeyIdentifier = hash
authorityKeyIdentifier = keyid:always,issuer:always
basicConstraints = critical, CA:FALSE
keyUsage = critical, nonRepudiation, digitalSignature, keyEncipherment
extendedKeyUsage = clientAuth, serverAuth, emailProtection
nsCertType = server, client, email
nsComment = "User Certificate Generated By OpenSSL for PBSPro"
```

3. Generate your root certificate authority:

```
# openssl genrsa -out rootca.key.pem 4096
# openssl req -new -key rootca.key.pem -out rootca.csr.pem -subj "/O=PBSPro/OU=PBSPro/CN=RootCA/"
# openssl x509 -req -signkey ./rootca.key.pem -extfile ./my.conf -extensions cacert -days 12775
    -in rootca.csr.pem -out rootca.cert.pem
```

4. Generate your intermediate certificate authority:

```
# openssl genrsa -out intca.key.pem 4096
# openssl req -new -key intca.key.pem -out intca.csr.pem -subj "/O=PBSPro/OU=PBSPro/CN=IntCA/"
# openssl x509 -req -CAkey ./rootca.key.pem -CA ./rootca.cert.pem -CAcreateserial -CAserial
    ./serials.txt -extfile ./my.conf -extensions cacert -days 9125 -in intca.csr.pem -out
    intca.cert.pem
```

5. Generate your CA certificate:

```
# cat rootca.cert.pem intca.cert.pem > ca.cert.pem
```

6. Generate certificates for PBS server and communication daemons:

```
# openssl genrsa -out pbspro.key.pem 2048
# openssl req -new -key pbspro.key.pem -out pbspro.csr.pem -subj "/O=PBSPro/OU=PBSPro/CN=PBSProS-
    ervices/"
# openssl x509 -req -CAkey ./intca.key.pem -CA ./intca.cert.pem -CAcreateserial -CAserial ./seri-
    als.txt -extfile ./my.conf -extensions usrcert -days 1825 -in pbspro.csr.pem -out
    pbspro.cert.pem
# openssl verify -CAfile ca.cert.pem pbspro.cert.pem
```

7. Edit PBS configuration files:

On each PBS host (server, scheduler, MoM, comm, client), edit `pbs.conf`, and set the PBS_ENCRYPT_METHOD parameter to "tls" (don't include the quotes). The PBS_ENCRYPT_METHOD parameter is case-insensitive.

8. Make it so we can use the value of PBS_HOME in `pbs.conf`:

```
# source /etc/pbs.conf
```

9. Create certificate directory:

   The PBS server and comms use a certificate key pair stored in a certificate directory.

   On each host running a PBS server or comm, create `PBS_HOME/certs`:

```
# mkdir ${PBS_HOME}/certs
```

10. Copy files into certificate directory:

    a. Copy your `pbspro.cert.pem` file to `${PBS_HOME}/certs/cert.pem`:

```
# cp /root/certs/pbspro.cert.pem ${PBS_HOME}/certs/cert.pem
```

    b. Copy your `pbspro.key.pem` file to `${PBS_HOME}/certs/key.pem`:

```
# cp /root/certs/pbspro.key.pem ${PBS_HOME}/certs/key.pem
```

11. Set permissions and ownership for certificate directory:

    a. Make sure that permissions for the certificate directory and its contents are *0600:*

```
# chmod -R 0600 ${PBS_HOME}/certs
```

    b. Make sure the owner is root on Linux or Administrator on Windows:

```
# chown -R root: ${PBS_HOME}/certs
```

12. Install CA certificate file:

    On each host running a PBS server or comm, install the file in `/etc/pbs_ca.pem` (Linux), or `<PBS installation directory>/pbs_ca.pem` (Windows). For example, if PBS is installed on Windows in `C:\Program Files (x86)\PBS`, you'd put the file there.

    Copy your `/root/certs/ca.cert.pem` file to `/etc/pbs_ca.pem`:

```
# cp /root/certs/ca.cert.pem /etc/pbs_ca.pem
```

13. Set permissions and ownership for CA certificate file:

    a. Make sure the permissions for the file are *0644:*

```
# chmod -R 0644 /etc/pbs_ca.pem
```

    b. Make sure the owner is root on Linux or Administrator on Windows:

```
# chown -R root: /etc/pbs_ca.pem
```

14. Restart PBS daemons:

    - On every Linux host in the complex:

```
# <path to start/stop script>/pbs restart
```

      or

```
# systemctl start pbs
```

    - On every Windows execution host in the complex:

```
net stop pbs_mom
net start pbs_mom
```

8.6 Restricting Execution Host Access

You can configure each PBS execution host so that the only users who have access to the machine are those who are running jobs on the machine. You can specify this by adding the $restrict_user parameter to the MoM configuration file `PBS_HOME/mom_priv/config`. This parameter is a Boolean, which if set to *True*, prevents any user not running a job from running any process on the machine for more than 10 seconds. The interval between when PBS applies restrictions depends upon MoM's other activities, but can be no more than 10 seconds.

You can specify which users are exempt from this restriction by adding the $restrict_user_exceptions parameter to the same file. See the description of the parameter in the next section.

You can allow system processes to run by specifying the maximum numeric user ID allowed access to the machine when not running a job. You do this by adding the $restrict_user_maxsysid parameter to the MoM configuration file. PBS automatically tries to allow system processes to run: if $restrict_user is enabled and $restrict_user_maxsysid is unset, PBS looks in `/etc/login.defs for` SYSTEM_UID_MAX for the value to use. If there is no maximum ID set there, it looks for SYSTEM_MIN_UID, and uses that value minus 1. Otherwise PBS uses the default value of *999*. See section 15.4.7, "Restricting User Access to Execution Hosts", on page 558 and "$restrict_user {True | False}" on page 247 of the PBS Professional Reference Guide.

Access to `pbs_mom` is controlled through a list of hosts specified in the $clienthost parameter in the `pbs_mom's` configuration file. By default, only "localhost", the name returned by `gethostname(2)`, and the host named by `PBS_SERVER` from `/etc/pbs.conf` are allowed. See "MoM Parameters" on page 241 of the PBS Professional Reference Guide for more information on the configuration file.

8.6.1 MoM Access Configuration Parameters

These are the configuration parameters in `PBS_HOME/mom_priv/config` that can be set to restrict and specify access to each execution host. Each execution host has its own configuration file.

$clienthost

List of hosts which are allowed to connect to MoM as long as they are using a privileged port. For example, this allows the hosts "fred" and "wilma" to connect to MoM:

```
$clienthost fred
$clienthost wilma
```

The following hostnames are added to $clienthost automatically: the server, the localhost, and if configured, the secondary server. The server sends each MoM a list of the hosts in the nodes file, and these are added internally to *$clienthost*. None of these hostnames need to be listed in the configuration file.

Two hostnames are always allowed to connect to `pbs_mom`, "`localhost`" and the name returned to MoM by the system call `gethostname()`. These hostnames do not need to be added to the MoM configuration file.

The hosts listed as "clienthosts" make up a "sisterhood" of machines. Any one of the sisterhood will accept connections from within the sisterhood. The sisterhood must all use the same port number.

$restrict_user <value>

Controls whether users not submitting jobs have access to this machine. When *True*, only those users running jobs are allowed access.

Format: Boolean

Default: off

$restrict_user_exceptions <user_list>

List of users who are exempt from access restrictions applied by $restrict_user. Maximum number of names in list is 10.

Format: Comma-separated list of usernames; space allowed after comma

$restrict_user_maxsysid <value>

Allows system processes to run when $restrict_user is enabled. Any user with a numeric user ID less than or equal to value is exempt from restrictions applied by $restrict_user.

Format: Integer

Default: 999

8.6.2 Examples of Restricting Access

To restrict user access to those running jobs, add:

```
$restrict_user True
```

To specify the users who are allowed access whether or not they are running jobs, add:

```
$restrict_user_exceptions <user list>
```

For example:

```
$restrict_user_exceptions User1, User2
```

To allow system processes to run, specify the maximum numeric user ID by adding:

```
$restrict_user_maxsysid <user ID>
```

For example:

```
$restrict_user_maxsysid 999
```

8.7 Access to Schedulers

Access to `pbs_sched` is not limited other than it must be from a privileged port.

8.8 Changing the PBS Service Account Password

Normally, the password for the PBS service account on Windows should not be changed. But if it is necessary to change it, perhaps due to a security breach, then do so using the following steps:

1. Change the PBS service account's password on one machine in a command prompt from an admin-type of account by typing:

   Domain environments:

   ```
   net user <name of PBS service account> * /domain
   ```

   Non-domain environment:

   ```
   net user <name of PBS service account> *
   ```

2. Provide the Service Control Manager (SCM) with the new password given above. Do this either using the GUI-based Services application which is one of the Administrative Tools, or by unregistering and re-registering the PBS services with the password. See “pbs_account” on page 54 of the PBS Professional Reference Guide.

   To unregister:

   ```
   pbs_account --unreg "\Program Files (x86)\PBS\exec\sbin\pbs_mom.exe"
   ```

   To re-register:

   ```
   pbs_account --reg "\Program Files (x86)\PBS\exec\sbin\pbs_mom.exe"
   ```

When re-registering, you can give an additional -p password argument to the `pbs_account` command, to specify the password on the command line.

8.9 Paths and Environment Variables

A significant effort has been made to ensure the various PBS components themselves cannot be a target of opportunity in an attack on the system. The two major parts of this effort are the security of files used by PBS and the security of the environment. Any file used by PBS, especially files that specify configuration or other programs to be run, must be secure. The files must be owned by root and in general cannot be writable by anyone other than root.

A corrupted environment is another source of attack on a system. To prevent this type of attack, each component resets its environment when it starts. If it does not already exist, the `environment` file is created during the install process. As built by the install process, it will contain a very basic path and, if found in root's environment, the following variables:

- TZ
- LANG
- LC_ALL
- LC_COLLATE
- LC_CTYPE
- LC_MONETARY
- LC_NUMERIC
- LC_TIME

The `environment` file may be edited to include the other variables required on your system.

The entries in the `PBS_ENVIRONMENT` file can take two possible forms:

```
variable_name=value
variable_name
```

In the latter case, the value for the variable is obtained before the environment is reset.

8.9.1 Path Caveats

Note that PATH must be included. This value of PATH will be passed on to batch jobs. To maintain security, it is important that PATH be restricted to known, safe directories. Do NOT include "." in PATH. Another variable which can be dangerous and should not be set is IFS.

8.10 File and Directory Permissions

Each parent directory above `PBS_HOME` must be owned by root and writable by root only. All files and directories used by PBS should be writable by root only. Permissions should allow read access for all files and directories except those that are private to the daemons. The following should not be writable by any but root:

```
PBS_HOME/mom_priv
<sched_priv directory>
PBS_HOME/server_priv
```

The `PBS_HOME` directory must be readable and writable from server hosts by root (Administrator) on Linux.

On Windows, `PBS_HOME` must have Full Control permissions for the local "Administrators" group on the local host.

PBS checks permissions for certain files and directories. The following error message is printed for certain files and directories (e.g. /etc/pbs.conf, /var/spool/PBS/mom_priv/config, etc.) if their permissions present a security risk:

```
<command>: Not owner (1) in chk_file_sec, Security violation "<directory>" resolves to
   "<directory>"
<command>: Unable to configure temporary directory.
```

8.11 Root-owned Jobs

The server will reject any job which would execute under the UID of zero unless the owner of the job, typically root, is listed in the server attribute acl_roots.

In order to submit a job from a root account on the local host, be sure to set acl_roots. For instance, if user foo has root privilege, you need to set:

```
Qmgr: set server acl_roots += foo
```

in order to submit jobs and not get a "bad UID for job execution" message.

Windows Administrators are not considered to have root access, so a Windows Administrator can run a job without being listed in acl_roots.

8.11.1 Caveats for Root-owned Jobs

Allowing root jobs means that they can run on a configured host under the same account which could also be a privileged account on that host.

8.12 Passwords

PBS has different password requirements dictated by the Linux and Windows operating systems. Jobs submitted on Linux systems do not require passwords. Jobs on Windows MoM systems require passwords.

See the PBS Professional 2021.1.2 release notes for a list of supported architectures.

8.12.1 Windows User Passwords

Windows execution host systems require a password for PBS to run a process as the user, so users on these systems must supply a password. Users cache their passwords via the pbs_login command. Job submitters run the pbs_login command once per submission host, initially and for each password change.

8.12.2 Changing the PBS Service Account Password

Normally, the PBS service account password should not be changed. But if it is necessary to change it perhaps due to a security breach, then do so using the following steps:

1. Change the PBS service account's password on a machine in a command prompt from an admin-type of account by typing:

   ```
   net user <name of PBS service account> * /domain
   ```

2. Provide the Service Control Manager (SCM) with the new password specified above. This can be done via the GUI-based Services application found as one of the Administrative Tools, or by unregistering and re-registering the PBS MoM with the new password.

   ```
   pbs_account --unreg "\Program Files (x86)\PBS\exec\sbin\pbs_mom.exe"
   pbs_account --reg "\Program Files (x86)\PBS\exec\sbin\pbs_mom.exe"
   ```

   The register form (last line above) can take an additional argument `-p password` so that you can specify the password on the command line directly.

3. Run the `pbs_login` command:

   ```
   pbs_login -m <PBS service account password>
   ```

4. Restart MoM:

   ```
   net stop pbs_mom
   net start pbs_mom
   ```

8.12.2.1 Caveats for Changing Service Account Password

Using `pbs_account --unreg` and `pbs_account--reg` stops and restarts MoM, which can kill jobs.

8.13 Windows Firewall

Under Windows, the Windows Firewall may have been turned on by default. If so, it will block incoming network connections to all services including PBS. Therefore after installing PBS Professional, to allow `pbs_mom` to accept incoming connections:

Access *Settings->Control Panel->Security Center->Windows Firewall*, and verify that the Windows Firewall has been set to "*ON*" to block incoming network connections.

From this panel, you can either turn Windows Firewall "*off*", or click on the *Exceptions* tab and add the following to the list:

```
[INSTALL PATH]\exec\sbin\pbs_mom.exe
```

8.14 Logging Security Events

Each PBS daemon logs security-related events, at event class 32 (0x0020) or at event class 128 (0x0080). For information about daemon logfiles, see section 15.3, “Event Logging”, on page 548.

8.14.1 Events Logged at Event Class 32 (0x0020)

The following security-related events are logged at decimal event class 32 (0x0020):

- When an execution host has access restrictions in place via the $restrict_user configuration parameter, and MoM detects that a user who is not exempt from access restriction is running a process on the execution host, MoM kills that user's processes and writes a log message:

  ```
  01/16/2006 22:50:16;0002;pbs_mom;Svr;restrict_user;
  killed uid 1001 pid 13397(bash) with log event class PBSE_SYSTEM.
  ```

  See section 8.6, "Restricting Execution Host Access", on page 393.

- If for some reason the access permissions on the PBS file tree are changed from their default settings, a daemon may detect this as a security violation, refuse to execute, and write an error message in the corresponding log file. The following are examples of each daemon's log entry:

  ```
  Server@<host>: Permission denied (13) in chk_file_sec, Security violation
      "/var/spool/pbs/server_priv/jobs/" resolves to "/var/spool/pbs"
  pbs_mom: Permission denied (13) in chk_file_sec, Security violation
      "/var/spool/pbs/mom_priv/jobs/" resolves to "/var/spool/pbs"
  pbs_sched: Permission denied (13) in chk_file_sec, Security violation "/var/spool/pbs/sched_priv"
      resolves to "/var/spool/pbs"
  ```

A Manager can run `pbs_probe` (on Linux) or `pbs_mkdirs` (on Windows) to check and optionally correct any directory permission or ownership problems.

- When a user without a password entry (an account) on the server attempts to submit a job, the server logs this event. The following is an example log entry:

  ```
  8/21/2009 15:28:30;0080;Server@capella;Req;req_reject;Reject reply code=15023, aux=0, type=1,
      from User1@host1.example.com
  ```

- If a daemon detects that a file or directory in the PBS hierarchy is a symbolic link pointing to a non-secure location, this is written to the daemon's log. The resulting log message is the same as for a permission violation:

  ```
  Server@<host>: Permission denied (13) in chk_file_sec, Security violation
      "/var/spool/pbs/server_priv/jobs/" resolves to "/var/spool/pbs"
  pbs_mom: Permission denied (13) in chk_file_sec, Security violation
      "/var/spool/pbs/mom_priv/jobs/" resolves to "/var/spool/pbs"
  pbs_sched: Permission denied (13) in chk_file_sec, Security violation "/var/spool/pbs/sched_priv"
      resolves to "/var/spool/pbs"
  ```

- If an $action script is to be executed for a job belonging to a user who does not have an account on an execution host, the execution host's MoM logs this event. The following is an example log entry:

  ```
  08/21/2009 16:06:49;0028;pbs_mom;Job;2.host1;No Password Entry for User User1
  ```

- When a job triggers an action script for which the environment cannot be set up, perhaps due to a system error, the MoM attempting to run the action script logs the event. The log message contains the following:

  ```
  :<job ID>:failed to setup dependent environment!
  ```

- When the scheduler attempts to run a job on an execution host where the job's owner does not have an account, the MoM on the execution host logs this event. The following is an example log entry:

  ```
  08/21/2009 15:51:14;0028;pbs_mom;Job;1.host1;No Password Entry for User User1
  ```

- When the scheduler attempts to run a job on an execution host where the job's owner does not have a home directory, and when the job would use that home directory, the execution host's MoM logs this event. The log message contains the following:

  ```
  Access from host not allowed, or unknown host: <numeric IP address>
  ```

See “pbs_mom” on page 72 of the PBS Professional Reference Guide.

- If an attempt is made to connect to a host in the PBS complex from an unknown host, the PBS daemon logs the information at both levels 32 and 128 (0x0020 and 0080).

8.14.1.1 Events Logged at Event Class 128 (0x0080)

The following security-related event is logged at event class 128 (0x0080):

- If an attempt is made to connect to a host in the PBS complex from an unknown host, the PBS daemon logs the information at both levels 32 and 128 (0x0020 and 0080).
- If a user or Operator tries to set an attribute that can be set by Managers only, or attempts to create or delete vnodes:

  The `qmgr` command returns this error message:

  ```
  qmgr obj=<object> svr=default: Unauthorized Request
  qmgr: Error (15007) returned from server
  ```

  The server logs the following message:

  ```
  Req;req_reject;Reject reply code=15007, aux=0, type=9, from <username>
  ```
- When a user is denied access to the server because of the contents of the acl_users server attribute, the server logs the following:

  ```
  Req;req_reject;Reject reply code=15007, aux=0, type=21, from username@host.domain.com
  ```

8.14.1.2 Events Logged at Event Class 1

- When an attempt is made to contact MoM from a non-privileged port for a request requiring a privileged port, MoM logs the following:

  ```
  pbs_mom;Svr;pbs_mom;Unknown error: 0 (0) in rm_request, bad attempt to connect message refused
      from port 61558 addr 127.0.0.1
  ```

8.14.1.3 Events Not Logged

The following events are not logged:

- When an attempt is made to connect to a host in the PBS complex from a disallowed host
- When an ACL check denies an entity access to a PBS object
- A user tries to query other users' jobs when the server's query_other_jobs attribute is set to *False*
- When an Operator or Manager overrides the server's user ACL

8.15 Securing Containers

- Use the security enhancement named "pbs_container"; see section 18.4.4, “Configure Security Enhancement for Docker”, on page 633.
- Make sure that when you are configuring the container hook, if you whitelist any container arguments in the container_args_allowed hook configuration parameter, do not whitelist "--group-add". This would allow job submitters to add themselves to any groups inside the container. Instead, set the enable_group_add_arg hook parameter to *True* so the hook automatically adds the job owner to groups in the container; these are the groups on the execution host to which the job owner already belongs. See section 18.4.2, “Configure PBS Container Hook”, on page 629.

9

Making Your Site More Robust

This chapter describes how to configure PBS to make your site more robust.

9.1 Robustness

PBS provides the following mechanisms that support site robustness and flexibility:

Failover

The PBS complex can run a backup server. If the primary server fails, the secondary takes over without an interruption in service.

Checkpoint and Restart

Allows jobs to be checkpointed and restarted. Uses OS-provided or third-party checkpoint/restart facility.

Reservation Fault Tolerance

PBS attempts to ensure that reservations run by finding usable vnodes when reservation vnodes become unavailable.

Vnode Fault Tolerance for Job Start and Run

PBS lets you allocate extra vnodes at job startup or for the life of the job, to compensate for vnode failure and allow the job to successfully start or run on the required number of vnodes.

Preventing Communication and Timing Problems

PBS allows setting parameters to prevent problems in communication, timing, and load on vnodes.

Preventing File System Problems

PBS gives you tools to prevent file system problems.

OOM Killer Protection

PBS is installed so that daemons are protected from an OOM killer.

9.2 Failover

9.2.1 Glossary

Primary Server

The PBS Professional server daemon which is running during normal operation.

Secondary Server

The PBS Professional server daemon which takes over when the primary server fails.

Primary Scheduler

The PBS Professional scheduler daemon which is running during normal operation.

Secondary Scheduler

The PBS Professional scheduler daemon which takes over when the primary scheduler is not available.

Active

A server daemon is active when it is managing user requests and communicating with the scheduler and MoMs.

Idle

A server daemon is idle when it is running, but only accepting handshake messages, not performing workload management.

9.2.2 How Failover Works

During normal operation, the primary server is active and the secondary server is idle. If the primary server fails for any reason, the secondary server becomes active and takes over server functions for the complex. No work is lost during the transition between servers. PBS functions the same during failover as it does during normal operation. The PBS data service is considered to be part of the PBS server; if it fails, this triggers failover.

9.2.2.1 Primary and Secondary Schedulers

Each server is paired with and uses its own scheduler. If the secondary server becomes active, it starts its own scheduler.

9.2.2.2 Primary and Secondary Data Services

Each server is paired with and uses its own data service. If the secondary server becomes active, it starts its own data service.

9.2.2.3 Normal Post-configuration Behavior

After you have configured PBS for failover, and started both servers, the secondary server periodically attempts to connect to the primary server until it succeeds and registers itself with the primary server. The secondary server must be registered in order to take over upon failure of the primary server.

9.2.2.4 Behavior During Failover

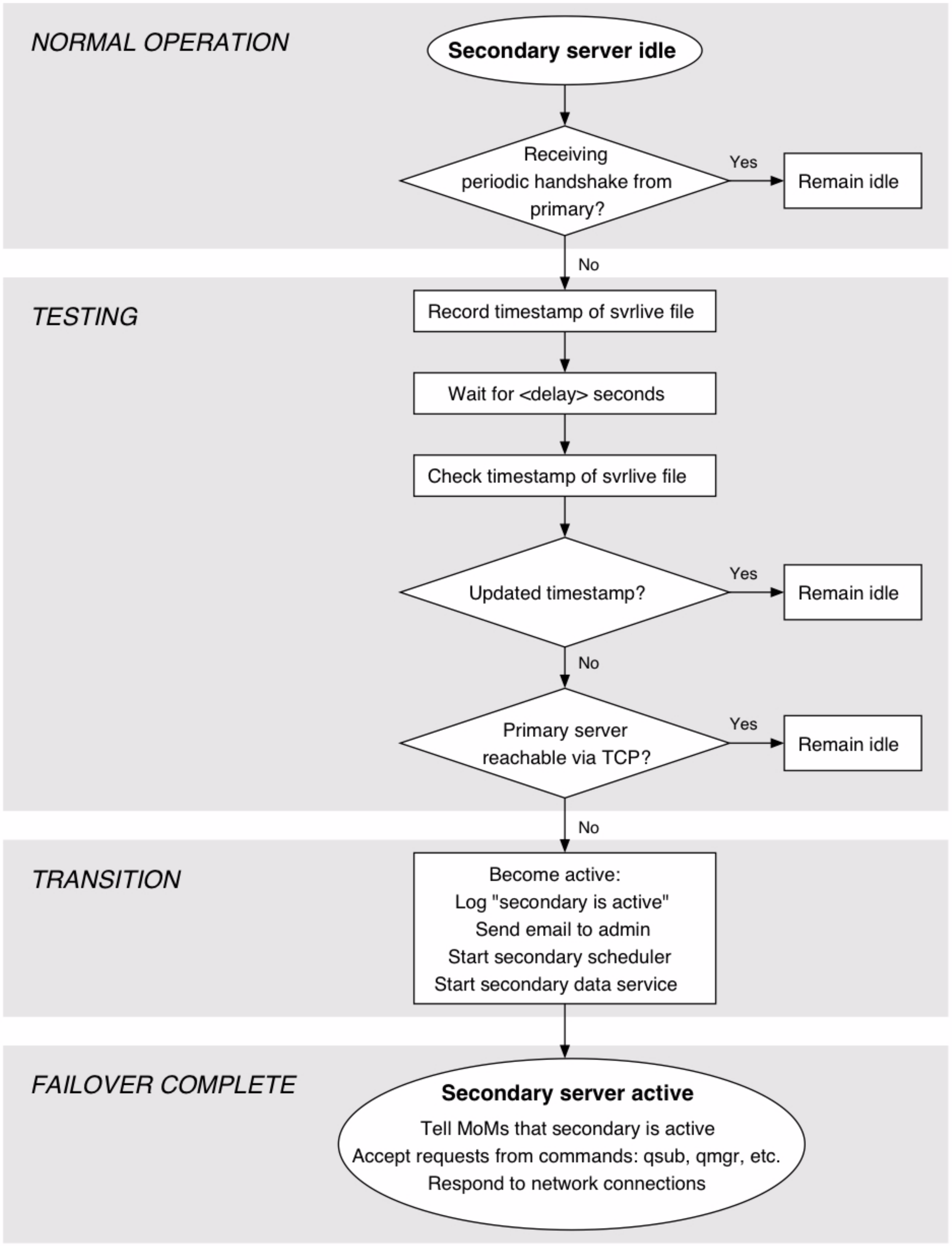

NORMAL OPERATION
Secondary server idle
Receiving periodic handshake from primary?
Yes
Remain idle
No
TESTING
Record timestamp of svrlive file
Wait for <delay> seconds
Check timestamp of svrlive file
Updated timestamp?
Yes
Remain idle
No
Primary server reachable via TCP?
Yes
Remain idle
No
TRANSITION
Become active:
Log "secondary is active"
Send email to admin
Start secondary scheduler
Start secondary data service
FAILOVER COMPLETE
Secondary server active
Tell MoMs that secondary is active
Accept requests from commands: qsub, qmgr, etc.
Respond to network connections

Figure 9-1:Behavior During Failover

When both server daemons are running, the primary server sends periodic handshake messages to the secondary. The primary server also periodically updates the timestamp of the `PBS_HOME/server_priv/svrlive` file. If the secondary server stops receiving handshake messages from the primary server, the following happens:

- The secondary server waits for a specified delay period before taking over. This delay is specified using the `pbs_server -F` option. The default period is 30 seconds.
  - The secondary server reads the timestamp of the `PBS_HOME/server_priv/svrlive` file and stores it in memory
  - The secondary waits for the specified delay, then checks the time stamp again, and compares it to the timestamp it stored in memory
  - If the timestamp has changed, the secondary server remains idle
  - If the timestamp has not changed, the secondary attempts to open a new TCP connection to the primary
  - If the secondary server cannot open a TCP connection to the primary, the secondary becomes active
- The secondary server logs a message saying that failover has occurred.
- An email is sent to and from the account defined in the server's mail_from attribute, saying that failover has occurred.
- The secondary server starts the secondary scheduler on the secondary server host.
- The secondary server starts the secondary data service on the secondary server host.
- The secondary server notifies all of the MoMs that it is the active server.
- The secondary server begins responding to network connections and accepting requests from client commands such as qstat and `qsub`.

9.2.2.5 Delay During Failover Transition

The default delay between when the primary becomes unavailable and the secondary takes over is about 5 minutes. You can change this using `pbs_server -F <seconds>`. If you use `pbs_server -F -1`, the secondary makes only one attempt to contact the primary, then takes over. We include these instructions in the configuration steps.

9.2.2.6 Behavior When Primary Resumes Control

When the primary server starts back up, it takes control from the secondary server, becoming the active server. The secondary server becomes idle and resumes listening for the regular handshake messages from the primary server.

The primary server may have been stopped for any of several reasons. The restart method will vary accordingly. If the host was stopped, the PBS server is restarted automatically when the host is started. If the host is still up but the server was stopped, restart the server. See "Starting Servers With Failover" on page 163 in the PBS Professional Installation & Upgrade Guide.

The primary server uses only its own scheduler and data service. When the primary server resumes control, it starts a scheduler and data service, and stops the secondary scheduler and data service. No data is lost in the transition.

When the primary has taken control, the secondary logs a message saying so:

```
received takeover message from primary, going inactive
```

9.2.2.7 Server Name and Job IDs During Failover

The server name and job IDs do not change when the secondary server is active. For example, the primary server is on a host named *PrimaryHost.example.com*, and the secondary server is on a host named *SecondaryHost.example.com*. When the primary server is active, the server name is *PrimaryHost*, jobs are given job IDs of the form *NNNN.PrimaryHost*, and the value of the server_host server attribute is *PrimaryHost.example.com*. When the secondary server is active, the server name is still *PrimaryHost*, jobs are still given job IDs of the form *NNNN.PrimaryHost*, but the value of server_host is *SecondaryHost.example.com*.

The table below summarizes the server name, value of server_host and the IDs given to jobs, when either the primary or secondary server is active.

Table 9-1: Server Name, Job ID and Value of server_host Depending on Which Server is Active

	Active Server	
	Primary	**Secondary**
Hostname	*PrimaryHost.example.com*	*SecondaryHost.example.com*
Server Name	*PrimaryHost*	*PrimaryHost*
Value of server_host	*PrimaryHost.example.com*	*SecondaryHost.example.com*
Job Name	*NNNN.PrimaryHost*	*NNNN.PrimaryHost*

9.2.2.8 Information Used by Primary and Secondary Servers

The primary and secondary servers share a single source for attribute information, so anything set via the `qmgr` command need only be set once. `PBS_HOME` is in a shared location. License information is shared and needs to be set at only one server.

Each server, execution and client host uses its own `pbs.conf` file, so these must be set for each host in the complex.

9.2.2.9 Impact on Users

Users may not notice when a failover occurs. When a user uses a PBS command such as `qstat`, the command tries to connect to the primary server first. If that fails, the command tries the secondary server. There may be up to a two-minute delay in server commands while failover is taking place.

If the secondary server responds to the command, the command creates a local file so that this process is not repeated for every PBS command.

The file is named:

```
/tmp/.pbsrc.UID
```

where *UID* is the user ID.

When this file exists, commands try the secondary server first, eliminating the delay in attempting to connect to the down server. If a command cannot connect to the secondary server, and can connect to the primary server, the command removes the file.

The file is removed when the primary server takes over.

9.2.2.10 Determining Which Server Is Active

The server attribute server_host contains the name of the host on which the active server is running. Use the `qstat -Bf` command to see the value of server_host.

9.2.2.11 Delay Between Primary Failure and Secondary Becoming Active

The default delay time from detection of possible primary server failure until the secondary server takes over is 30 seconds. A secondary server on a very reliable network can use a shorter delay. A secondary server on an unreliable network may need to use a longer delay. The delay is specified via the -F option to the `pbs_server` command.

9.2.2.12 Communication

If PBS is configured for failover, each server host runs a `pbs_comm`. Note that communication traffic is handled independently of failover behavior. During normal operation, the comm on the primary server host handles communication traffic, but if that comm becomes unavailable, the comm on the secondary automatically takes over the communication traffic. You do not need to perform any configuration to get this behavior; the communication daemons are automatically configured for you. See "Failover and Communication Daemons" on page 52 in the PBS Professional Installation & Upgrade Guide.

9.2.2.12.i Communication with MoMs

- If a MoM will see different server addresses, add a $clienthost entry to MoM's configuration file for each possible server address.
- The secondary server is automatically added to the list of hosts allowed to connect to MoMs, in the $clienthost MoM configuration parameter.

9.2.3 Windows Locations

PBS is installed on Windows systems in `\Program Files (x86)\PBS\`.

9.2.4 Prerequisites for Failover

9.2.4.1 Checklist of Prerequisites for Failover

The following table contains a checklist of the prerequisites for failover. Each entry has a link to more detailed information about the entry.

Table 9-2: Prerequisites for Failover

Prerequisite	Explanation
Identical server hosts	See section 9.2.4.2, "Server Host Requirements", on page 407
MoMs on server hosts don't share a `mom_priv` directory	See section 9.2.4.3, "Requirements for MoMs on Server Hosts", on page 407
All hosts must be able to communicate over the network	See section 9.2.4.4, "Ensuring Communication Between Hosts", on page 408
All hosts must be able resolve hostnames of other hosts in complex	See section 9.2.4.5, "Hostname Resolution", on page 408
Filesystem must be shared, on a separate host from either server host, and provide features required for failover; no root squash on shared filesystem	See section 9.2.4.6, "Shared Filesystem", on page 408
Administrator must have access to filesystem from both server hosts	See section 9.2.4.7, "Permission Requirements", on page 409
Same version of PBS for all components	See section 9.2.4.8, "Same PBS Versions Everywhere", on page 409
Primary server's scheduler must be able to run when primary server runs	See section 9.2.4.9, "Requirement for Scheduler", on page 409

Table 9-2: Prerequisites for Failover

Prerequisite	Explanation
Data service user account must be the same on both primary and secondary server hosts	See section 9.2.4.10, "Same Data Service Account on Both Server Hosts", on page 409
Data service host must be default	See section 9.2.4.11, "Data Service Host Configuration Requirement", on page 409
User names must be consistent across primary & secondary servers hosts	See section 9.2.4.12, "Consistent User Names", on page 409
The mail_from server attribute specifies an email address that is monitored. Not required, but recommended.	See section 9.2.4.13, "Monitor Server Mail", on page 410

9.2.4.2 Server Host Requirements

The primary and secondary servers must run on two separate host machines. Both host machines must have the same architecture. They must be binary compatible, including word length, byte order, and padding within structures. There must be exactly one primary and one secondary server.

On an HPE 8600, use two different service nodes to run the primary and secondary servers.

9.2.4.3 Requirements for MoMs on Server Hosts

You can run a MoM on both the primary and secondary server hosts, but this is **not** recommended.

If a MoM is to run on both server hosts, the two MoMs must not share the same `PBS_HOME/mom_priv` directory. In addition, it is strongly recommended that the following be true:

- The `mom_priv` directory structure be replicated on a local, non-shared, filesystem. On Windows, MoM already has a local directory on each server host. On Linux, you must create these.

  Replicate the `mom_priv` and `mom_logs` directory structures on the primary server host if they don't exist there already. You must put these in the same location. Do the following on the primary server host:

  ```
  scp -r <existing PBS_HOME/mom_priv> <local PBS_HOME/mom_priv>
  scp -r <existing PBS_HOME/mom_logs> <local PBS_HOME/mom_logs>
  ```

  Replicate the `mom_priv` and `mom_logs` directory structures on the secondary server host if they don't exist there already. You must put these in the same location. Do the following on the secondary server host:

  ```
  scp -r <existing PBS_HOME/mom_priv> <local PBS_HOME/mom_priv>
  scp -r <existing PBS_HOME/mom_logs> <local PBS_HOME/mom_logs>
  ```

- Each MoM use its own, local, `mom_priv` directory structure

  The PBS_MOM_HOME entry in `pbs.conf` specifies the location that contains the `mom_priv` and `mom_logs` directories. If PBS_MOM_HOME is specified in `pbs.conf`, `pbs_mom` uses that location instead of `PBS_HOME`.

  To prevent the MoMs from automatically using the same directory, do one of the following:

  - Recommended: Specify the separate, local PBS_MOM_HOME entry in each server host's `pbs.conf` file (each `pbs_mom` will use the location for `mom_priv` specified in its PBS_MOM_HOME). Give the location of the local `PBS_HOME/mom_priv` that you replicated on each host. You can perform this step now, or later, when editing `pbs.conf` on each server host, in section 9.2.5.3, "Host Configuration for Failover on Linux", on page 413, or section 9.2.5.4, "Host Configuration for Failover on Windows", on page 417.
  - Use the -d option when starting at least one `pbs_mom` to specify that they use the local, non-default locations for `mom_priv`

9.2.4.4 Ensuring Communication Between Hosts

Both the primary and secondary server hosts must be able to communicate over the network with each other and all execution hosts.

Beware of dependencies on remote file systems: The $PBS_CONF_FILE environment variable must point to `pbs.conf`. PBS depends on the paths in `pbs.conf` being available when its start/stop script is executed. PBS will hang if a remote file access hangs, and normal privileges don't necessarily carry over for access to remote file systems. For example, a FAT filesystem mounted via NFS won't support permissions.

9.2.4.5 Hostname Resolution

Hostname resolution must work between each host in the PBS complex. **Make sure that all hosts in the complex** (the primary and secondary server hosts, the file server host, and all execution and client hosts) **are set up so that they can resolve the names of all other hosts in the complex**. If you are not sure whether hostname resolution is working, run the `pbs_hostn` command at each host, testing the hostnames of the other hosts. The `pbs_hostn` command will return the canonical hostname of the specified host.

9.2.4.6 Shared Filesystem

The filesystem you use for the machines managed by PBS should be highly reliable. We recommend, in this order, the following filesystems:

- HA DAS
- DAS, such as `xfs` or `gfs`
- HA NFS
- NFS

`PBS_HOME` is the top directory used by the PBS server. The primary and secondary servers share the same `PBS_HOME` directory. The `PBS_HOME` directory must conform to the following:

- The `PBS_HOME` directory must be available under the same name to both the primary and secondary server hosts.
- The `PBS_HOME` directory must be on a file system which meets the following requirements:
  - It should reside on a different machine from either of the server hosts.
  - It must be shared by the primary and secondary server hosts.
  - It must be reliable. The file system must be always available to both the primary and secondary servers. A failure of the file system will stop PBS from working.
  - The file system protocol must provide file locking support.
  - The file locking daemons must be running.
  - For Linux, the filesystem must support POSIX (Open Group) file semantics.
  - It must support concurrent read and write access from two hosts.
  - It must support multiple export/mounting.
  - No root squash on the shared filesystem.

If your filesystem does not conform to the specifications above, follow the steps in the next sections.

9.2.4.6.i Using NFS Filesystems

When using NFS for `PBS_EXEC`, NFS must be configured to allow root access and to allow `setuid-root` programs to execute from it.

If possible, mount NFS file systems synchronously (without caching) to avoid reliability problems.

NFS filesystems should be hard mounted.

9.2.4.6.ii Setting Up the Shared Filesystem

You can use NFS or another filesystem protocol to set up the shared filesystem on which `PBS_HOME` resides. Examples are Lustre, IBM GPFS, and Red Hat GFS. Make sure your protocol supports:

- Multiple export/mounting
- Simultaneous read/write from two hosts
- File locking support

To set up your file system:

1. Choose a machine for the file server host. This machine must not be either of the server hosts.
2. Make sure the file system is mounted by both the primary and secondary server hosts. For NFS, make sure the file system is hard mounted by both hosts.
3. Make sure the file system can provide file locking. For NFS, the lock daemon, `lockd`, must be running.
4. Make sure that PBS_HOME is available under the same name to both the primary and secondary server hosts.

9.2.4.7 Permission Requirements

The `PBS_HOME` directory must meet the security requirements of PBS. Each parent directory above `PBS_HOME` must be owned by root and writable by root only.

The `PBS_HOME` directory must be readable and writable from both server hosts by the PBS Administrator.

9.2.4.8 Same PBS Versions Everywhere

Both server hosts, all the execution hosts, and all the client hosts must run the same version of PBS Professional.

9.2.4.9 Requirement for Scheduler

The primary scheduler must be able to run whenever the primary server is running, and the secondary scheduler must be able to run when the secondary server is running. If a server becomes active but cannot use its own scheduler, PBS will not be able to schedule jobs.

9.2.4.10 Same Data Service Account on Both Server Hosts

The PBS Data service management account must be the same on both server hosts. The UID of the PBS data service management account must be identical on both the primary and secondary server hosts. We recommend that the PBS data service management account is called *pbsdata*.

If you change either data service management account, both must be changed at the same time and both servers must be restarted. The name of the Data service account must be the same as the data service management account.

9.2.4.11 Data Service Host Configuration Requirement

The DATA_SERVICE_HOST parameter must not be set in `pbs.conf`. If this parameter is set, failover cannot take place.

9.2.4.12 Consistent User Names

User names must be consistent across the primary and secondary server hosts. If usernames are not consistent, jobs are killed.

9.2.4.13 Monitor Server Mail

Use the `qmgr` command to set the mail_from server attribute to an address that is monitored regularly:

```
Qmgr: s server mail_from=<address>
```

See section 2.2.1, "Configuring Server Mail Address", on page 21.

9.2.5 Configuring Failover

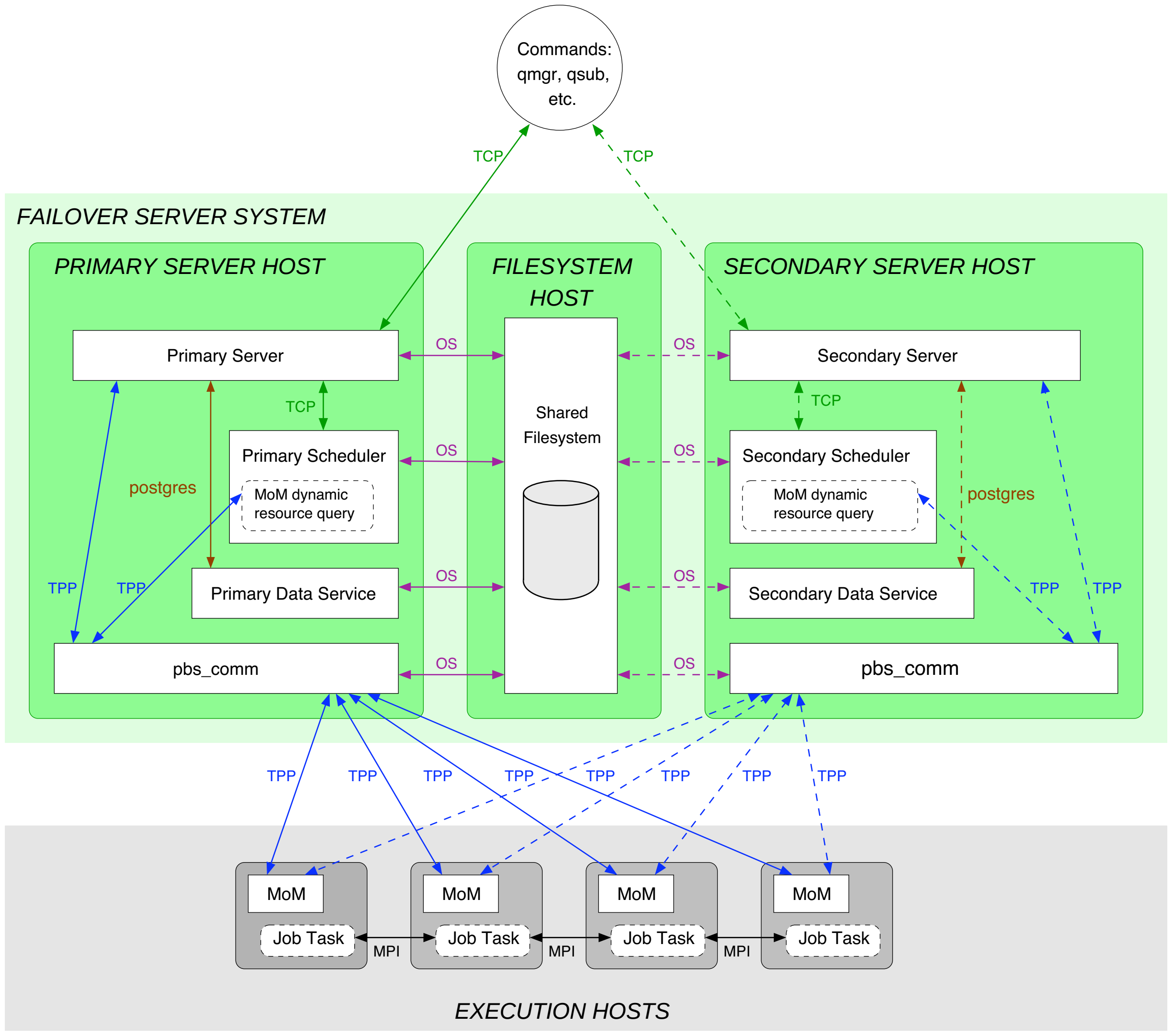


Figure 9-2:Failover Configuration

9.2.5.1 Overview of Configuring Failover

If PBS is not already installed, install it according to the PBS Professional Installation & Upgrade Guide.

Please make sure that you have satisfied all of the prerequisites under section 9.2.4, "Prerequisites for Failover", on page 406.

Make a copy of your PBS configuration. Follow the instructions in “Back Everything Up to Transfer Location” on page 97 in the PBS Professional Installation & Upgrade Guide.

The following table contains a guide to the steps in configuring PBS for failover. The table contains a link to the description of each step.

Table 9-3: Overview of Configuring Failover

Step	Linux	Windows
Configure `/etc/pbs.conf` on each host in the complex	See section 9.2.5.2, “Configuring the pbs.conf File for Failover”, on page 411	
Configure the primary server	See section 9.2.5.3.i, “Configuring Failover For the Primary Server on Linux”, on page 413	
Configure the secondary server	See section 9.2.5.3.ii, “Configuring Failover For the Secondary Server on Linux”, on page 415	
Recommended: configure STONITH script	See section 9.2.5.3.iii, “Configuring STONITH Script for Use by Secondary Server”, on page 415	
Configure execution and client hosts	See section 9.2.5.3.iv, “Configuring Failover For Execution and Client Hosts on Linux”, on page 416	See section 9.2.5.4.i, “Configuring Failover for Execution and Client Hosts on Windows”, on page 417
Configure failover with peer scheduling	See section 9.2.6.2, “Configuring Failover to Work With Peer Scheduling”, on page 417	
Configure failover with routing queues	See section 9.2.6.1, “Configuring Failover to Work with Routing Queues”, on page 417	
Configure failover with access control	See section 9.2.6.3, “Configuring Failover to Work With Access Controls”, on page 418	

9.2.5.2 Configuring the `pbs.conf` File for Failover

The $PBS_CONF_FILE environment variable contains the path to the `pbs.conf` file. Each host in the complex must have a properly configured `/etc/pbs.conf` file. This file specifies the hostnames of the primary and secondary servers, the location of `PBS_HOME` and `PBS_MOM_HOME`, and whether to start a server, a scheduler, or a MoM on this host.

The name used for the server in the PBS_SERVER variable in the `pbs.conf` file must not be longer than 255 characters. If the short name for the server resolves to the correct host, you can use this in `pbs.conf` as the value of PBS_SERVER. However, if the fully-qualified domain name is required in order to resolve to the correct host, then the this must be the value of the PBS_SERVER variable.

Table 9-4: Parameters in `pbs.conf` for Failover

Parameters	Value	Meaning
PBS_EXEC	Path	Location of PBS `bin` and `sbin` directories
PBS_HOME	Path	Location of PBS working directories in shared filesystem; use specific path on that host
PBS_MOM_HOME	Path	Location of `mom_priv` on each host; overrides `PBS_HOME` for `mom_priv`
PBS_PRIMARY	FQDN of hostname	Hostname of primary server host. If you set PBS_LEAF_NAME on the primary server host, make sure that PBS_PRIMARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_PRIMARY matches the hostname of the server host.
PBS_SECONDARY	FQDN of hostname	Hostname of secondary server host. If you set PBS_LEAF_NAME on the secondary server host, make sure that PBS_SECONDARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_SECONDARY matches the hostname of the server host.
PBS_SERVER	Hostname	Name of primary server host. Cannot be longer than 255 characters. If the short name of the server host resolves to the correct IP address, you can use the short name for the value of the PBS_SERVER entry in `pbs.conf`. If only the FQDN of the server host resolves to the correct IP address, you must use the FQDN for the value of PBS_SERVER.
PBS_START_COMM	*0* or *1*	Specifies whether a comm is to run on this host
PBS_START_MOM	*0* or *1*	Specifies whether a MoM is to run on this host
PBS_START_SCHED	*0* or *1*	Specifies whether scheduler is to run on this host
PBS_START_SERVER	*0* or *1*	Specifies whether server is to run on this host

9.2.5.2.i Editing Configuration Files Under Windows

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

9.2.5.3 Host Configuration for Failover on Linux

- Make sure that you have satisfied all of the prerequisites under section 9.2.4, "Prerequisites for Failover", on page 406.
- PBS should already be installed in the default location on the primary and secondary server hosts and on the execution hosts. The client commands should already be installed on the client hosts.
- Make root a Manager on both server hosts:

  ```
  qmgr -c "set server managers =root@<primary server host>"
  qmgr -c "set server managers +=root@<secondary server host>"
  ```
- If the primary server and scheduler are running, shut them down. See "qterm" on page 234 of the PBS Professional Reference Guide.

9.2.5.3.i Configuring Failover For the Primary Server on Linux

1. Make sure that you have satisfied all of the prerequisites under section 9.2.4, "Prerequisites for Failover", on page 406.
2. Stop PBS on both the primary and secondary server hosts:

   On the primary server host:

   ```
   systemctl stop pbs
   ```

   or

   ```
   <path to init.d>/init.d/pbs stop
   ```

   On the secondary server host:

   ```
   systemctl stop pbs
   ```

   or

   ```
   <path to init.d>/init.d/pbs stop
   ```
3. On the primary server host, edit the `/etc/pbs.conf` file so that it DOES NOT include failover settings. It should look like this:

   ```
   PBS_SERVER=<short name for primary host>
   PBS_HOME=<shared location of PBS_HOME>
   PBS_START_SCHED=1
   ```

   We recommend not running a MoM on any server host. The following setting in `pbs.conf` will prevent a MoM from running:

   ```
   PBS_START_MOM=0
   ```

   If you will run a MoM on the server hosts, specify this:

   ```
   PBS_START_MOM=1
   ```

   If you will run a MoM on both server hosts, specify `PBS_MOM_HOME` on this host. The location you specify is the directory that you replicated in section 9.2.4.3, "Requirements for MoMs on Server Hosts", on page 407:

   ```
   PBS_MOM_HOME=<location of local, replicated mom_priv>
   ```
4. On the primary server host, start the primary PBS server and scheduler daemons:

   ```
   systemctl start pbs
   ```

or

```
<path to init.d>/init.d/pbs start
```

5. Stop the PBS server on the primary server host:

   ```
   systemctl stop pbs
   ```

   or

   ```
   <path to init.d>/init.d/pbs stop
   ```

6. On the primary server host, edit the `/etc/pbs.conf` file to include the failover settings for PBS_PRIMARY and PBS_SECONDARY. It should look like this:

   ```
   PBS_PRIMARY=<primary_host>
   PBS_SECONDARY=<secondary_host>
   PBS_SERVER=<short name for primary host>
   PBS_HOME=<shared location of PBS_HOME>
   ```

   The primary scheduler will start automatically:

   ```
   PBS_START_SCHED=1
   ```

   We recommend not running a MoM on any server host. The following setting in `pbs.conf` will prevent a MoM from running:

   ```
   PBS_START_MOM=0
   ```

   If you will run a MoM on the server hosts, specify this:

   ```
   PBS_START_MOM=1
   ```

   If you will run a MoM on both server hosts, specify `PBS_MOM_HOME` on this host. The location you specify is the directory that you replicated in section 9.2.4.3, “Requirements for MoMs on Server Hosts”, on page 407:

   ```
   PBS_MOM_HOME=<location of local, replicated mom_priv>
   ```

   If you set PBS_LEAF_NAME on the primary server host, make sure that PBS_PRIMARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_PRIMARY matches the hostname of the server host.

   If you set PBS_LEAF_NAME on the secondary server host, make sure that PBS_SECONDARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_SECONDARY matches the hostname of the server host.

7. Run a comm on the primary server host. Set the following in `pbs.conf` on the primary server host:

   ```
   PBS_START_COMM = 1
   ```

8. On the primary server host, start the primary PBS server, scheduler, and comm daemons:

   ```
   systemctl start pbs
   ```

   or

   ```
   <path to init.d>/init.d/pbs start
   ```

9.2.5.3.ii Configuring Failover For the Secondary Server on Linux

1. Make sure that you have satisfied all of the prerequisites under section 9.2.4, "Prerequisites for Failover", on page 406.
2. On the secondary server host, edit the `/etc/pbs.conf` file to include the following settings:

   ```
   PBS_PRIMARY=<primary_host>
   PBS_SECONDARY=<secondary_host>
   PBS_SERVER=<short name for primary host>
   PBS_HOME=<shared location of PBS_HOME>
   ```

   The secondary server will start its own scheduler if it needs to; a scheduler should not automatically start on the secondary server host. Include the following so that a scheduler does not automatically start on this host:

   ```
   PBS_START_SCHED=0
   ```

   We recommend not running a MoM on any server host. The following setting in `pbs.conf` will prevent a MoM from running:

   ```
   PBS_START_MOM=0
   ```

   If you will run a MoM on the server hosts, specify this:

   ```
   PBS_START_MOM=1
   ```

   If you will run a MoM on both server hosts, specify `PBS_MOM_HOME` on this host. The location you specify is the directory that you replicated in section 9.2.4.3, "Requirements for MoMs on Server Hosts", on page 407:

   ```
   PBS_MOM_HOME=<location of local, replicated mom_priv>
   ```

   If you set PBS_LEAF_NAME on the primary server host, make sure that PBS_PRIMARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_PRIMARY matches the hostname of the server host.

   If you set PBS_LEAF_NAME on the secondary server host, make sure that PBS_SECONDARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_SECONDARY matches the hostname of the server host.
3. On the secondary server host, to change the delay time between failure of the primary server and activation of the secondary server from its default of 30 seconds, use the -F <delay> option on the secondary server's command line in the PBS start script on the secondary server host. Edit the `init.d/pbs` script so that the server is invoked with the -F <delay> option:

   ```
   pbs_server -F <delay>
   ```

   See "pbs_server" on page 109 of the PBS Professional Reference Guide.
4. Run a comm on the secondary server host. Set the following in `pbs.conf` on the secondary server host:

   ```
   PBS_START_COMM = 1
   ```

5. On the secondary server host, start the secondary PBS server and comm daemons:

   `systemctl start pbs`

   or

   `<path to init.d>/init.d/pbs start`

9.2.5.3.iii Configuring STONITH Script for Use by Secondary Server

We strongly recommend that before the secondary server becomes active, it prevents a race condition between the primary and secondary data services by calling a script which shuts down the primary server host. This script is called STONITH, for "shoot the other node in the head". If the script returns failure, the secondary server waits for 10 seconds, then calls the script again. The secondary server does not become active until the script returns success.

Requirements for STONITH:

- You must write the STONITH script, and put it in `$PBS_HOME/server_priv/stonith`.
- Permissions for the script should be *0755*.
- The STONITH script takes one argument, which is the hostname of the primary server. This hostname is the same as what is listed for PBS_PRIMARY in `pbs.conf`.
- The STONITH script returns zero for success, and non-zero for failure.

Note that you must supply the command used to power down the primary server host.

Example 9-1: Sample STONITH Script

```
#!/bin/bash
# This script powers down the primary server host.
# This script runs only on the secondary server host.
PBS_PRIMARY=$1
SECONDARY=`hostname`
POWERDOWN_CMD="<command to power down the primary server host>"

echo  "INFO: Secondary starting Stonith script.  Secondary server host is ${SECONDARY}."
echo  "INFO: This Stonith script will power down the primary server host."
echo  "INFO: Primary server host is ${PBS_PRIMARY}."

# Power down the primary server host
# You can also include a timeout, and check the value of the result.
# Example: timeout_result=$( { timeout 10 ${POWERDOWN_CMD} ${PBS_PRIMARY} ; } 2>&1 )
${POWERDOWN_CMD} ${PBS_PRIMARY}

if [ $? -eq 0 ] ; then
    echo "INFO: Stonith script succeeded in powering down primary server host ${PBS_PRIMARY}."
        exit 0
else
    echo "ERROR: Stonith script failed to power down primary server host ${PBS_PRIMARY}."
    exit 1
fi
```

9.2.5.3.iv Configuring Failover For Execution and Client Hosts on Linux

1. Make sure that you have satisfied all of the prerequisites under section 9.2.4, "Prerequisites for Failover", on page 406.
2. On each execution or client host, configure the `/etc/pbs.conf` file to include the following parameters:

```
PBS_PRIMARY=<primary_host>
PBS_SECONDARY=<secondary_host>
PBS_SERVER=<short name for primary host>
PBS_HOME=<location of PBS_HOME>
```

   The `pbs.conf` files on execution hosts are already configured to start the MoM daemon only. Similarly, the `pbs.conf` files on client hosts are already configured to start no daemons.
3. On each execution host, restart the MoM:

```
systemctl start pbs
```

or

```
<path to init.d>/init.d/pbs start
```

9.2.5.4 Host Configuration for Failover on Windows

9.2.5.4.i Configuring Failover for Execution and Client Hosts on Windows

1. Make sure that you have satisfied all of the prerequisites under section 9.2.4, “Prerequisites for Failover”, on page 406.
2. On each execution or client host, specify the location of `PBS_HOME` for the primary server:

   ```
   pbs-config-add "PBS_HOME=\\<shared filesystem host>\pbs_home"
   ```
3. On each execution or client host, specify the primary and secondary server names in the `pbs.conf` file by running the following commands:

   ```
   pbs-config-add "PBS_SERVER=<short name of primary server host>"
   pbs-config-add "PBS_PRIMARY=<FQDN of primary server host>"
   pbs-config-add "PBS_SECONDARY=<FQDN of secondary server host>"
   ```
4. If this is an execution host, restart the MoM:

   ```
   net start pbs_mom
   ```

9.2.6 Configuring Failover with Other PBS Features

9.2.6.1 Configuring Failover to Work with Routing Queues

You must configure failover to work with routing queues which have destinations in another complex. No additional configuration is required for routing queues which have destinations in the same complex.

For a routing queue in one complex which points to a queue *Q1* in another PBS complex that is set up for failover, it is a good idea to specify both *Q1@primary.example.com* and *Q1@secondary.example.com* as destinations.

For example, if a routing queue has a destination queue at another complex's primary server:

```
Qmgr: set queue r66 route_destinations=workq@primary.example.com
```

you need to add the same queue at the other complex's secondary server:

```
Qmgr: set queue r66 route_destinations+=workq@secondary.example.com
```

See section 2.3.6, “Routing Queues”, on page 27.

9.2.6.2 Configuring Failover to Work With Peer Scheduling

For peer queueing where the furnishing complex is set up for failover:

- You must list the furnishing queue at both primary and secondary servers. If the furnishing queue is *Q1*, the `peer_queue` line in the pulling complex's `sched_config` file must list *Q1@primary.example.com* and *Q1@secondary.example.com*

For peer queueing where the pulling complex is set up for failover:

- You must add *<manager>@primary.example.com* and *<manager>@secondary.example.com* to the list of managers at the furnishing server.

See section 4.9.31, “Peer Scheduling”, on page 167.

9.2.6.3 Configuring Failover to Work With Access Controls

If you are using access control on the server (the acl_host_enable server attribute is set to *True* and the acl_hosts server attribute is specified), add the secondary server to the host list in acl_hosts:

```
Qmgr: s server acl_hosts+=<secondary server host>
```

See section 8.3.4, “ACLs”, on page 365.

9.2.7 Using PBS with Failover Configured

9.2.7.1 Stopping Servers

To stop both servers when the primary server is active, and the secondary server is running and idle, do the following:

```
qterm -f
```

To stop the primary server and leave the secondary server idle:

```
qterm -i
```

To stop the secondary server only:

```
qterm -F
```

9.2.7.2 Starting Servers

After configuring the servers, you can start them in any order.

If you want to start the primary server when the secondary server is the active server, you do not need to stop the secondary. When the primary server starts, it informs the secondary that the secondary can become idle.

However, if there is a network outage while the primary starts and the secondary cannot contact it, the secondary will assume the primary is still down, and remain active, resulting in two active servers. In this case, stop the secondary server, and restart it when the network is working:

```
qterm -F
pbs_server
```

To restart the secondary server while it is the active server:

```
pbs_server -F -1
```

The secondary server makes one attempt to contact the primary server, and becomes active immediately if it cannot.

See “pbs_server” on page 109 of the PBS Professional Reference Guide and “qterm” on page 234 of the PBS Professional Reference Guide.

9.2.8 Recommendations and Caveats

- **Do not** start or stop the data service using anything except the `pbs_dataservice` command. Start or stop the data service using only the `pbs_dataservice` command.
- If you do not wish for the secondary server to take over, use the -i option to the `qterm` command when stopping the primary server.
- When the primary server is active, and the secondary server is running and idle, the `pbs start/stop` script stops the active server, but leaves the idle server running. This means that the idle server becomes the active server.
- `PBS_HOME` should not be on either server host
- Neither PBS server should be the NFS fileserver
- Each scheduler and data service must be able to run when its server is started, otherwise no jobs will be scheduled; each server can use only its own scheduler and data service.
- Just because servers are redundant, that doesn't mean that your complex is. Look for single points of failure.
- If the "*take over*" delay time specified with the `pbs_server -F` option is too long, there may be a period, up to that amount of time, when clients cannot connect to either server.
- If the "*take over*" delay time specified with the `pbs_server -F` option is too short and there are transient network failures, then the secondary server may attempt to take over while the primary server is still active.
- While the primary server is active and the secondary server is inactive, the secondary server will not respond to any network connection attempts. Therefore, you cannot status the secondary server to determine whether it is running.
- If the secondary server is running, and the primary server cannot contact the secondary server when the primary server is restarted, the primary assumes the secondary is not running and takes over. This can result in two servers running at once.

9.2.9 Troubleshooting Failover

9.2.9.1 PBS Does Not Start

- If you see the following error:

  ```
  "Failover is configured. Temporarily disable failover before running pbs_ds_password"
  ```

  This means that PBS was started for the first time with failover configured. PBS cannot be started for the first time with failover configured. Remove definitions for PBS_PRIMARY and PBS_SECONDARY from `pbs.conf` on the primary server host, start PBS, stop PBS, replace the definitions, and start PBS again.

9.2.9.2 Primary and Secondary Servers Both Running

If both servers are running, this may be because the primary server was stopped and then restarted, and while the primary was stopped, the secondary began to take over. While the secondary server was coming up, it was not able to receive the message from the primary server indicating that it should go idle, or it couldn't register with the primary.

To avoid this problem, use the -i option to the `qterm` command, which tells the secondary server to remain idle.

9.2.9.3 Primary or Secondary Server Fails to Start

It does not matter in which order the primary and secondary servers are started.

If the primary or secondary server fails to start with the error:

```
another server running
```

then check for the following conditions:

1. There may be lock files left in `PBS_HOME/server_priv` that need to be removed.

   The primary and secondary servers use different lock files:

   - primary: `server.lock`
   - secondary: `server.lock.secondary`

2. On Linux, the RPC `lockd` daemon may not be running. You can manually start this daemon by running as root:

   ```
   <path to daemon>/rpc.lockd
   ```

   Check that all daemons required by your NFS are running.

9.2.9.4 Primary Server Periodically Restarting

If the primary server keeps restarting, an unknown secondary server may be contacting it. This can happen when PBS_PRIMARY and PBS_SECONDARY are missing from `pbs.conf`, but a secondary server has been started.

9.2.9.5 Cannot Connect to Host

If you see an error message about not being able to connect to server, check the permissions of pbs_iff on the secondary server. The setuid bit may be wrong (permissions should be -rsxr-xr-x), or it may be on a shared filesystem that disallows `setuid` programs from running.

9.3 Checkpoint and Restart

PBS Professional allows you to configure MoM to checkpoint jobs using your scripts and checkpoint tools. In addition, users may manage their own checkpointing from within their application.

9.3.1 Glossary

Application Checkpoint

The application performs its own checkpointing when it receives the appropriate signal etc.

Checkpoint and Abort, checkpoint_abort

The checkpoint script or tool writes a restart file, then PBS kills and requeues the job. The job uses the restart file when it resumes execution.

Restart

A job that was stopped after being checkpointed while previously executing is executed again, starting from the point where it was checkpointed.

Restart File

The job-specific file that is written by the checkpoint script or tool. This file contains any information needed to restart the job from where it was when it was checkpointed.

Restart Script

The script that MoM runs to restart a job. This script is common to all jobs, and so must use the information in a job's restart file to restart the job.

Snapshot Checkpoint

The checkpoint script or tool writes a restart file, and the job continues to execute. The job resumes based on this restart file if the system experiences a problem during the job's subsequent execution.

9.3.2 How Checkpointing Works

When a job is checkpointed, MoM executes a checkpoint script. The checkpoint script saves all of the information necessary to checkpoint the job. If the checkpoint is for a snapshot, the job continues to run. If the job is checkpointed and aborted, PBS kills and requeues the job after checkpointing it.

When a job is restarted, MoM executes a restart script. The restart script uses the saved information to restore the job. The restart script also reads the $PBS_NODEFILE. The manner of restarting the job depends on how it was checkpointed:

- If the job was checkpointed during shutdown, the job becomes eligible to run when PBS is restarted, and will start from where it was checkpointed.
- If the job was checkpointed by the scheduler because it was preempted, the scheduler briefly applies a hold, but releases the hold immediately after checkpointing the job, and runs the restart script when the job is scheduled to run.
- If the job was checkpointed and held via the `qhold` command, the hold must be released via the `qrls` command for the job to be eligible to run. Then when the scheduler next runs the job, the restart script is executed, and the job runs from where it was checkpointed.

You can configure PBS to requeue jobs that were snapshot checkpointed while they ran, if the epilogue exits with a special value. These jobs are then restarted from the restart file. However, if you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

You can provide checkpointing for jobs using any combination of scripts that you write and third-party checkpointing tools such as Meiosys Checkpoint and BLCR (Berkeley Lab Checkpoint/Restart). You can configure PBS to trigger the scripts or tools, so that the scripts and/or tools create a job's restart file.

You can configure one behavior for snapshots, and another behavior for checkpoint and abort.

Some applications provide their own checkpointing, which is triggered, for example, when the application receives a signal or detects a change in a file.

9.3.2.1 Types of Checkpointing

9.3.2.1.i Checkpoint and Abort

Checkpoint and abort is used when a job is checkpointed before being killed. When the job is checkpointed, the following takes place:

- MoM runs the checkpoint_abort script; the checkpoint script or tool writes a restart file specific to that job
- The checkpoint_abort script terminates the job
- PBS requeues the job
- If the job was held via the `qhold` command, PBS applies a hold to the job (puts it in the *Held* state)

The job resumes execution based on the information in the restart file.

Checkpoint and abort is applied when:

- The `qhold` command is used on a job
- The server is shut down via `qterm -t immediate` or `qterm -t delay`
- The scheduler preempts a job using the checkpoint method

9.3.2.1.ii Snapshot Checkpoint

Snapshot checkpointing is used for checkpointing a job at regular intervals. The job continues to run. When the job is checkpointed, the following takes place:

- MoM runs the snapshot checkpoint script; the checkpoint script or tool writes a restart file specific to that job
- The job continues to execute

The job resumes execution based on this restart file if the system crashes or if the epilogue returns -2. See section 9.3.7.3, "Requeueing via Epilogue", on page 431.

The interval can be specified by the user via `qsub -c <checkpoint spec>`. You can specify a default interval, in the checkpoint_min queue attribute, or in the Checkpoint job attribute. See "qsub" on page 214 of the PBS Professional Reference Guide and "Job Attributes" on page 330 of the PBS Professional Reference Guide.

9.3.2.1.iii Application Checkpoint

Application checkpointing is when an application checkpoints itself. PBS can be used to trigger application checkpointing, but does not manage the checkpoint files or process. Application checkpointing can be triggered when the application receives a signal or detects a change in a file.

9.3.2.2 Events That Trigger Checkpointing

The following table lists the events that can trigger checkpointing, and the kind of checkpointing that is used.

Table 9-5: Events Triggering Checkpointing

Event	Type of Checkpointing Used	Description
The `qhold` command is used on a job	checkpoint_abort	See section 9.3.7.6, "Holding a Job", on page 432
Server shut down via `qterm -t immediate` or `qterm -t delay`	checkpoint_abort	See section 9.3.7.2, "Checkpointing During Shutdown", on page 431
Scheduler preempts a job using the checkpoint method	checkpoint_abort	See section 9.3.7.5, "Preemption Using Checkpoint", on page 432
Periodic checkpointing of a job, as specified by `qsub -c <checkpoint spec>`, or the queue's checkpoint_min attribute	Snapshot	See section 9.3.7.1, "Periodic Job Checkpointing", on page 431
Periodic checkpoint of an application, where checkpoint script triggers application checkpoint	Snapshot and application checkpoint	See section 9.3.7.7, "Periodic Application Checkpoint", on page 433
User sends application checkpoint signal, or user creates checkpoint trigger file	Application checkpoint	See section 9.3.7.8, "Manual Application Checkpoint", on page 433

9.3.2.3 Effect of Checkpointing on Jobs

When a job is checkpointed and aborted (requeued), its accumulated queue waiting time depends on how that time is calculated:

- If you are using eligible time, the accumulated waiting time is preserved
- If you are not using eligible time, the accumulated waiting time is lost

The job exit code for being checkpointed and aborted is *-12*, named *JOB_EXEC_CHKP*.

When a job is restarted, it runs on the same machine as it did when it was checkpointed.

9.3.2.4 Effect of Checkpointing on Job Resources

When a job is checkpointed and aborted, all of its resources are freed.

A snapshot checkpoint does not affect a job's resources.

9.3.2.5 Restarting a Job

When a job is restarted, MoM runs the restart script specified in the $action restart MoM parameter. This script looks in the checkpoint directory (see section 9.3.6.5, "Specifying Checkpoint Path", on page 430) for the restart file for that job. It uses the information in that file to restart the job.

For a job that was checkpointed and aborted because it was held, the job has had a hold placed on it so that it will not be eligible for execution until the hold is released. In order for a checkpointed and held job to be eligible for execution, the hold must be removed using the `qrls` command. The job's owner can remove a User hold, but other holds must be removed by a Manager or Operator. See "qrls" on page 181 of the PBS Professional Reference Guide.

If the job was preempted via checkpointing, the scheduler releases the hold on the job immediately after checkpointing the job. This will show up in the scheduler's log file, but the job will not appear to be held because the hold duration is very short.

A job that was checkpointed and requeued during shutdown is not held. This job is eligible for execution as soon as the necessary daemons are back up. See section 9.3.7.4, "Checkpointed Jobs and Server Restart", on page 432.

A job that was snapshot checkpointed and later requeued because the epilogue returned a special exit status is requeued in the *Q* state, and is eligible to be restarted when the scheduler selects it for execution.

When a checkpointed and aborted job is restarted, MoM resumes tracking the job. She tracks either the original PID of the job, or the PID of the restart script, depending on the setting of the $restart_transmogrify MoM parameter. See section 9.3.4.3, "Setting $restart_transmogrify MoM Parameter", on page 426.

9.3.3 Prerequisites for Checkpointing Jobs

The following are the prerequisites for checkpointing jobs:

- The MoM must be configured for checkpointing
  - Specified checkpoint directories must correspond to available directories (see section 9.3.6.5, "Specifying Checkpoint Path", on page 430)
  - Checkpoint and restart MoM configuration parameters must be specified (see section 9.3.4.2, "Specifying Checkpoint and Restart Parameters", on page 424)
- A checkpointing script or tool must be available for each type of checkpointing to be used

9.3.3.1 Restrictions on Checkpointing

- Checkpointing is not supported for job arrays.
- PBS does not directly support OS-level checkpointing.
- You can configure only one snapshot script, so if more than one kind of snapshot checkpointing is required, the script must distinguish which kind of snapshot to perform.
- You can configure only one checkpoint_abort script, so if more than one kind of checkpoint_abort is required, the script must also distinguish which kind of checkpoint_abort to perform.
- You can configure only one restart script. The restart script is run once for each of the job's tasks, so if some restarts are for application checkpointing, the script must handle those restarts correctly (application restarts may require only one iteration.)
- A restarted job must run on the same machine where it was running when it was checkpointed.
- Checkpointing cannot be used for interactive jobs. See section 9.3.8.2, "Sockets and Checkpointing", on page 433.

9.3.4 Configuring Checkpointing

9.3.4.1 Overview of Configuring Checkpointing

You configure checkpointing by editing the MoM configuration file, `PBS_HOME/mom_priv/config`. You edit MoM configuration parameters to do the following:

- Specify script paths
  - Specify path to checkpoint_abort script, if needed
  - Specify path to snapshot script, if needed
  - Specify path to restart script
- Set $restart_transmogrify MoM parameter to fit your restart script
- Make the checkpoint path match that specified in the restart script

9.3.4.1.i Editing Configuration Files Under Windows

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

9.3.4.2 Specifying Checkpoint and Restart Parameters

To configure checkpointing, you specify a path to a script that MoM executes when checkpointing is called for. You can specify a separate path/script for each of checkpoint_abort, snapshot, and restart using the following MoM configuration parameters:

$action checkpoint timeout !path/script script-args

Specifies snapshot behavior.

$action checkpoint_abort timeout !path/script script-args

Specifies checkpoint_abort behavior.

$action restart timeout !path/script script-args

Specifies restart behavior.

where

$action

Specifies that MoM perform the indicated action.

checkpoint

MoM executes the script specified in path/script once for each of the job's tasks when a snapshot is called for.

checkpoint_abort

MoM executes the script specified in path/script once for each of the job's tasks when a checkpoint_abort is called for.

restart

MoM executes the script specified in path/script once for each of the job's tasks when a restart is called for.

timeout

The number of seconds allowed for the script or tool to execute. The value of the $restart_transmogrify MoM parameter determines whether this limit is applied. Values for $restart_transmogrify, and resulting behavior:

False

If the script/tool does not finish running during this time, it is killed and handled as if it had returned failure.

True

No timeout limit is applied.

path/script

The path to the script, including the name of the script. The path can be absolute or relative. If the path is relative, it is relative to `PBS_HOME/mom_priv`.

Examples of absolute paths and script names:

```
/usr/bin/checkpoint/snapshot
/usr/bin/checkpoint/checkpt-abort
/usr/bin/checkpoint/restart
```

script-args

These are the arguments to the script, if any.

PBS automatically expands some arguments to checkpoint and restart scripts. The following table lists the arguments that are expanded by PBS:

Table 9-6: Checkpoint Script Arguments Expanded by PBS

Argument	Description
%globid	Global ID (no longer used)
%jobid	Job ID
%sid	Session ID
%taskid	Task ID
%path	File or directory name to contain restart files

9.3.4.2.i Examples of Checkpoint and Restart Parameters

The following are examples of snapshot, checkpoint_abort, and restart MoM parameters:

```
$action checkpoint 60 !/usr/bin/checkpoint/snapshot %jobid %sid %taskid %path
$action checkpoint_abort 60 !/usr/bin/checkpoint/checkpt-abort %jobid %sid %taskid %path
$action restart 30 !/usr/bin/checkpoint/restart %jobid %sid %taskid %path
```

9.3.4.3 Setting $restart_transmogrify MoM Parameter

The $restart_transmogrify MoM parameter controls how MoM runs the restart script, and whether she expects to resume tracking the job's original PID or a new PID. When she runs a restart script, MoM forks a child process, which `exec()`s the start script. If $restart_transmogrify is *True*, the start script becomes the top task of the job. If $restart_transmogrify is *False*, the start script does not become the top task of the job.

If your restart script preserves the job's original PID, set $restart_transmogrify to *False*. This way, the script does not become the top task of the job, and MoM continues to track the job's original PID.

If your restart script results in a new PID for the job, set $restart_transmogrify to *True*. This way, the restart script becomes the top task of the job, and MoM tracks the PID of the new top process, which is the script.

9.3.5 Parameters and Attributes Affecting Checkpointing

9.3.5.1 MoM Configuration Parameters Affecting Checkpointing

$action checkpoint <timeout> !<script-path> <args>

Checkpoints the job, allowing the job to continue running.

$action checkpoint_abort <timeout> !<script-path> <args>

Checkpoints, kills, and requeues the job.

$action restart <timeout> !<script-path> <args>

Restarts checkpointed job.

The <timeout> is the time allowed for checkpoint or restart script to run.

$checkpoint_path <path>

MoM passes this parameter to the checkpoint and restart scripts. This path can be absolute or relative to `PBS_HOME/mom_priv`. Overrides default. Overridden by path specified in the `pbs_mom -C` option and by PBS_CHECKPOINT_PATH environment variable.

$restart_background <*True*|*False*>

Specifies whether MoM runs the restart script in the background (MoM doesn't wait) or foreground (MoM waits). When set to *True*, MoM runs the restart script in the background.

Automatically set by MoM; Controlled by value of $restart_transmogrify. When $restart_transmogrify is *True*, $restart_background is set to *False*. When $restart_transmogrify is *False*, $restart_background is set to *True*.

Format: *Boolean*

Default: *False*

$restart_transmogrify <*True*|*False*>

Specifies which PID MoM tracks for a job that has been checkpointed and restarted.

When this parameter is set to *True*, MoM tracks the PID of the restart script. When this parameter is set to *False*, MoM tracks the PID of the original job.

The value of $restart_transmogrify controls the value of $restart_background.

Format: *Boolean*

Default: *False*

9.3.5.2 Options to `pbs_mom` Affecting Checkpointing

-C checkpoint_directory

Specifies the path to the directory where MoM creates job-specific subdirectories used to hold each job's restart files. MoM passes this path to checkpoint and restart scripts. Overrides other checkpoint path specification methods. Any directory specified with the -C option must be owned, readable, writable, and executable by root only (*rwx,---,---*, or *0700*), to protect the security of the restart files. See the -d option to `pbs_mom`.

Format: *String*

Default: `PBS_HOME/checkpoint`

9.3.5.3 Job Attribute Affecting Checkpointing

Checkpoint

Determines when the job will be checkpointed. Can take on one of the following values:

c

Checkpoint at intervals, measured in CPU time, set on the job's execution queue. If there is no interval set on the queue, the job is not checkpointed.

c=<minutes of CPU time>

Checkpoint at intervals of the specified number of minutes of job CPU time. This value must be greater than zero. If the interval specified is less than that set on the job's execution queue, the queue's interval is used.

Format: *Integer*

w

Checkpoint at intervals, measured in walltime, set on the job's execution queue. If there is no interval set at the queue, the job is not checkpointed.

w=<minutes of walltime>

Checkpoint at intervals of the specified number of minutes of job walltime. This value must be greater than zero. If the interval specified is less that that set on the execution queue in which the job resides, the queue's interval is used.

Format: *Integer*

n

No checkpointing.

s

Checkpoint only when the server is shut down.

u

Unset. Defaults to behavior when interval argument is set to *s*.

Default: *u*.

Format: *String*

9.3.5.4 Queue Attribute Affecting Checkpointing

checkpoint_min

Specifies the minimum number of minutes of CPU time or walltime allowed between checkpoints of a job. If a user specifies a time less than this value, this value is used instead. The value given in checkpoint_min is used for both CPU minutes and walltime minutes. See the Checkpoint job attribute.

Format: *Integer*

Default: None

Python attribute value type: pbs.duration

9.3.5.5 Environment Variable Affecting Checkpointing

PBS_CHECKPOINT_PATH

MoM passes this path to the checkpoint and restart scripts. Overridden by `-C` option to `pbs_mom`; overrides $checkpoint_path MoM parameter and default. See section 9.3.6.5, "Specifying Checkpoint Path", on page 430.

PBS_NODEFILE

PBS uses the $PBS_NODEFILE to restart the job. Make sure it is available.

9.3.5.6 The Epilogue

PBS will requeue a job which was snapshot checkpointed, if the epilogue returns the value *2*. See section 9.3.7.3, "Requeueing via Epilogue", on page 431.

If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

9.3.6 Checkpoint and Restart Scripts

The restart script is run by the same MoM that ran the checkpoint script. The checkpoint and restart scripts are run for each task of the job. When MoM executes a checkpoint or restart script, she forks a child process, which `exec()`s the script. The restart script looks for the restart file in the job-specific subdirectory created by MoM, under the specified path. See section 9.3.6.5, "Specifying Checkpoint Path", on page 430.

9.3.6.1 Environment Variables for Scripts

PBS sets the following variables in the checkpoint and restart scripts' environments before running the scripts:

Table 9-7: Checkpoint/Restart Script Environment Variables

Environment Variable	Value of Variable
GID	Job owner's group ID
HOME	Job owner's PBS home directory
LOGNAME	Job owner's login name
PBS_JOBCOOKIE	128-bit random number used as token to authenticate job processes
PBS_JOBID	The job's ID
PBS_JOBNAME	The job's name
PBS_MOMPORT	Port number on which MoM listens for resource manager requests
PBS_NODEFILE	Path and filename of this job's node file
PBS_NODENUM	Index into the node file; index of this vnode; starts at 0
PBS_QUEUE	Name of the job's execution queue
PBS_SID	Session ID of task for which script is being called
PBS_TASKNUM	Index into task table for this job; index of task for which script is being called
SHELL	Job owner's login shell

Table 9-7: Checkpoint/Restart Script Environment Variables

Environment Variable	Value of Variable
UID	Job owner's execution ID
USER	Job owner's username
USERPROFILE	(Windows only) Job owner's Windows home directory
USERNAME	(Windows only) Job owner's Windows username

9.3.6.2 The Checkpoint Script

The checkpoint script writes a restart file that is specific to the job being checkpointed. The checkpoint script must save all of the information needed to restart the job. This is the information that will be used by the restart script to restart the job. PBS runs the script for each running job task, on each vnode where a task is running.

9.3.6.2.i Requirements for Checkpoint Script

- The first line of the script must specify the shell to be used, for example:
  `#!/bin/sh`
- The script should return the following error codes:
  - *Zero* for success
  - *Non-zero* for failure
- The script should block until the checkpoint process is finished.
- The restart file and its directory should be owned by root, and writable by root only, with permission 0755.
- Under Linux, the checkpoint script should be owned by root, and writable by root only, with permission 0755.
- Under Windows, the checkpoint script must have at least Full Control permission for the local Administrators group.
- The checkpoint script must write the restart file(s) in the location expected by the restart script. You don't have to use the %path parameter passed by MoM.
- If the script is for checkpoint-abort, the script must ensure that all processes are killed, whether directly or indirectly, for example by touching a file. All job processes must exit.

9.3.6.3 The Restart Script

The restart script does only one of the following:

- Reinstates the job's original PID, so that MoM tracks the original PID
- Becomes the new top process of the job, so that MoM tracks the PID of the script

If $restart_transmogrify is set to *True*, the restart script becomes the new top task for the job, and MoM begins tracking its process ID, where she was tracking the job's original process ID. If $restart_transmogrify is set to *False*, MoM continues to track the original job PID.

The restart script can use `pbs_attach()` to attach job processes to the original job PID, or to the script's PID. See "pbs_attach" on page 56 of the PBS Professional Reference Guide.

9.3.6.3.i Caveats for Restart Script

The `pbs_attach()` command is not supported under Windows.

9.3.6.3.ii Requirements for Restart Script

The restart script must handle everything required to restart the job from the information saved by the checkpoint script.

The restart script must block until the restart process is finished.

Under Linux, the restart script should be owned by root, and writable by root only, with permission 0755.

Under Windows, the restart script must have at least Full Control permission for the local Administrators group.

9.3.6.3.iii Return Values for Restart Script

The restart script must inform PBS of success or failure. It must return one of the following:

- *Zero* for success
- *Non-zero* for failure

9.3.6.4 Scripts for Application Checkpointing

If a user's application can be checkpointed periodically according to walltime or CPU time, you can use the PBS snapshot checkpoint facility to trigger snapshot checkpointing by the application.

If a user's application can be checkpointed, you can use the PBS checkpoint_abort facility before shutting down PBS to avoid losing intermediate results.

Some applications produce a restart file when they are sent a specific signal, or when a specific file is affected. A checkpoint script for this purpose sends the application the correct signal, or makes the correct change to the file.

Some applications only need the checkpoint and restart scripts to be run once each. In this case, the checkpoint and restart scripts should handle this requirement.

9.3.6.5 Specifying Checkpoint Path

When a job is checkpointed, information about the job is saved into a file. The location for this file can be any directory accessible to MoM.

The path to the checkpoint directory is composed of two parts. The first part is common to all jobs; this part can specified. The second part is a job-specific subdirectory, created by MoM for each job, under the common directory. The job's restart file is written in this job-specific subdirectory.

The default common directory, `PBS_HOME/checkpoint`, is provided for convenience.

You can specify the filename and the path for the common directory using any of the following methods. If the first is specified, PBS uses it. If not, and the second is specified, PBS uses the second, and so on.

- The -C path option to the `pbs_mom` command
- The PBS_CHECKPOINT_PATH environment variable
- The $checkpoint_path MoM configuration option in `PBS_HOME/mom_priv/config`
- The default value of `PBS_HOME/checkpoint`

The job-specific subdirectory is named with the following format:

<job ID>.CK

For example, if you specify `/usr/bin/checkpoint` for the common directory, and the job's ID is *1234.host1*, the job's restart file is written under `/usr/bin/checkpoint/1234.host1.CK`.

The restart file and its directory should be owned by root, and writable by root only.

9.3.6.5.i Checkpoint Path Caveats

If the checkpoint file is in `PBS_HOME/checkpoint/<job ID>.CK/`, and MoM thinks that a checkpoint failed (the checkpoint script returned non-zero), she will remove the checkpoint file. If the checkpoint script puts the checkpoint file in another location, MoM does not remove the checkpoint file.

9.3.7 Using Checkpointing

9.3.7.1 Periodic Job Checkpointing

If a job's Checkpoint attribute is set to *c*, *c=<minutes>*, *w*, or *w=<minutes>*, the job is periodically checkpointed. The checkpoint interval is specified either in the job's Checkpoint attribute or in the queue's checkpoint_min attribute. See "Job Attributes" on page 330 of the PBS Professional Reference Guide. The job's Checkpoint attribute is set using the -c <interval> option to the `qsub` command. See "qsub" on page 214 of the PBS Professional Reference Guide.

When this attribute is set, at every *<interval>* the job is checkpointed and a restart file is written, but the job keeps running.

9.3.7.2 Checkpointing During Shutdown

The effect on jobs of shutting down PBS depends on the method used to shut PBS down. When a job is checkpointed during shutdown, MoM runs the checkpoint_abort script, and PBS kills and requeues the job. PBS does not hold the job, so the job is eligible to be run again as soon as the server starts up.

If you use the `qterm` command, there are three different suboptions to the -t option to control whether jobs are checkpointed, requeued, or allowed to continue running.

If you use the PBS start/stop script, the script affects only the host where the script is run. Any jobs running completely or partly on that host are killed and requeued, but not checkpointed. Any jobs not running on that host are left running.

The effect of each shutdown method is described here:

Table 9-8: Effect of Shutdown on Jobs

Shutdown Method	Effect on Checkpointable Jobs	Effect on Non-checkpointable Jobs
`qterm -t quick`	Continue to run	Continue to run
`qterm -t delay`	Checkpointed, killed, requeued, held	Requeued if rerunnable; continue to run if not rerunnable
`qterm -t immediate`	Checkpointed, killed, requeued, held	Requeued if rerunnable; deleted if not rerunnable
`systemctl stop pbs` or `init.d/pbs stop`	Any jobs running completely or partly on host where stop script is run are killed and requeued Jobs not running on host where stop script is run are left running	Any jobs running completely or partly on host where stop script is run are killed and requeued Jobs not running on host where stop script is run are left running

Any running subjobs of a job array keep running when the server is shut down.

9.3.7.3 Requeueing via Epilogue

You can configure MoM to requeue a failed job that was snapshot checkpointed during its execution. For example, if a job terminates, but had a hardware failure during execution, PBS can requeue the job, and MoM will run the start script, which can restart the job from its restart file.

When the job is requeued via the epilogue mechanism, it is in the *Q* state.

If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

9.3.7.3.i Requirements for Requeueing via Epilogue

The following requirements must be met in order for a job to be requeued via the epilogue mechanism:

- The epilogue must return a value of *2*
- The job must have been checkpointed under the control of PBS
- The MoM must be configured with a restart script in the $action restart MoM configuration parameter
- The MoM must be configured to snapshot checkpoint jobs in the $action checkpoint MoM configuration parameter
- The jobs must request checkpointing via their Checkpoint attribute. See section 9.3.7.1, “Periodic Job Checkpointing”, on page 431
- The epilogue script in `PBS_HOME/mom_priv/epilogue` must return the following:
    - *Zero* (*0*) for successful termination (requeue is not required)
    - *Two* (*2*) for failure (requeue is required)

9.3.7.4 Checkpointed Jobs and Server Restart

When the server is restarted using the `pbs_server -t warm` command, `systemd`, or the `init.d/pbs start` script, jobs that were checkpointed and aborted upon shutdown are waiting in their queues, and are eligible to be run according to the scheduler's algorithm.

When the server is restarted using the `pbs_server -t hot` command, jobs that were checkpointed and aborted upon shutdown are immediately rerun, before the scheduler selects which jobs to run.

9.3.7.5 Preemption Using Checkpoint

When a job is preempted via checkpointing, MoM runs the checkpoint_abort script, and PBS kills and requeues the job. When the scheduler elects to run the job again, the scheduler runs the restart script to restart the job from where it was checkpointed. For a description of using preemption, see section 4.9.33, “Using Preemption”, on page 182.

9.3.7.6 Holding a Job

When anyone uses the `qhold` command to hold a checkpointable job, MoM runs the checkpoint_abort script, which kills all job processes, and PBS requeues, and holds the job.

A job with a hold on it must have the hold released via the `qrls` command in order to be eligible to run.

The following is the sequence of events when a job is held:

- MoM runs the checkpoint_abort script
- The job's execution is halted
- The resources assigned to the job are released
- The job is placed in the *Held* state in the execution queue
- The job's Hold_Types attribute is set appropriately

A held job is waiting in its queue. The following is the sequence of events when a held job is restarted:

- The hold is released by means of the `qrls` command; the job is now in the *Queued* state
- The job continues to wait in its queue until the scheduler schedules it for execution
- The scheduler selects the job for execution
- The job is sent to its original MoM for execution
- The MoM runs the restart script

9.3.7.6.i Restrictions on Holding a Job

A job in the process of provisioning cannot be held.

The `qhold` command can be used on jobs and job arrays, but not on subjobs or ranges of subjobs.

If the job cannot be checkpointed and aborted, `qhold` simply sets the job's Hold_Types attribute. The job continues to execute.

The checkpoint-abort script must terminate all job processes, or the `qhold` command will appear to hang.

9.3.7.7 Periodic Application Checkpoint

The snapshot checkpoint script can trigger checkpoint by a job's application, if the application is written to support checkpointing itself. Note that an application may be designed to be checkpointed at specific stages in its execution, rather than at specific points in time. If an application can be usefully checkpointed at specific points in time, then snapshot checkpointing may be useful. See section 9.3.7.1, “Periodic Job Checkpointing”, on page 431.

9.3.7.8 Manual Application Checkpoint

When an application is checkpointed manually, the user triggers checkpointing by the application by sending the application a specific signal, or by creating a file.

9.3.8 Advice and Caveats

9.3.8.1 PBS_NODEFILE Required

Make sure that the $PBS_NODEFILE is available during restart.

9.3.8.2 Sockets and Checkpointing

Multi-vnode jobs may cause network sockets to be opened between submission and execution hosts, and open sockets may cause a checkpointing script or tool to fail. The following use sockets:

- An interactive job, i.e. a job submitted using `qsub -I`, opens unprivileged sockets. `qsub` binds a socket to a port, then waits to accept a connection from MoM on that socket. Data from standard in is written to the socket and data from the socket is written to standard out.
- The `pbs_demux` process collects `stdio` streams from all tasks
- The `pbsdsh` program spawns tasks. The `-o` option to this command prevents it from waiting for spawned tasks to finish, so that no socket is left open to the MoM to receive task manager events. When the `-o` option is used, the shell must use some other method to wait for the tasks to finish. See “pbsdsh” on page 30 of the PBS Professional Reference Guide.

9.3.9 Accounting

If a job is checkpointed and requeued, the exit status passed to the epilogue and recorded in the accounting record is the following:

-12, meaning that the job was checkpointed and aborted

A checkpoint ("*C*") record is written in the accounting log when the job is checkpointed and requeued, as when the `qhold` command is used, or the job is checkpointed and aborted.

9.4 Reservation Fault Tolerance

If the vnodes associated with an advance reservation, the soonest occurrence of a standing reservation, or a job-specific reservation become unavailable, PBS marks the reservation as *degraded* (state *10*). If the vnodes are instead taken over by a maintenance reservation, PBS marks the reservation as *in conflict* (state *12*).

PBS attempts to reconfirm degraded or in-conflict reservations by finding replacements for vnodes that have become unavailable.

When a reservation is degraded, PBS may still be able to use the unavailable original vnodes, if they become available in time. When a reservation is in conflict, the vnodes that were taken over by the maintenance reservation are removed from the reservation; they are no longer in the reservation's resv_nodes attribute, and PBS looks for other vnodes.

States of available vnodes:

free

busy

job-exclusive

job-sharing

job-busy

States of unavailable vnodes:

down

maintenance

offline

provisioning

stale

state-unknown, down

unresolvable

wait-provisioning

9.4.1 States for Degraded and In-conflict Reservations

A degraded reservation's state becomes *RESV_DEGRADED*, abbreviated DG, and its substate becomes *RESV_DEGRADED*.

If vnodes associated with an occurrence later than the soonest occurrence of a standing reservation become unavailable, the reservation stays in state *RESV_CONFIRMED*, but its substate becomes *RESV_DEGRADED*.

During the time that a degraded advance or job-specific reservation, or the soonest occurrence of a degraded standing reservation is running, its state is *RESV_RUNNING*, and its substate is *RESV_DEGRADED*.

An in-conflict reservation's state becomes *RESV_IN_CONFLICT*, abbreviated IC, and its substate becomes *RESV_IN_CONFLICT*.

For a table of degraded and in-conflict reservation states and substates, see "Degraded Reservation Substates" on page 370 of the PBS Professional Reference Guide. For a table of numeric values for reservation states and substates, see "Reservation States" on page 369 of the PBS Professional Reference Guide.

9.4.2 Finding Replacement Vnodes for Degraded and In-conflict Reservations

PBS attempts to reconfirm reservations by finding replacements for vnodes that have become unavailable. If a reservation is not running, PBS will use any available vnodes. If it is running, PBS retains usable vnodes from the original reservation.

PBS attempts to reconfirm a reservation only during periods when this makes sense:

- If a reservation is not actively running, PBS waits the time specified in reserve_retry_time, then starts periodically trying to reconfirm the reservation, including making an attempt to reconfirm the reservation just before the start time of each occurrence.
- If an in-conflict reservation is actively running, PBS does not attempt to reconfirm it.
- If a degraded reservation is actively running, and the reservation is not in conflict, and the reservation has no running jobs on the unavailable vnodes, PBS periodically attempts to reconfirm it every reserve_retry_time seconds.
- If an actively running reservation is degraded because a vnode becomes unavailable, and the reservation has running jobs:
  - If the unavailable vnode has any jobs running on it, PBS waits until those jobs are finished to periodically attempt to reconfirm the reservation.
  - If the unavailable vnode has no jobs running on it, PBS does not wait until the jobs are finished to periodically attempt to reconfirm the reservation. PBS periodically attempts to reconfirm it every reserve_retry_time seconds.

A degraded or in-conflict reservation has a read-only reservation attribute called reserve_retry, whose value is the next time at which the reservation is due to be reconfirmed.

9.4.2.1 Attributes Affecting Reservation Reconfirmation

reserve_retry_time

Server attribute. The time period between attempts to reconfirm the reservation.

Settable by Manager; readable by all

Format: Integer (seconds)

Values: Must be greater than *zero*

Default: *600* (10 minutes)

Python attribute value type: int

9.4.3 Allocating New Vnodes

Once new vnodes are allocated for a reservation:

- The reservation has been confirmed
- If the reservation is not running, the state and substate of the reservation are *RESV_CONFIRMED*
- If the reservation is running, the state of the reservation is *RESV_RUNNING* and the substate is *RESV_CONFIRMED*
- The reservation's resv_nodes attribute lists the new vnodes

9.4.4 Restarting the Server

When the server is restarted, reservations are assumed confirmed until associated vnodes are recognized as unavailable. If any reservations become degraded or in conflict after a server restart, PBS sets the time when the reservation becomes degraded to the time of the restart. If a vnode is set *offline* before the restart, it is considered unavailable after the restart, so all its associated reservations become degraded.

9.5 Vnode Fault Tolerance for Job Start and Run

PBS lets you allocate extra vnodes to a job so that the job can successfully start and run even if some vnodes fail. You can allocate the extra vnodes only for startup, or for the life of the job. Later, for jobs where the extra vnodes are needed only for reliable startup, you can trim the allocated vnodes back to just what the job will use to run, releasing the unneeded vnodes for other jobs.

You allocate extra vnodes in a queuejob hook using the pbs.select.increment_chunks() method, and you release vnodes in an execjob_launch or execjob_prologue hook using the pbs.event().job.release_nodes() method.

We provide an example hook in `$PBS_EXEC/unsupported/ReliableJobStartup.py`.

9.5.1 Overview of Padding and Trimming Vnode Requests

Here is an overview of the steps for improving job startup and run reliability. We describe each of them in detail in the next subsections, and we give an example at the end of this section.

- Use a queuejob hook to do the following:
    - Save the job's initial vnode request
    - Set the job's tolerate_node_failures attribute to the desired value
    - Pad the job's vnode request
- Configure primary MoMs to wait for sister MoMs to acknowledge joining job
- Configure primary MoMs to wait for hooks to complete
- Use an execjob_launch or execjob_prologue hook to trim the vnodes not used by the job from the job's vnode request

9.5.2 Saving Job Initial Vnode Request

To save the job's initial resource request so that you know how much to trim later, use a queuejob hook to save it into a built-in resource such as the site resource (currently, it cannot be a custom resource). Here is a code snippet:

```
import pbs
e=pbs.event()
j = e.job
e.job.Resource_List["site"] = str(e.job.Resource_List["select"])
```

9.5.3 Configuring Primary MoMs to Wait for Sister MoMs

When the primary MoM gets a job whose tolerate_node_failures attribute is set to *all* or *job_start*, the primary MoM can wait to start the job for up to a configured number of seconds if the sister MoMs do not immediately acknowledge joining the job. This gives the sister MoMs more time to join the job. You configure the number of seconds for the primary MoM to wait for sister MoMs via the sister_join_job_alarm configuration parameter in MoM's config file:

```
$sister_join_job_alarm <number of seconds to wait>
```

The default value for this parameter is the sum of the values of the alarm attributes of any enabled execjob_begin hooks. If there are no enabled execjob_begin hooks, the default value is 30 seconds. For example, if there are two enabled execjob_begin hooks, one with alarm = 30 and one with alarm = 20, the default value of MoM's sister_join_job_alarm is 50 seconds.

After all the sister MoMs have joined the job, or MoM has waited for the value of the sister_join_job_alarm parameter, she starts the job.

9.5.4 Configuring MoMs to Wait for Hooks

When the primary MoM gets a job whose tolerate_node_failures attribute is set to *all* or *job_start*, the primary MoM can wait to start the job (running the job script or executable) for up to a configured number of seconds. During this time, execjob_prologue hooks can finish and the primary MoM can check for communication problems with sister MoMs. You configure the number of seconds for the primary MoM to wait for hooks via the job_launch_delay configuration parameter in MoM's config file:

```
$job_launch_delay <number of seconds to wait>
```

The default value for this parameter is the sum of the values of the alarm attributes of any enabled execjob_prologue hooks. If there are no enabled execjob_prologue hooks, the default value is 30 seconds. For example, if there are two enabled execjob_prologue hooks, one with alarm = 30 and one with alarm = 60, the default value of MoM's job_launch_delay is 90 seconds.

After all the execjob_prologue hooks have finished, or MoM has waited for the value of the job_launch_delay parameter, she starts the job.

9.5.4.1 Caveats for Configuring MoMs to Wait for Hooks

This configuration option is not supported under Windows.

9.5.5 Padding Vnode Request

To add extra vnodes to a job's vnode request, specify for the job whether you want more vnodes for startup, for the life of the job, or not at all, and specify how you want to pad the job's vnode request.

9.5.5.1 Specifying Whether and When to Pad Vnode Request

To specify whether and when the job gets extra vnodes, set the job's tolerate_node_failures attribute to one of *none*, *job_start*, or *all*.

Table 9-9: Behavior for tolerate_node_failures

Value of tolerate_node_failures	Behavior
none or unset	No extra vnodes are allocated to the job. Default behavior.
job_start	Extra vnodes are allocated only long enough to start the job successfully. Tolerate vnode failures that occur only during job start, just before executing the job's top level shell or executable or any execjob_launch hooks. Failures tolerated are those such as an assigned sister MoM failing to join the job and communication errors between MoMs.
all	Extra vnodes are allocated for the life of the job. Tolerate all node failures resulting from communication problems, such as polling problems, between the primary MoM and the sister MoMs assigned to the job Tolerate failures due to rejections from execjob_begin or execjob_prologue hooks run at sister MoMs.

9.5.5.1.i Setting the tolerate_node_failures Job Attribute

You or the job submitter can set the job's tolerate_node_failures attribute via `qsub`, `qalter`, or in a Python hook, for example a queuejob hook. If set via `qalter` while the job is already running, the attribute is consulted the next time the job is rerun.

You can set a value for tolerate_node_failures for all jobs via the server's default_qsub_arguments attribute.

Examples of setting this attribute:

- Via `qsub`:
  ```
  qsub -W tolerate_node_failures="all" <job script>
  ```
- Via `qalter`:
  ```
  qalter -W tolerate_node_failures="job_start" <job ID>
  ```
- Via a hook. The following code snippet shows how to set this attribute:
  ```
  # cat qjob.py
  import pbs
  e=pbs.event()
  e.job.tolerate_node_failures = "all"
  ```

9.5.5.2 Specifying How Chunks Are Padded

To specify how you want each chunk padded, use the pbs.select.increment_chunks(<increment specification>) method. This method increments the job's chunks according to the rules you give in the *increment specification*. See "Method to Increment select Object Chunks" on page 148 in the PBS Professional Hooks Guide.

9.5.5.2.i Example of Padding Chunks

The following code snippet illustrates padding a job's vnode request by one extra vnode per chunk:

```
import pbs
e=pbs.event()
j = e.job
new_select = e.job.Resource_List["select"].increment_chunks(1)
e.job.Resource_List["select"] = new_select
```

9.5.5.3 Caveats for Padding Vnode Requests

The tolerate_node_failures job attribute is not supported on Cray systems. It is ignored on Cray systems.

9.5.6 Trimming Vnode Request

When you trim a job's vnode request, you can trim the larger padded amount back to the job's initial vnode request. To trim a job's vnode request, use the pbs.event().job.release_nodes(keep_select) method. This method automatically selects vnodes that satisfy the new request and are healthy, keeps them in the job's vnode request, and releases all others. The method automatically trims out any vnodes in the pbs.event().vnode_list_fail[] list.

You can call pbs.event().job.release_nodes(keep_select = <desired vnodes>) in an execjob_launch or execjob_prologue hook. Note that despite the method being named "release_nodes", it **keeps** the specified vnodes and **releases** all other vnodes. You can specify the job's original vnode request as the vnodes to keep.

The pbs.event().job.release_nodes() method returns a PBS job object which has the updated values for the job's exec_vnode and Resource_List attributes.

See "Job Object Method to Release Vnodes" on page 128 in the PBS Professional Hooks Guide.

9.5.6.1 Example of Trimming Job Vnode Request

Here we use an execjob_prologue hook to trim a job's vnode request:

```
pj = e.job.release_nodes(keep_select="ncpus=2:mem=2gb+ncpus=2:mem=2gb+ncpus=1:mem=1gb")
if pj != None:
   pbs.logmsg(pbs.LOG_DEBUG, "pj.exec_vnode=%s" % (pj.exec_vnode,))
else:               # returned None job object, so we can put a hold on the job and requeue it,
    rejecting the hook event
   e.job.Hold_Types = pbs.hold_types("s")
   e.job.rerun()
   e.reject("unsuccessful at LAUNCH")
```

9.5.6.2 Offlining Vnodes that Have Gone Bad During Start or Run

See "Using List of Failed Vnodes to Offline Vnodes that Have Gone Bad During Start or Run" on page 66 in the PBS Professional Hooks Guide.

9.5.7 Checking Vnodes and Marking Them as Failed

For each execjob_prologue and execjob_launch event, PBS records the list of vnodes, with their assigned resources, that are marked as bad by MoM. PBS records this list in the pbs.event().vnode_list_fail[] object. See "The Failed Vnode List Event Member" on page 115 in the PBS Professional Hooks Guide.

Any sister vnodes that are able to join the job are considered healthy.

The successful outcome of a join job request may be the result of a check made by a remote execjob_begin hook. After successfully joining the job, the vnode may further check its status via a remote execjob_prologue hook. A rejection by the remote execjob_prologue hook causes the primary MoM to treat the sister vnode as a problem vnode, and the sister vnode is marked as unhealthy.

If there's an execjob_prologue hook in place, the primary MoM tracks vnode hosts that have acknowledged their execution of the execjob_prologue hook. Then after some job_launch_delay amount of time for job startup, the primary MoM starts reporting as failed vnodes those which have not given their positive acknowledgement during execjob_prologue hook execution.

If after some time, a vnode's host comes back with an acknowledgement of successful execjob_prologue hook execution, the primary MoM adds that host back to the healthy list.

You may want to offline any bad vnodes; see "Offlining Bad Vnodes" on page 66 in the PBS Professional Hooks Guide.

9.5.8 Example of Reliable Job Startup and Run

In order to have a job start reliably, we need these:

- A queuejob hook that does the following:
  - Makes the job tolerate vnode failures by setting the tolerate_node_failures job attribute to *job_start*
  - Adds extra chunks to the job's select specification using the pbs.event().job.select.increment_chunks() method
  - Saves the job's original vnode request into a built-in string resource (for example, "site")
- An execjob_launch hook that calls pbs.event().job.release_nodes() to trim the job's vnode request back to the original.

9.5.8.1 Example Queuejob Hook for Setup and Padding

We will use a queuejob hook called *qjob.py* in our example. In the queuejob hook:

- Make the job tolerant of failures:
  ```
  import pbs
  e=pbs.event()
  j = e.job
  j.tolerate_node_failures = job_start
  ```
- Save the job's initial vnode request in the built-in resource named *site*:
  ```
  e.job.Resource_List["site"] = str(e.job.Resource_List["select"])
  ```
- Add extra chunks to the vnode request:
  ```
  new_select = e.job.Resource_List["select"].increment_chunks(1)
  e.job.Resource_List["select"] = new_select
  ```

Instantiate the queuejob hook:

```
# qmgr -c "c h qjob event=queuejob"
# qmgr -c "i h qjob application/x-python default qjob.py"
```

9.5.8.2 Example Hook for Trimming

We will use an execjob_launch hook named *launch.py* to trim the job's padded vnode request back to the original vnode request. This hook runs before the job executes.

```
import pbs
e=pbs.event()
if 'PBS_NODEFILE' not in e.env:
    e.accept()
j = e.job
pj = j.release_nodes(keep_select=e.job.Resource_List["site"])
if pj is None:       # not successful pruning the vnodes
    j.rerun()        # rerun (requeue) the job
    e.reject("something went wrong pruning the job back to its original select request")
```

Instantiate the execjob_launch hook:

```
# qmgr -c "c h launch event=execjob_launch"
# qmgr -c "i h launch application/x-python default launch.py"
```

9.5.8.3 Example Job

Here is our example job:

```
% cat jobr.scr
#PBS -l select="ncpus=3:mem=1gb+ncpus=2:mem=2gb+ncpus=1:mem=3gb"
#PBS -l place=scatter:excl

echo $PBS_NODEFILE
cat $PBS_NODEFILE
echo END
echo "HOSTNAME tests"
echo "pbsdsh -n 0 hostname"
pbsdsh -n 0 hostname
echo "pbsdsh -n 1 hostname"
pbsdsh -n 1 hostname
echo "pbsdsh -n 2 hostname"
pbsdsh -n 2 hostname
echo "PBS_NODEFILE tests"
for host in `cat $PBS_NODEFILE`
do
    echo "HOST=$host"
    echo "pbs_tmrsh $host hostname"
    pbs_tmrsh $host hostname
    echo "ssh $host pbs_attach -j $PBS_JOBID hostname"
    ssh $host pbs_attach -j $PBS_JOBID hostname
done
```

9.5.8.4 Example of Job Vnode Assignment Padding and Trimming

When our job first starts, it is assigned 5 vnodes, because its select specification was modified by adding 2 vnodes:

```
% qstat -f 20
Job Id: 20.mars.example.com
...
exec_host = mars/0*3+jupiter/0*2+saturn/0*2+mercury/0+neptune/0
exec_vnode =
    (mars:ncpus=3:mem=1048576kb)+(jupiter:ncpus=2:mem=2097152kb)+(saturn:ncpus=2:mem=2097152kb)+
    (mercury:ncpus=1:mem=3145728kb)+(neptune:ncpus=1:mem=3145728kb)
Resource_List.mem = 11gb
Resource_List.ncpus = 9
Resource_List.nodect = 5
Resource_List.place = scatter:excl
Resource_List.select = ncpus=3:mem=1gb+2:ncpus=2:mem=2gb+2:ncpus=1:mem=3gb
Resource_List.site = 1:ncpus=3:mem=1gb+1:ncpus=2:mem=2gb+1:ncpus1:mem=3gb

tolerate_node_failures = job_start
```

Now jupiter and neptune go down, and just before the job runs its program, the execjob_launch hook executes and prunes the job's vnode assignment back to the original select request. Now the job has this vnode assignment:

```
% qstat -f 20
Job Id: 20.mars.example.com
...
exec_host = mars/0*3+saturn/0*2+mercury/0*2
exec_vnode =
    (mars:ncpus=3:mem=1048576kb)+(saturn:ncpus=2:mem=2097152kb)+(mercury:ncpus=1:mem=3145728kb)
Resource_List.mem = 6gb
Resource_List.ncpus = 6
Resource_List.nodect = 3
Resource_List.place = scatter:excl
Resource_List.select = 1:ncpus=3:mem=1gb+1:ncpus=2:mem=2gb+1:ncpus1:mem=3gb

Resource_List.site = 1:ncpus=3:mem=1gb+1:ncpus=2:mem=2gb+1:ncpus1:mem=3gb
```

A snapshot of the job's output shows the pruned list of vnodes:

```
/var/spool/PBS/aux/20.mars.example.com <-- updated contents of $PBS_NODEFILE
mars.example.com
saturn.example.com
mercury.example.com
END

HOSTNAME tests

pbsdsh -n 0 hostname
mars.example.com
pbsdsh -n 1 hostname
saturn.example.com
pbsdsh -n 2 hostname
mercury.example.com

PBS_NODEFILE tests
HOST=mars.example.com
pbs_tmrsh mars.example.com hostname
mars.example.com
ssh mars.example.com pbs_attach -j 20.mars.example.com hostname
mars.example.com
HOST=saturn.example.com
pbs_tmrsh saturn.example.com hostname
saturn.example.com
ssh saturn.example.com pbs_attach -j 20.mars.example.com hostname
saturn.example.com
HOST=mercury.example.com
pbs_tmrsh mercury.example.com hostname
mercury.example.com
ssh mercury.example.com pbs_attach -j 20.mars.example.com hostname
mercury.example.com
```

9.6 Preventing Communication and Timing Problems

9.6.1 Introduction

PBS communicates with remote execution hosts in order to track their availability and manage the jobs running on them. PBS is dependent upon your network for this communication. If there are network outages, or if the execution node becomes too busy for MoM to be able to respond to the server's queries, PBS will not be able to function properly. You can configure PBS to be better able to withstand these types of communication issues.

The following attributes and parameters control how PBS handles communication timing:

Table 9-10: Attributes and Parameters For Communication and Timing

Attribute or Parameter	Description	Cross Reference
Server Attributes		
job_requeue_timeout	Controls how long the process of requeueing a job is allowed to take	See section 9.6.3, “Setting Job Requeue Timeout”, on page 447
node_fail_requeue	Controls how long the server waits before requeueing or deleting a job when it loses contact with the MoM on the job's primary execution host	See section 9.6.2, “Node Fail Requeue: Jobs on Failed Vnodes”, on page 445
rpp_max_pkt_check	Maximum number of TPP messages processed by the main server thread per iteration. Default: 64	See “Communication” on page 45 in the PBS Professional Installation & Upgrade Guide
rpp_retry	Server attribute. In a fault-tolerant setup (multiple `pbs_comms`), when the first `pbs_comm` fails partway through a message, this is number of times TPP tries to use any other remaining `pbs_comms` to send the message. Integer Valid values: *Greater than or equal to zero* Default: *10* Python type: *int*	See “Communication” on page 45 in the PBS Professional Installation & Upgrade Guide
rpp_highwater	Server attribute. This is the maximum number of messages per stream (meaning the maximum number of messages between each pair of endpoints). Integer Valid values: *Greater than or equal to one* Default: *1024* Python type: *int*	See “Communication” on page 45 in the PBS Professional Installation & Upgrade Guide
MoM Configuration Parameters		
$max_load	Vnode is considered to be *busy* if it is above this load.	See section 9.6.5, “Managing Load Levels on Vnodes”, on page 447
$ideal_load	Vnode is considered to be not *busy* if it is below this load.	See section 9.6.5, “Managing Load Levels on Vnodes”, on page 447
$prologalarm	Maximum number of seconds the prologue and epilogue may run before timing out	See section 9.6.6, “Prologue & Epilogue Running Time”, on page 449
Queue Attributes		
route_retry_time	Interval between retries at routing a job	See section 9.6.7, “Time Between Routing Retries”, on page 450

See “Robust Communication with TPP” on page 52 in the PBS Professional Installation & Upgrade Guide.

9.6.2 Node Fail Requeue: Jobs on Failed Vnodes

The node_fail_requeue server attribute controls how long the server waits before requeueing or deleting a job when it loses contact with the MoM on the job's primary execution host.

9.6.2.1 How Node Fail Requeue Works

You can specify how long the server waits after it loses contact with the primary execution host before deleting or requeueing her jobs. This behavior is controlled by the server's node_fail_requeue attribute.

This attribute's value is the delay between the time the server determines that the primary execution host MoM cannot be contacted and the time it requeues the job, and does not include the time it takes to determine that the host is out of contact.

If this attribute is set to a value other than zero, and the server loses contact with an execution host, all jobs for which this is the primary execution host are requeued or deleted at the same time.

If node_fail_requeue is unset, and the host where primary execution is running fails, the server assumes that the job is still running until one of the following happens:

- The primary execution host MoM comes back up and tells the server to requeue the job
- The job is manually rerun

9.6.2.2 Effect Of Requeueing On Jobs

When a job is thus requeued, it retains its original place in its execution queue with its former priority. The job is usually the next job to be considered during scheduling, unless the relative priorities of the jobs in the queue have changed. This can happen when the job sorting formula assigns higher priority to another job, another higher-priority job is submitted after the requeued job started, this job's owner has gone over their fairshare limit, etc.

Any resources that were being used by a job are freed when the job is requeued.

9.6.2.3 The node_fail_requeue Server Attribute

Format: *Integer*

9.6.2.3.i Allowable Values

The node_fail_requeue attribute can take these values:

Greater than zero

The server waits for the specified number of seconds after losing contact with a primary execution host MoM, then attempts to contact the primary execution host MoM, and if it cannot, requeues any jobs that can be rerun and deletes any jobs that cannot be rerun.

Zero

Jobs are not requeued; they are left in the *Running* state until the execution host MoM is recovered, whether or not the server has contact with their primary execution host MoM.

Less than zero

The attribute is treated as if it were set to *1*, and jobs are deleted or requeued after the server has been out of contact with the primary execution host MoM for 1 second.

Unset

Behaves as if set to the default value of *310*.

9.6.2.3.ii Default Value

The default value for this attribute is *310*, meaning that when the server loses contact with an execution host, it waits for 310 seconds after losing contact with the primary execution host MoM before requeueing or deleting jobs.

9.6.2.4 Where node_fail_requeue Applies

The server's node_fail_requeue attribute applies only in the case where the server loses contact with the primary execution host MoM.

When the primary execution host MoM loses contact with a sister MoM, the job is immediately deleted or requeued.

9.6.2.5 Jobs Eligible to be Requeued

Jobs are eligible to be requeued if they meet either of the following criteria:

- The job's Rerunable attribute is set to *y*
- The job did not begin execution, for example:
  - a multi-host job did not start on one or more vnodes
  - provisioning failed for the job

Jobs are ineligible to be requeued if their Rerunable attribute is set to *n* and they have started execution.

See “Job Attributes” on page 330 of the PBS Professional Reference Guide and “Server Attributes” on page 283 of the PBS Professional Reference Guide.

9.6.2.6 Using node_fail_requeue

The number of seconds selected should be long enough to exceed any transient non-vnode failures, but short enough to requeue the job in a timely fashion. Transient non-vnode failures can prevent MoM from reporting back to the server before the server marks the vnode *down*. These include:

- Network outages
- Vnode is too busy to respond, perhaps due to heavy swapping

Using this feature requires that you take the following into account:

- If the host where the primary execution host MoM is running fails, and node_fail_requeue is unset, the server assumes that the job is still running until one of the following happens:
  - The primary execution host MoM comes back up and tells the server to requeue the job
  - The job is manually rerun

  If your site has hosts that fail and are not monitored, failed jobs may go unnoticed for a long time.
- If your network has temporary failures, and node_fail_requeue is set to a duration shorter than the outage, jobs will be unnecessarily requeued. This can be especially annoying when the job has been running for days.

9.6.2.7 Advice and Caveats

- If your site experiences frequent network failures or your execution hosts are often too busy to respond to the server, it is recommended that you either set node_fail_requeue to a value greater than the time MoM is unavailable, or set it to *zero*. This way jobs won't be requeued just because the network had a temporary outage or the vnode was too busy. Choose a value greater than both the longest likely network outage time and the time MoM is unavailable. For example, one site has set the value to 10 minutes, and another has set it to 15 minutes (900 seconds) to avoid problems due to swapping.
- The value shown in the server log for the time between losing communication and requeueing a job is sometimes one or two seconds less than the specified value.
- If the server is restarted when node_fail_requeue is set to a given value, node_fail_requeue retains that value. If the server is started when node_fail_requeue is unset, node_fail_requeue reverts to its default value.

9.6.3 Setting Job Requeue Timeout

When jobs are preempted via requeueing, the requeue can fail if the job being preempted takes longer than the allowed timeout. The time for requeueing includes post-processing such as staging files out, deleting files, and changing the job's state from *R* to *Q*. See section 4.9.33, "Using Preemption", on page 182. The time allowed for a job to be requeued is controlled by the job_requeue_timeout server attribute.

You can use `qmgr` to set the job_requeue_timeout server attribute to a value that works for the jobs at your site. This attribute is of type Duration, with a minimum allowed value of 1 second and a maximum allowed value of 3 hours. The default timeout is 45 seconds. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

9.6.4 Setting MoM Reconnection Timeout

When the primary execution host MoM detects that a sister mom has lost connectivity (e.g. MoM went down or the network is having problems) it waits for a specified amount of time for the sister to reconnect before it gives up and kills the job. You can configure the time the primary execution host MoM waits by setting MoM's $max_poll_downtime parameter in `PBS_HOME/mom_priv/config`. The default value is five minutes.

9.6.5 Managing Load Levels on Vnodes

An overloaded execution host may end up too busy for MoM to respond to the server's queries, and causing the server to mark the MoM as *down*.

PBS can track the state of each execution host, running new jobs on the host according to whether the host is marked *busy* or not.

This behavior is somewhat different from load balancing, described in section 4.9.27, "Using Load Balancing", on page 158. In load balancing, the scheduler estimates how much load a job would produce, and will not place a job where doing so would put the load above the limit. When managing load levels on vnodes as described here, the scheduler uses the state of the vnode to determine whether to place a job on that vnode.

The state of the vnode is set by MoM, according to its load. You can set two load levels using the $max_load and $ideal_load MoM configuration parameters. When the load goes above $max_load, the vnode is marked as *busy*. When the load drops below $ideal_load, the vnode is marked *free*.

PBS does not run new jobs on vnodes under the following conditions:

- Vnodes that are marked *busy*
- Vnodes whose resources, such as ncpus, are already fully allocated
- Vnodes where the load is above $max_load, when load balancing is turned on. See section 4.9.27, "Using Load Balancing", on page 158.
- Vnodes where running the job would cause the load to go above $max_load, when load balancing is turned on. See section 4.9.27, "Using Load Balancing", on page 158.

The load used by MoM is the following:

- On Linux, it is the raw one-minute averaged "loadave" returned by the operating system
- On Windows, it is based on the processor queue length

The $max_load and $ideal_load MoM configuration parameters are also used for cycle harvesting (see section 4.9.9.6, "Cycle Harvesting Based on Load Average", on page 123) and load balancing (see section 4.9.27, "Using Load Balancing", on page 158.)

MoM checks the load average on her host every 10 seconds.

When a vnode's state changes, for example from *free* to *busy*, MoM informs the server.

9.6.5.1 Techniques for Managing Load

Whether or not you set $max_load, PBS will not run jobs requesting a total of more than the available number of CPUs, which is set in resources_available.ncpus. So for example if resources_available.ncpus is set to *4*, and a job running on the vnode has requested 2 CPUs, PBS will not run jobs requesting a total of more than 2 CPUs.

9.6.5.1.i Types of Workload

How you manage load depends on your workload. Some jobs do not lend themselves to sharing CPUs, but some jobs can share CPUs without being hindered. Most MPI jobs would be hindered if some processes had to wait because others were slowed by sharing a CPU. If you need a job to have reproducible timing, it cannot share a CPU. Certain single-vnode jobs that alternate between CPU usage and I/O can share a CPU without being slowed significantly, thereby increasing throughput.

9.6.5.1.ii How Not To Share CPUs

For vnodes primarily running jobs that would be slowed or invalidated by sharing a CPU, have PBS assign jobs according to the number of available CPUs, so that there is no sharing of CPUs. Set resources_available.ncpus to the number of available CPUs. Do not set $max_load or $ideal_load.

9.6.5.1.iii How To Share CPUs

For vnodes running only jobs that can share CPUs, you can have PBS manage jobs according to the load on the vnodes, not the number of CPUs. This is called oversubscribing the CPUs. Set resources_available.ncpus to a value greater than the actual number of CPUs, such as two or three times the actual number. Set $max_load to a reasonable value so that PBS will run new jobs until $max_load is reached. Set $ideal_load to the minimum load that you want on the vnode.

9.6.5.1.iv Suspending Jobs on Overloaded Vnodes

You can specify that MoM should suspend jobs when the load goes above $max_load, by adding the suspend argument to the $max_load parameter. See section , "$max_load <load> [suspend]", on page 449. In this case, MoM suspends all jobs on the vnode until the load drops below $ideal_load, then resumes them. This option is useful only when the source of the load includes work other than PBS jobs. This option is not recommended when the load is due solely to PBS jobs, because it can lead to the vnode cycling back and forth between being overloaded, being marked busy, suspending all jobs, being marked free, then starting all jobs, being overloaded, and so on.

9.6.5.2 Caveats and Recommendations

- It is recommended that the value for $ideal_load be lower than the value for $max_load. The value for $ideal_load should be low enough that new jobs are not run before existing jobs are done using the vnode's spare load.
- If you set only one of $max_load and $ideal_load, for example you set $max_load, but not $ideal_load, PBS sets the other to the same value.
- Do not allow reservations on hosts where $max_load and $ideal_load are configured. Set the resv_enable vnode attribute on these hosts to *False*.
- If you are using cycle harvesting via load balancing, be careful with the settings for $ideal_load and $max_load. You want to make sure that when the workstation owner is using the machine, the load on the machine triggers MoM to report being busy, and that PBS does not start any new jobs while the user is working. See section 4.9.9.6, "Cycle Harvesting Based on Load Average", on page 123.

9.6.5.2.i Allowing Non-job Processes on Execution Host

If you wish to run non-PBS processes on a host, you can prevent PBS from using more than you want on that host. Set the $ideal_load and $max_load MoM configuration parameters to values that are low enough to allow other processes to use some of the host.

9.6.5.3 Load Configuration Parameters

$ideal_load <load>

MoM parameter. Defines the load below which the vnode is not considered to be busy. Used with the $max_load parameter.

Example:

```
$ideal_load 1.8
```

Format: *Float*

No default

$max_load <load> [suspend]

MoM parameter. Defines the load above which the vnode is considered to be busy. Used with the $ideal_load parameter.

If the optional suspend argument is specified, PBS suspends jobs running on the vnode when the load average exceeds $max_load, regardless of the source of the load (PBS and/or logged-in users).

Example:

```
$max_load 3.5
```

Format: *Float*

Default: number of CPUs

9.6.6 Prologue & Epilogue Running Time

Each time the scheduler runs a job, it waits for the prologue to finish before it runs another job. In order to prevent a hung prologue from halting job execution, prologues and epilogues are only allowed to run for a specified amount of time before PBS kills them. The running time is specified in the $prologalarm MoM configuration parameter. The default value for this parameter is *30 seconds*.

9.6.6.1 Prologue Timeout Configuration Parameter

$prologalarm <timeout>

Defines the maximum number of seconds the prologue and epilogue may run before timing out.

Example:

```
$prologalarm 30
```

Format: *Integer*

Default: *30*

9.6.7 Time Between Routing Retries

If the network is flaky, PBS may not be able to route a job from a routing queue to the destination queue. If all destination queues for a routing queue are at capacity, a job in a routing queue remains where it is. The time between routing retries is controlled by the route_retry_time queue attribute.

If the network experiences long outages, you may wish to set the time between retries to a sufficiently long time that PBS is not wasting cycles attempting to route jobs.

If jobs in a routing queue are not being routed because the destination queues are full, and most jobs are long-running jobs, you may wish to set the time between retries so that attempts are infrequent. It is recommended that the time between retries be no longer than the longest time acceptable to have an open slot in an execution queue.

9.6.7.1 Routing Retry Attribute

route_retry_time

Time delay between routing retries. Typically used when the network between servers is down. Used only with routing queues.

Format: *Integer seconds*

Default: *30 seconds*

Python type: pbs.duration

9.7 Preventing File System Problems

9.7.1 Avoid Filling Location of Temp Files for PBS Components

When the location used by PBS components to store temporary files becomes full, various failures may result, including jobs not initializing properly. To help avoid this, you can set the root directory for these files to a location less likely to fill up. See section 15.8, “Temporary File Location for PBS Components”, on page 569.

In addition, we recommend periodic cleaning of this location.

9.7.2 Avoid Filling Filesystem with Log Files

You must avoid having log files fill up the available space. You may have to rotate and archive log files frequently to ensure that adequate space remains available. See “Adequate Space for Logfiles” on page 8 in the PBS Professional Installation & Upgrade Guide.

9.8 OOM Killer Protection

PBS automatically protects against OOM killers. If the system hosting a PBS daemon or data service runs low on memory, the system may use an out-of-memory killer (OOM killer) to terminate processes. The PBS daemons and data service are protected from being terminated by an OOM killer.

10 Using MPI with PBS

10.1 Integration with MPI

PBS Professional is integrated with several implementations of MPI. When PBS is integrated with an MPI, PBS can track resource usage, control jobs, clean up job processes, perform accounting for all of the tasks run under the MPI, and create TMPDIR on each of the job's hosts.

When PBS is not integrated with an MPI, PBS can track resource usage, clean up processes, and perform accounting only for processes running on the primary host. This means that accounting and tracking of CPU time and memory aren't accurate, and job processes on sister hosts cannot be signaled.

10.2 Prerequisites

Before you integrate an MPI with PBS, the MPI must be working by itself. For example, you must make sure that all required environment variables are set correctly for the MPI to function.

10.3 Types of Integration

PBS provides support for integration for many MPIs. You can integrate MPIs with PBS using the following methods:

- Intel MPI 4.0.3 on Linux uses `pbs_tmrsh` when it sees certain environment variables set. No other steps are required. See section 10.5, "Integrating Intel MPI 4.0.3 On Linux Using Environment Variables", on page 455.
- Wrapping the MPI with a PBS-supplied script which uses the TM (task manager) interface to manage job processes. PBS supplies a master script to wrap any of several MPIs. See section 10.10, "Integration by Wrapping", on page 457
- PBS supplies wrapper scripts for some MPIs, for wrapping those MPIs by hand. See section 10.13, "Integration By Hand", on page 462
- For non-integrated MPIs, job scripts can integrate the MPIs on the fly using the `pbs_tmrsh` command. Note that a PBS job script that uses `mpirun` with `pbs_tmrsh` cannot be used outside of PBS. See section 10.9, "Integration on the Fly using the pbs_tmrsh Command", on page 456 and "Integrating an MPI on the Fly", on page 83 of the PBS Professional User's Guide.
- Some MPIs can be compiled to use the TM interface. See section 10.8, "Integration Using the TM Interface", on page 456
- Some MPIs require users to call `pbs_attach` See section 10.13.5, "Integrating HPE MPI", on page 467.
- Altair support can help integrate your MPI with PBS so that the MPI always calls `pbs_attach` when it calls `ssh`. If you would like to use this method, contact Altair support at www.pbsworks.com.

To integrate an MPI with PBS, you use just one of the methods above. The method you choose depends on the MPI. The following table lists the supported MPIs, how to integrate them, and gives links to the steps involved and any special notes about that MPI:

Table 10-1: List of Supported MPIs

MPI Name	Versions	Method	Integration Steps	MPI-specific Notes
HP MPI	1.08.03 2.0.0	Use `pbs_mpihp`	"Steps to Integrate HP MPI or Platform MPI"	"Integrating HP MPI and Platform MPI"
Intel MPI	4.0.3 on Linux	Set environment variables	"Integrating Intel MPI 4.0.3 On Linux Using Environment Variables"	None
Intel MPI	4.0.3 on Windows	Use wrapper script	"Integrating Intel MPI 4.0.3 on Windows Using Wrapper Script"	None
Intel MPI	2.0.022 3 4	Use `pbsrun_wrap` (**wrapper is deprecated**)	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
LAM MPI	6.5.9 **Support is deprecated.**	Use `pbs_mpilam` and `pbs_lamboot`	"Wrapping LAM MPI 6.5.9"	"Integrating LAM MPI and Open MPI"
LAM MPI	7.0.6 7.1.1 **Support for LAM is deprecated.**	Compile with TM	"Integration Using the TM Interface"	"Integrating LAM MPI and Open MPI"
MPICH-P4	1.2.5 1.2.6 1.2.7 **Support for all is deprecated.**	Use `pbs_mpirun`	"Steps to Integrate MPICH-P4"	"Integrating MPICH-P4"
MPICH-GM (MPICH 1.2.6.14b)	**Support for wrapper is deprecated.**	Use `pbsrun_wrap`	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
MPICH-MX	**Support for wrapper is deprecated.**	Use `pbsrun_wrap`	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
MPICH2	1.0.3 1.0.5 1.0.7 on Linux	Use `pbsrun_wrap`	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
MPICH2	1.4.1p1 on Windows	Use wrapper script	"Integrating MPICH2 1.4.1p1 on Windows Using Wrapper Script"	None

Table 10-1: List of Supported MPIs

MPI Name	Versions	Method	Integration Steps	MPI-specific Notes
MVAPICH	1.2 **Support for wrapper is deprecated.**	Use `pbsrun_wrap`	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
MVAPICH2	1.8	Use `pbsrun_wrap`	"Wrapping an MPI Using the pbsrun_wrap Script"	"Integration by Wrapping"
Open MPI	1.4.x	Compile with TM	"Integration Using the TM Interface"	"Integrating LAM MPI and Open MPI"
Platform MPI	8.0	Use `pbs_mpihp`	"Steps to Integrate HP MPI or Platform MPI"	"Integrating HP MPI and Platform MPI"
HPE MPI	Any	Optional: Use `mpiexec`, or users put `pbs_attach` in `mpirun` command line	"Steps to Integrate HPE MPI"	"Integrating HPE MPI"

10.4 Transparency to the User

Many MPIs can be integrated with PBS in a way that is transparent to the job submitter. This means that a job submitter can use the same MPI command line inside and outside of PBS. All of the MPIs listed above can be made to be transparent.

10.5 Integrating Intel MPI 4.0.3 On Linux Using Environment Variables

You can allow Intel MPI 4.0.3 to automatically detect when it runs inside a PBS job and use `pbs_tmrsh` to integrate with PBS. When it has detected that it is running in a PBS job, it uses the hosts allocated to the job.

On hosts running Intel MPI 4.0.3 that have `PBS_EXEC/bin` in the default PATH, set the following environment variables in `PBS_HOME/pbs_environment`:

```
I_MPI_HYDRA_BOOTSTRAP=rsh
I_MPI_HYDRA_BOOTSTRAP_EXEC=pbs_tmrsh
```

On hosts running Intel MPI 4.0.3 that do not have PBS_EXEC/bin in their default PATH, use the full path to `pbs_tmrsh`. For example:

```
I_MPI_HYDRA_BOOTSTRAP_EXEC=/opt/pbs/bin/pbs_tmrsh
```

The default process manager for Intel MPI 4.0.3 is Hydra.

10.5.1 Restrictions for Intel MPI 4.0.3

The unwrapped version of Intel MPI 4.0.3 `mpirun` on Linux does not support MPD.

10.6 Integrating Intel MPI 4.0.3 on Windows Using Wrapper Script

This version of PBS provides a wrapper script for Intel MPI 4.0.3 on Windows. The wrapper script is named pbs_intelmpi_mpirun.bat, and it is located in $PBS_EXEC\bin. This script uses pbs_attach to attach MPI tasks to a PBS job. You do not need to take any steps to integrate Intel MPI on Windows; job submitters must call the wrapper script inside their job scripts.

10.7 Integrating MPICH2 1.4.1p1 on Windows Using Wrapper Script

This version of PBS provides a wrapper script for MPICH2 1.4.1p1 on Windows. The wrapper script is named pbs_mpich2_mpirun.bat, and it is located in $PBS_EXEC\bin. This script uses pbs_attach to attach MPI tasks to a PBS job. You do not need to take any steps to integrate Intel MPI on Windows; job submitters must call the wrapper script inside their job scripts.

10.8 Integration Using the TM Interface

PBS provides an API to the PBS task manager, or TM, interface. You can configure an MPI to use the PBS TM interface directly.

When a job process is started on a sister host using the TM interface, the sister host's MoM starts the process and the primary host's MoM has access to job process information.

An MPI that we know can be compiled with the TM interface is Open MPI.

10.9 Integration on the Fly using the pbs_tmrsh Command

If using a non-integrated MPI, job submitters can integrate an MPI on the fly by using the pbs_tmrsh command. This command emulates rsh, but uses the TM interface to talk directly to pbs_mom on sister hosts. The pbs_tmrsh command informs the primary and sister MoMs about job processes on sister hosts. PBS can track resource usage for all job processes.

Job submitters use this command by setting the appropriate environment variable to pbs_tmrsh. For example, to integrate MPICH, set P4_RSHCOMMAND to pbs_tmrsh. For details, see "Integrating an MPI on the Fly", on page 83 of the PBS Professional User's Guide.

The following figure illustrates how a the `pbs_tmrsh` command can be used to integrate an MPI on the fly:

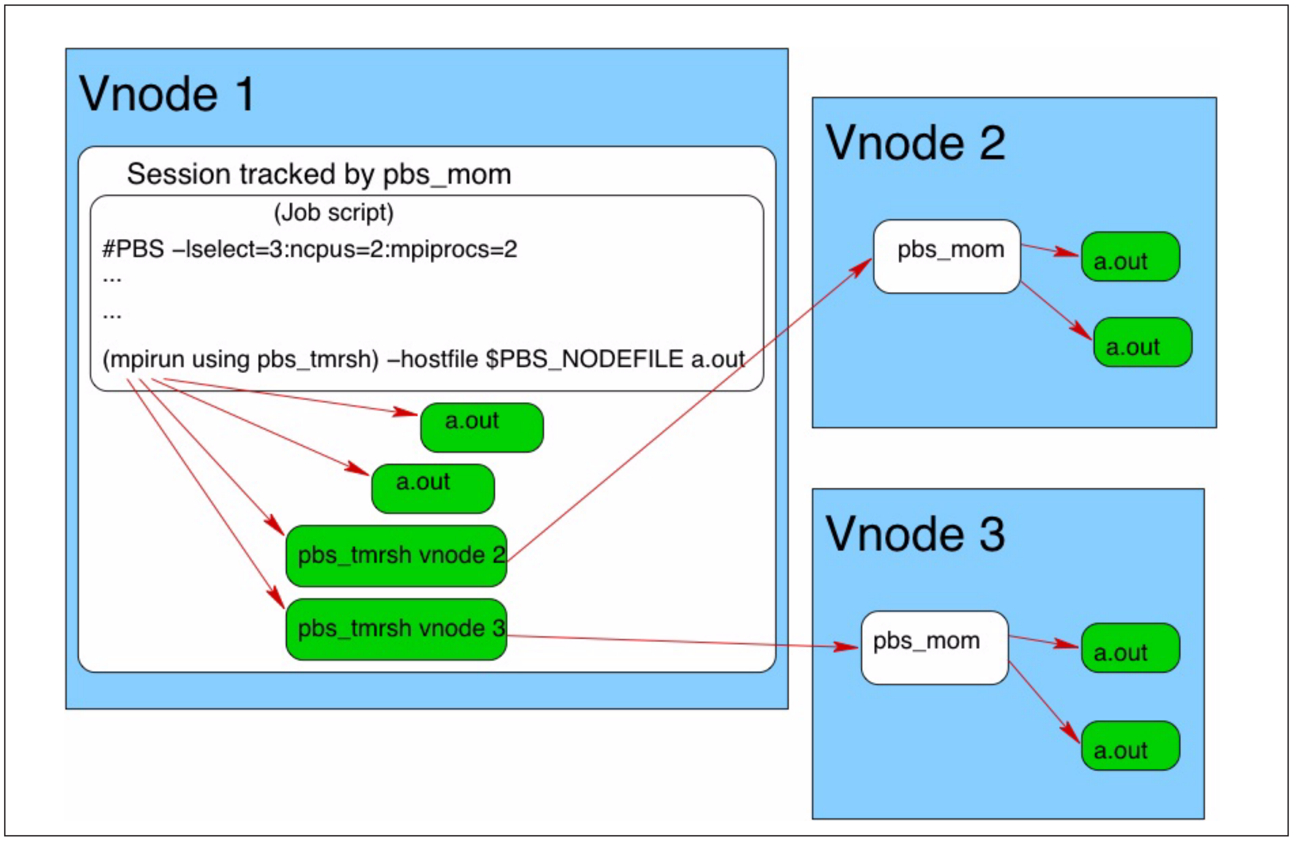


Figure 10-1: PBS knows about processes on vnodes 2 and 3, because `pbs_tmrsh` talks directly to `pbs_mom`, and `pbs_mom` starts the processes on vnodes 2 and 3

10.9.1 Caveats for the `pbs_tmrsh` Command

- This command cannot be used outside of a PBS job; if used outside a PBS job, this command will fail.
- The `pbs_tmrsh` command does not perform exactly like `rsh`. For example, you cannot pipe output from `pbs_tmrsh`; this will fail.

10.10 Integration by Wrapping

Wrapping an MPI means replacing its `mpirun` or `mpiexec` with a script which calls the original executable and, indirectly, `pbs_attach`. Job processes are started by `rsh` or `ssh`, but the `pbs_attach` command informs the primary and sister MoMs about the processes, so that PBS has control of the job processes. See "pbs_attach" on page 56 of the PBS Professional Reference Guide.

PBS provides a master script called `pbsrun_wrap` that you use to wrap many MPIs. PBS supplies special wrapper scripts so that you can wrap other MPIs by hand.

The following figure shows how a wrapped `mpirun` call works:

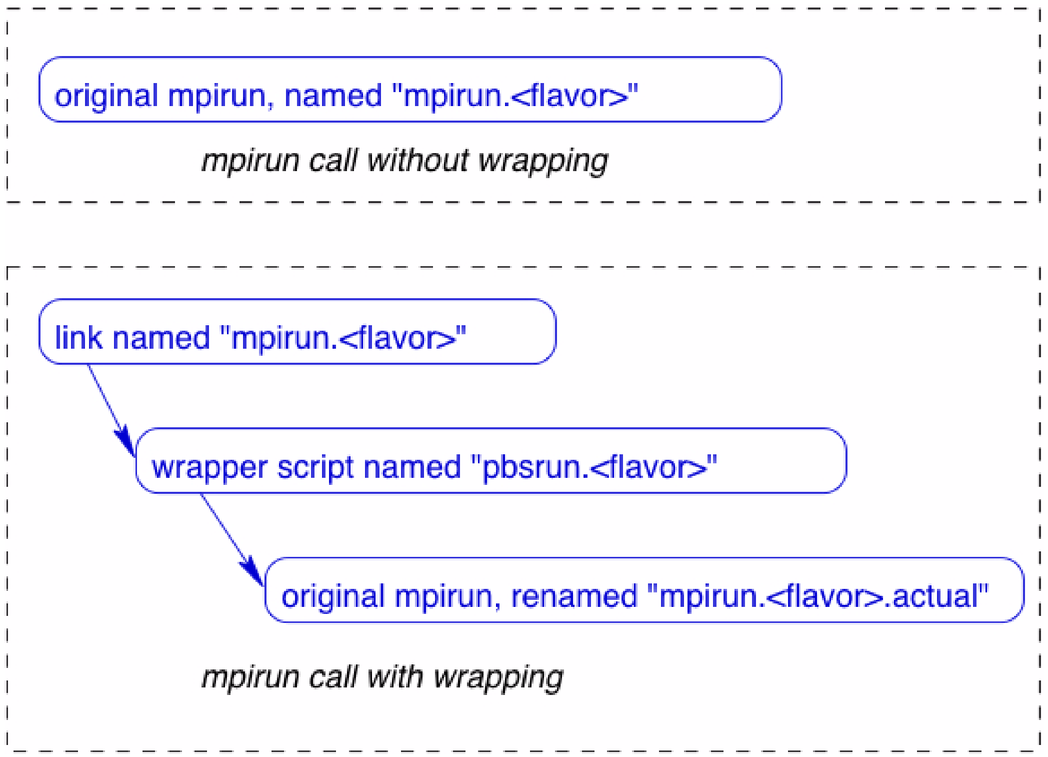

original mpirun, named "mpirun.<flavor>"
mpirun call without wrapping
link named "mpirun.<flavor>"
wrapper script named "pbsrun.<flavor>"
original mpirun, renamed "mpirun.<flavor>.actual"
mpirun call with wrapping

Figure 10-2:The job script calls the link that has the name of the original `mpirun`

10.10.1 Wrap the Correct Instance

Figure 10-3: The job script calls the link that has the name of the original `mpirun`

When you wrap an MPI, make sure that you are wrapping the first instance of the name found in the user's search path. This is the one returned by the 'which' command on Linux.

For example, on our example system `my_mpi` is installed as follows:

```
rwxrwxrwx 1 root system 31 Apr 18 19:21 /usr/bin/my_mpi -> /usr/my_mpi_dir/bin/my_mpi
```

And '`which`' returns the following:

```
bash-2.05b# which my_mpi
/usr/bin/my_mpi
```

Here, you must wrap the link, not the binary.

10.11 Wrapping an MPI Using the `pbsrun_wrap` Script

The master script is the `pbsrun_wrap` command, which takes two arguments: the `mpirun` to be wrapped, and a PBS-supplied wrapper. The `pbsrun_wrap` command neatly wraps the original `mpirun` so that everything is transparent for the job submitter. See "pbsrun_wrap" on page 52 of the PBS Professional Reference Guide, and "pbsrun" on page 41 of the PBS Professional Reference Guide.

The `pbsrun_wrap` command does the following:

- Renames the original, named *mpirun.<flavor>*, to *mpirun.<flavor>.actual*
- Instantiates the wrapper as *pbsrun.<flavor>*
- Creates a link named *mpirun.<flavor>* that calls `pbsrun.<flavor>`
- Creates a link so that `pbsrun.<flavor>` calls `mpirun.<flavor>.actual`

10.11.1 Passing Arguments

Any `mpirun` version/flavor that can be wrapped has an initialization script ending in "*.init*", found in `$PBS_EXEC/lib/MPI`:

```
$PBS_EXEC/lib/MPI/pbsrun.<mpirun version/flavor>.init
```

When executed inside a PBS job, the `pbsrun.<flavor>` script calls a version-specific initialization script which sets variables to control how the `pbsrun.<flavor>` script uses options passed to it. For example, `pbsrun.<flavor>` calls `$PBS_EXEC/lib/MPI/pbsrun.<flavor>.init` to manage the arguments passed to it. You can modify the `.init` scripts to specify which arguments should be retained, ignored, or transformed.

When the `mpirun` wrapper script is run inside a PBS job, then it translates any `mpirun` call of the form:

mpirun [options] <executable> [args]

into

mpirun [options] pbs_attach [special_option_to_pbs_attach] <executable> [args]

where *[special options]* refers to any option needed by `pbs_attach` to do its job (e.g. -j $PBS_JOBID).

See "Options" on page 42 of the PBS Professional Reference Guide for a description of how to customize the initialization scripts.

10.11.2 Restricting MPI Use to PBS Jobs

You can specify that a wrapped MPI can be used only inside of PBS, by using the `-s` option to the `pbsrun_wrap` command. This sets the strict_pbs option in the initialization script (e.g. `pbsrun.ch_gm.init`, etc...) to *1* from the default of *0*. This means that the `mpirun` being wrapped by `pbsrun` will be executed only when it is called inside a PBS environment. Otherwise, the user gets the following error:

```
Not running under PBS
exiting since strict_pbs is enabled; execute only in PBS
```

By default, when the wrapper script is executed outside of PBS, a warning is issued about "not running under PBS", but it proceeds as if the actual program had been called in standalone fashion.

10.11.3 Format of `pbsrun_wrap` Command

The `pbsrun_wrap` command has this format:

pbsrun_wrap [-s] <path_to_actual_mpirun> pbsrun.<keyword>

Make sure that you wrap the correct instance of the `mpirun`. If a user's job script would call a link, wrap the link. See section 10.10.1, "Wrap the Correct Instance", on page 458.

10.11.4 Actions During Wrapping

The `pbsrun_wrap` script instantiates the `pbsrun` wrapper script as `pbsrun.<mpirun version/flavor>` in the same directory where `pbsrun` is located, and sets up the link to the actual `mpirun` call via the symbolic link:

```
$PBS_EXEC/lib/MPI/pbsrun.<mpirun version/flavor>.link
```

For example, running:

```
pbsrun_wrap /opt/mpich-gm/bin/mpirun.ch_gm pbsrun.ch_gm
```

causes the following actions:

- Save original `mpirun.ch_gm` script:
  `mv /opt/mpich-gm/bin/mpirun.ch_gm /opt/mpich-gm/bin/mpirun.ch_gm.actual`
- Instantiate `pbsrun` wrapper script as `pbsrun.ch_gm`:
  `cp $PBS_EXEC/bin/pbsrun $PBS_EXEC/bin/pbsrun.ch_gm`
- Link `mpirun.ch_gm` to actually call `pbsrun.ch_gm`:
  `ln -s $PBS_EXEC/bin/pbsrun.ch_gm /opt/mpich-gm/bin/mpirun.ch_gm`
- Create a link so that `pbsrun.ch_gm` calls `mpirun.ch_gm.actual`:
  `ln -s /opt/mpich-gm/bin/mpirun.ch_gm.actual $PBS_EXEC/lib/MPI/pbsrun.ch_gm.link`

10.11.5 Requirements

The `mpirun` being wrapped must be installed and working on all the vnodes in the PBS cluster.

10.11.6 Caveats and Restrictions

- For MPIs that are wrapped using `pbsrun_wrap`, the maximum number of ranks that can be launched in a job is the number of entries in the $PBS_NODEFILE.
- MVAPICH2 must use the "mpd" process manager if it is to be integrated with PBS. During the configuration step when you build MVAPICH2, set the "process manager" setting to *mpd*, as follows:
  `--with-pm=mpd`

  Other process managers such as "hydra" and "gforker" may not work correctly with PBS.
- If you wrap a version of Intel MPI `mpirun` less than 4.0.3, Hydra is not supported.
- Wrapping Intel MPI is **deprecated**.

10.11.7 Links to Wrapper Script Information

The following table lists the links to the description of each wrapper script used by `pbsrun_wrap`:

Table 10-2: Links to Wrapper Descriptions

MPI Wrapper	Link to Description
MPICH2	See "MPICH2 mpirun: pbsrun.mpich2" on page 47 of the PBS Professional Reference Guide.
MPICH-GM with MPD **Wrapper is deprecated.**	"MPICH-GM mpirun (mpirun.mpd) with MPD: pbsrun.gm_mpd" on page 45 of the PBS Professional Reference Guide.
MPICH-GM with `rsh/ssh` **Wrapper is deprecated.**	"MPICH-GM mpirun (mpirun.ch_gm) with rsh/ssh: pbsrun.ch_gm" on page 44 of the PBS Professional Reference Guide.
MPICH-MX with MPD **Wrapper is deprecated.**	"MPICH-MX mpirun (mpirun.mpd) with MPD: pbsrun.mx_mpd" on page 46 of the PBS Professional Reference Guide.
MPICH-MX with `rsh/ssh` **Wrapper is deprecated.**	"MPICH-MX mpirun (mpirun.ch_mx) with rsh/ssh: pbsrun.ch_mx" on page 45 of the PBS Professional Reference Guide
MVAPICH **Wrapper is deprecated.**	"MVAPICH1 mpirun: pbsrun.mvapich1" on page 49 of the PBS Professional Reference Guide.
MVAPICH2	"MVAPICH2 mpiexec: pbsrun.mvapich2" on page 50 of the PBS Professional Reference Guide.
Intel MPI	"Intel MPI mpirun: pbsrun.intelmpi" on page 48 of the PBS Professional Reference Guide.

10.11.8 Wrapping Multiple MPIs with the Same Name

You may want more than one MPI environment with the same name, for example a 32-bit and a 64-bit version of MPICH2.

1. Create two new MPICH2 initialization scripts by copying that for MPICH2:
```
# cd $PBS_EXEC/lib/MPI
# cp pbsrun.mpich2.init.in pbsrun.mpich2_32.init.in
# cp pbsrun.mpich2.init.in pbsrun.mpich2_64.init.in
```
2. Then wrap them:
```
# pbsrun_wrap <path to 32-bit MPICH2>/bin/mpirun  pbsrun.mpich2_32
# pbsrun_wrap <path to 64-bit MPICH2>/bin/mpirun  pbsrun.mpich2_64
```

Calls to `<path to 32-bit MPICH2>/bin/mpirun` will invoke `/usr/pbs/bin/pbsrun.mpich2_32`. The 64-bit version is invoked with calls to `<path to 64-bit MPICH2>/bin/mpirun`.

10.11.9 See Also

See "pbsrun" on page 41 of the PBS Professional Reference Guide for a description of the `pbsrun` script. See "pbsrun_wrap" on page 52 of the PBS Professional Reference Guide for a description of the master wrapping script.

10.12 Unwrapping MPIs Using the `pbsrun_unwrap` Script

You can also use the matching `pbsrun_unwrap` command to unwrap the MPIs you wrapped using `pbsrun_wrap`.

For example, you can unwrap the two MPICH2 MPIs from 10.11.8 above:

```
# pbsrun_unwrap pbsrun.mpich2_32
# pbsrun_unwrap pbsrun.mpich2_64
```

See "pbsrun_unwrap" on page 51 of the PBS Professional Reference Guide.

10.13 Integration By Hand

For MPIs that must be wrapped by hand, PBS supplies wrapper scripts which call the original and use `pbs_attach` to give MoM control of jobs.

Wrapping an MPI by hand yields the same result as wrapping using `pbsrun_wrap`, but you must perform the steps by hand.

Wrapping by hand involves the following steps (which are the same steps taken by `pbsrun_wrap`):

- You rename the original MPI command
- You create a link whose name is the same as the original MPI command; this link calls the wrapper script
- You edit the wrapper script to call the original MPI command
- You make sure that the link to the wrapper script(s) is available to each user's PATH.

The following table lists MPIs, their wrapper scripts, and a link to instructions:

Table 10-3: Scripts for Wrapping MPIs by Hand

MPI Name	Script Name	Link to Instructions
HP MPI	`pbs_mpihp`	section 10.13.1, "Integrating HP MPI and Platform MPI", on page 462
LAM MPI 6.5.9 **Deprecated**.	`pbs_mpilam`	section 10.13.3, "Integrating LAM MPI and Open MPI", on page 463
MPICH **Wrapper is deprecated**.	`pbs_mpirun`	section 10.13.4, "Integrating MPICH-P4", on page 465
Platform MPI	`pbs_mpihp`	section 10.13.1, "Integrating HP MPI and Platform MPI", on page 462
HPE MPI	`mpiexec`	section 10.13.5, "Integrating HPE MPI", on page 467

10.13.1 Integrating HP MPI and Platform MPI

PBS supplies a wrapper script for HP MPI and Platform MPI called `pbs_mpihp`. The `pbs_mpihp` script allows PBS to clean up job processes, track and limit job resource usage, and perform accounting for all job processes.

You can make `pbs_mpihp` transparent to users; see the instructions that follow.

10.13.2 Steps to Integrate HP MPI or Platform MPI

Make sure that you wrap the correct instance of the MPI. If a user's job script would call a link, wrap the link. See section 10.10.1, “Wrap the Correct Instance”, on page 458.

The `pbs_mpirun` command looks for a link with the name `PBS_EXEC/etc/pbs_mpihp` that points to the HP `mpirun`. The `pbs_mpihp` command follows this link to HP's `mpirun`. Therefore, the wrapping instructions are different from the usual. See “pbs_mpihp” on page 77 of the PBS Professional Reference Guide for more information on `pbs_mpihp`.

1. Rename HP's `mpirun`:

```
cd <MPI installation location>/bin
mv mpirun mpirun.hp
```

2. Link the user-callable `mpirun` to `pbs_mpihp`:

```
cd <MPI installation location>/bin
ln -s $PBS_EXEC/bin/pbs_mpihp mpirun
```

3. Create a link to `mpirun.hp` from `PBS_EXEC/etc/pbs_mpihp`. `pbs_mpihp` will call the real HP `mpirun`:

```
cd $PBS_EXEC/etc
ln -s <MPI installation location>/bin/mpirun.hp pbs_mpihp
```

10.13.2.1 Setting Up `rsh` and `ssh` Commands

When wrapping HP MPI with `pbs_mpihp`, note that `rsh` is the default used to start the mpids. If you wish to use `ssh` or something else, be sure to set the following or its equivalent in `$PBS_HOME/pbs_environment`:

```
PBS_RSHCOMMAND=ssh
```

10.13.2.2 Restrictions and Caveats for HP MPI and Platform MPI

- The `pbs_mpihp` script can be used only on HP-UX and Linux.
- The HP `mpirun` or `mpiexec` must be in the job submitter's PATH.
- The version of the HP `mpirun` or `mpiexec` must be HPMPI or Platform.
- Under the wrapped HP MPI, the job's working directory is changed to the user's home directory.

10.13.3 Integrating LAM MPI and Open MPI

The 7.x LAM MPI and all Open MPI versions allow you to compile the MPI with the PBS TM interface. We recommend compiling 7.x LAM MPI and all Open MPI versions with the TM module. You can either compile the later LAM with TM or wrap it, but not both. (You can wrap the newer versions if you want, but compiling yields better results.)

All versions of LAM MPI and Open MPI can be transparent to the job submitter.

The 6.5.9 version of LAM MPI requires wrapping for integration.

Support for LAM MPI is **deprecated**.

10.13.3.1 Compiling LAM MPI 7.x/Open MPI with the TM Module

To integrate 7.x LAM MPI with PBS, compile it with the `--with-boot-tm=/usr/pbs` option. Next, check `laminfo` to confirm that the the SSI line that says *tm* is there.

If the TM interface library is in the standard location, `PBS_EXEC/lib/`, Open MPI will find it and use it. You need to explicitly configure with TM only if it's in a non-standard location.

To integrate Open MPI with PBS, configure Open MPI with the `--with-tm` command-line option to the `configure` script. For example:

```
./configure --prefix=/opt/openmpi/1.4.4 --with-tm=${PBS_EXEC}
make
make install
```

After you compile LAM MPI or Open MPI on one host, make it available on every execution host that will use it, by means of shared file systems or local copies.

For the Open MPI website information on compiling with the TM option, see:

`http://www.open-mpi.org/faq/?category=building#build-rte-tm`

10.13.3.2 Wrapping LAM MPI 6.5.9

PBS provides wrapper scripts so that you can integrate LAM MPI 6.5.9 with PBS by hand. The `pbs_mpilam` script is used in place of `mpirun`, and the `pbs_lamboot` script replaces `lamboot`. The `pbs_lamboot` and `pbs_mpilam` scripts allow PBS to clean up job processes, track and limit job resource usage, and perform accounting for all job processes. You make LAM calls transparent to the user by allowing them to use unchanged `lamboot` and `lamhalt` calls in their scripts.

The PBS command `pbs_lamboot` replaces the standard `lamboot` command in a PBS LAM MPI job, for starting LAM software on each of the PBS execution hosts. Usage is the same as for LAM `lamboot`. All arguments except for `bhost` are passed directly to `lamboot`. PBS will issue a warning saying that the `bhost` argument is ignored by PBS since input is taken automatically from $PBS_NODEFILE. The `pbs_lamboot` command can be instructed to boot the hosts using the `tm` module by setting the LAM_MPI_SSI_boot environment variable to *tm*, or by passing an argument to `pbs_lamboot` that contains "`-ssi boot tm`". In this case, the `pbs_lamboot` program does not redundantly consult the $PBS_NODEFILE.

The PBS command `pbs_mpilam` replaces the standard `mpirun` command in a PBS LAM MPI job, for executing programs. It attaches the user's processes to the PBS job. This allows PBS to collect accounting information, and to manage the processes. Usage is the same as for LAM `mpirun`. All options are passed directly to `mpirun`. If the where argument is not specified, `pbs_mpilam` will try to run the user's program on all available CPUs using the *C* keyword.

Make sure that you wrap the correct instance of the MPI. If a user's job script would call a link, wrap the link. See section 10.10.1, "Wrap the Correct Instance", on page 458.

- You wrap LAM `lamboot` using `pbs_lamboot`.
  a. Install LAM MPI into `/usr/local/lam-6.5.9`.
  b. Rename LAM `lamboot` to *lamboot.lam*:
  ```
  mv /usr/local/lam-6.5.9/bin/lamboot /user/local/lam-6.5.9/bin/lamboot.lam
  ```
  c. Edit `pbs_lamboot` to change "`lamboot`" call to "`lamboot.lam`":
  d. Create a link for `pbs_lamboot` named *lamboot*:
  ```
  cd /usr/local/lam-6.5.9/bin
  ln  -s PBS_EXEC/bin/pbs_lamboot lamboot
  ```

At this point, using "`lamboot`" will actually invoke `pbs_lamboot`.

- You wrap LAM mpirun using the `pbs_mpilam` script.
  a. Install LAM MPI into `/usr/local/lam-6.5.9`.
  b. Rename LAM `mpirun` to *mpirun.lam*:

     ```
     mv /usr/local/lam-6.5.9/bin/mpirun /user/local/lam-6.5.9/bin/mpirun.lam
     ```
  c. Edit `pbs_mpilam` to change "`mpirun`" call to "`mpirun.lam`"
  d. Create a link for `pbs_mpilam` named *mpirun*:

     ```
     cd /usr/local/lam-6.5.9/bin
     ln -s PBS_EXEC/bin/pbs_mpilam mpirun
     ```

For more information on `pbs_lamboot` and `pbs_mpilam`, see "pbs_lamboot" on page 69 of the PBS Professional Reference Guide and "pbs_mpilam" on page 79 of the PBS Professional Reference Guide.

10.13.3.3 Setting up `rsh` and `ssh` Commands

If you intend to use `ssh`, you should set either LAMRSH or LAM_SSI_rsh_agent to the value "*ssh -x*", except under SuSE Linux, where it should be *"ssh -n"*.

10.13.3.4 Setting up Environment Variables

Set the LAM_MPI_SSI_boot environment variable to *tm* so that `pbs_lamboot` boots the hosts from the `tm` module.

10.13.3.5 Verifying Use of TM Interface

To see whether your Open MPI installation has been configured to use the TM interface:

```
% ompi_info | grep tm
MCA ras: tm (MCA v2.0, API v2.0, Component v1.3)
MCA plm: tm (MCA v2.0, API v2.0, Component v1.3)
```

10.13.3.6 See Also

See `www.lam-mpi.org` for more information about LAM MPI.

See `http://www.open-mpi.org/faq/?category=building#build-rte-tm` for information about building Open MPI with the TM option.

10.13.4 Integrating MPICH-P4

Wrapper is deprecated. PBS supplies a wrapper script called `pbs_mpirun` for integrating MPICH-P4 with PBS by hand. The `pbs_mpirun` script allows PBS to clean up job processes, track and limit job resource usage, and perform accounting for all job processes.

You can make `pbs_mpirun` transparent to job submitters. See the following steps.

10.13.4.1 Restrictions

- The `pbs_mpirun` command can be used only with MPICH using P4 on Linux.
- User names must be identical across hosts.

10.13.4.2 Options for `pbs_mpirun`

The usage for `pbs_mpirun` is the same as `mpirun` except for the listed options. All other options are passed directly to `mpirun`:

-machinefile

The value for this option is generated by `pbs_mpirun`. The value used for the `-machinefile` option is a temporary file created from the PBS_NODEFILE in the format expected by `mpirun`.

If the `-machinefile` option is specified on the command line, a warning is output saying "Warning, -machinefile value replaced by PBS".

-np

The default value for the `-np` option is the number of entries in `PBS_NODEFILE`.

10.13.4.3 Steps to Integrate MPICH-P4

To make `pbs_mpirun` transparent to the user, replace standard `mpirun` with `pbs_mpirun.` Make sure that you wrap the correct instance of the MPI. If a user's job script would call a link, wrap the link. See section 10.10.1, “Wrap the Correct Instance”, on page 458.

- Install MPICH-P4 into `<path to mpirun>`
- Rename `mpirun` to `mpirun.std`:
  ```
  mv <path to mpirun>/mpirun <path to mpirun>/mpirun.std
  ```
- Create link called `mpirun` in `<path to mpirun>` that points to `pbs_mpirun`
  ```
  ln -s <path to pbs_mpirun>/pbs_mpirun mpirun
  ```
- Edit `pbs_mpirun` to change the call to `mpirun` so that it calls `mpirun.std`

At this point, using `mpirun` actually invokes `pbs_mpirun`.

10.13.4.4 Setting Up Environment Variables and Paths

- For `pbs_mpirun` to function correctly for users who require the use of `ssh` instead of `rsh`, you can do one of the following:
  - Set PBS_RSHCOMMAND in the login environment
  - Set P4_RSHCOMMAND externally to the login environment, then have job submitters pass the value to PBS via `qsub(1)`'s `-v` or `-V` arguments:
    ```
    qsub -vP4_RSHCOMMAND=ssh ...
    ```
    or
    ```
    qsub -V ...
    ```
  - Set P4_RSHCOMMAND in the `pbs_environment` file in `PBS_HOME` and then advise users to not set P4_RSHCOMMAND in the login environment
- Make sure that PATH on remote machines contains `PBS_EXEC/bin`. Remote machines must all have `pbs_attach` in the PATH.
- The PBS_RSHCOMMAND environment variable should not be set by the user.
- When using SuSE Linux, use "`ssh -n`" in place of "`ssh`".

10.13.5 Integrating HPE MPI

PBS supplies its own `mpiexec` on machines running supported versions of HPE MPI, in order to provide a standard interface for use by job submitters. This `mpiexec` calls the standard HPE `mpirun`. If users call this `mpiexec`, PBS will manage, track, and cleanly terminate multi-host MPI jobs.

If job submitters call HPE MPI directly, they must use `pbs_attach` in their job scripts in order to give PBS the same control over jobs; see the HPE documentation.

MPI jobs can be launched across multiple machines. PBS users can run an MPI job within a specific partition.

When job submitters use `mpiexec` in their job scripts, HPE MPI is transparent. Jobs run normally whether the PBS-supplied `mpiexec` is called inside or outside of PBS.

10.13.5.1 Supported Platforms

The PBS-supplied `mpiexec` runs on machines running supported versions of HPE MPI.

10.13.5.2 Steps to Integrate HPE MPI

Make sure that the PBS-supplied `mpiexec` is in each user's PATH.

10.13.5.3 Invoking HPE MPI

PBS uses the MPI-2 industry standard `mpiexec` interface to launch MPI jobs within PBS. If executed on a non-HPE system, PBS's `mpiexec` will assume it was invoked by mistake. In this case it will use the value of PATH (outside of PBS) or PBS_O_PATH (inside PBS) to search for the correct `mpiexec` and if one is found, exec it.

10.13.5.4 Using HPE MPI Over InfiniBand

To use InfiniBand, set the MPI_USE_IB environment variable to 1.

10.13.5.5 Using CSA with HPE MPI

PBS support for CSA on HPE systems is no longer available. The CSA functionality for HPE systems has been **removed** from PBS.

10.13.5.6 Prerequisites

- In order to run single-host or multi-host jobs, the HPE Array Services must be correctly configured. An Array Services daemon (`arrayd`) must run on each host that will run MPI processes. For a single-host environment, `arrayd` only needs to be installed and activated. However, for a multi-host environment where applications will run across hosts, the hosts must be properly configured to be an array.
- HPE systems communicating via HPE's Array Services must all use the same version of the `sgi-mpt` and `sgi-arraysvcs` packages. HPE systems communicating via HPE's Array Services must have been configured to interoperate with each other using the default array. See HPE's `array_services`(5) man page.
- "**`rpm -qi sgi-arraysvcs`**" should report the same value for *Version* on all systems.
- "**`rpm -qi sgi-mpt`**" should report the same value for *Version* on all systems.
- "**`chkconfig array`**" must return "*on*" for all systems
- `/usr/lib/array/arrayd.conf` must contain an array definition that includes all systems.
- `/usr/lib/array/arrayd.auth` must be configured to allow remote access:

  The "AUTHENTICATION NOREMOTE" directive must be commented out or removed

Either "AUTHENTICATION NONE" should be enabled or keys should be added to enable the SIMPLE authentication method.

- If any changes have been made to the `arrayd` configuration files (`arrayd.auth` or `arrayd.conf`), the array service must be restarted.
- `rsh(1)` must work between the systems.
- PBS uses HPE's `mpirun(1)` command to launch MPI jobs. HPE's `mpirun` must be in the standard location.
- The location of `pbs_attach(8B)` on each vnode of a multi-vnode MPI job must be the same as it is on the primary execution host vnode.

10.13.5.7 Environment Variables

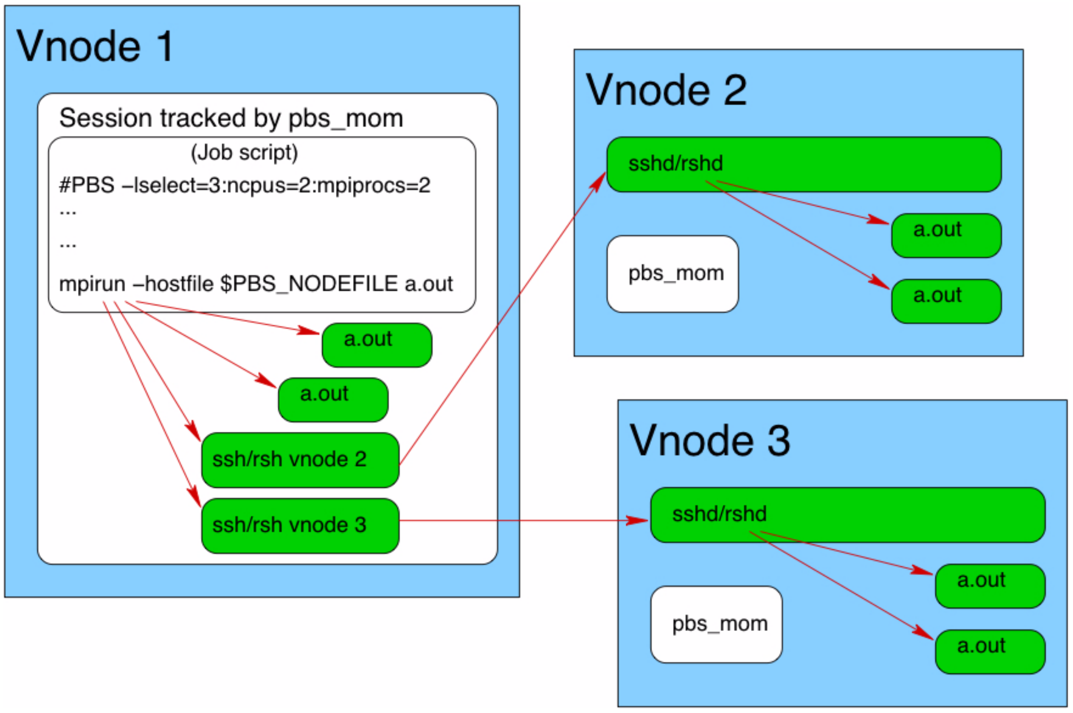
- If the PBS_MPI_DEBUG environment variable's value has a nonzero length, PBS will write debugging information to standard output.
- The PBS_ENVIRONMENT environment variable is used to determine whether `mpiexec` is being called from within a PBS job.
- If it was invoked by mistake, the PBS `mpiexec` uses the value of PBS_O_PATH to search for the correct `mpiexec`.
- To use InfiniBand, set the MPI_USE_IB environment variable to 1.

10.14 How Processes are Started Using MPI and PBS

10.14.1 Starting Processes under Non-integrated MPIs

The following figure illustrates how processes are started on sister vnodes when using a non-integrated MPI:

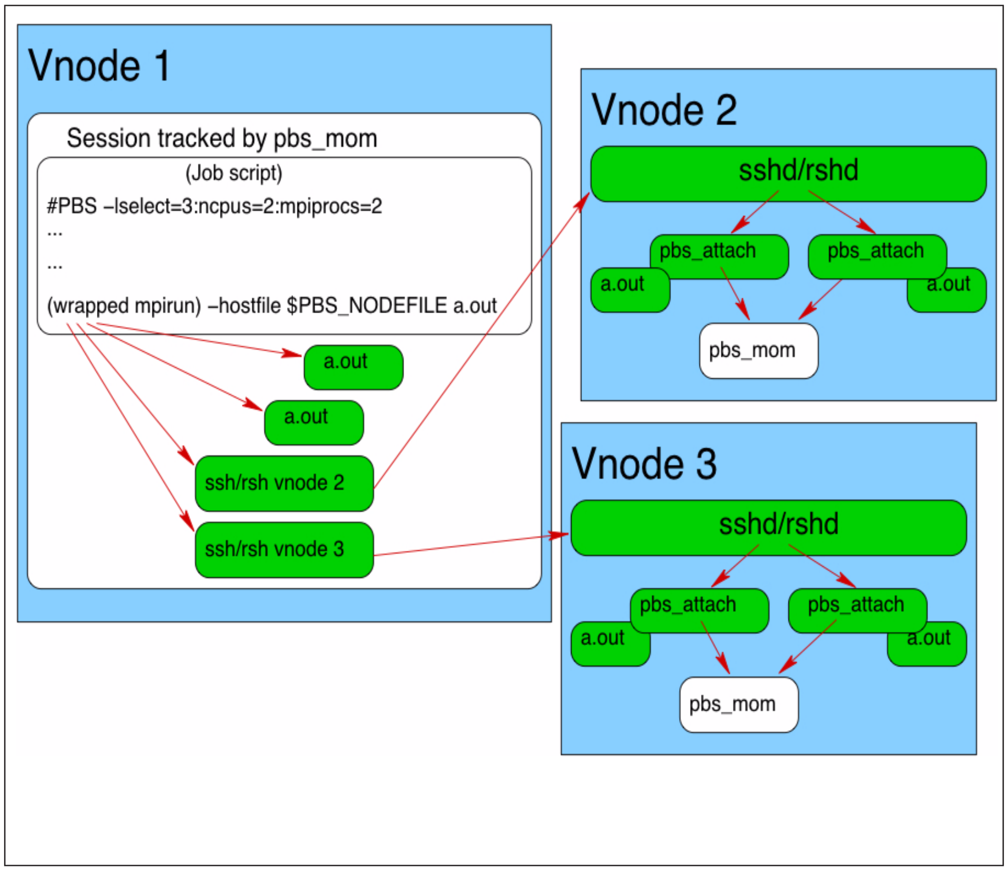
Figure 10-4:PBS does not know about the processes on vnodes 2 and 3, because those processes were generated outside of the scope of PBS.



10.14.2 Starting Processes under Wrapped MPIs

The following figure illustrates how processes are started on sister vnodes when using a wrapped MPI:

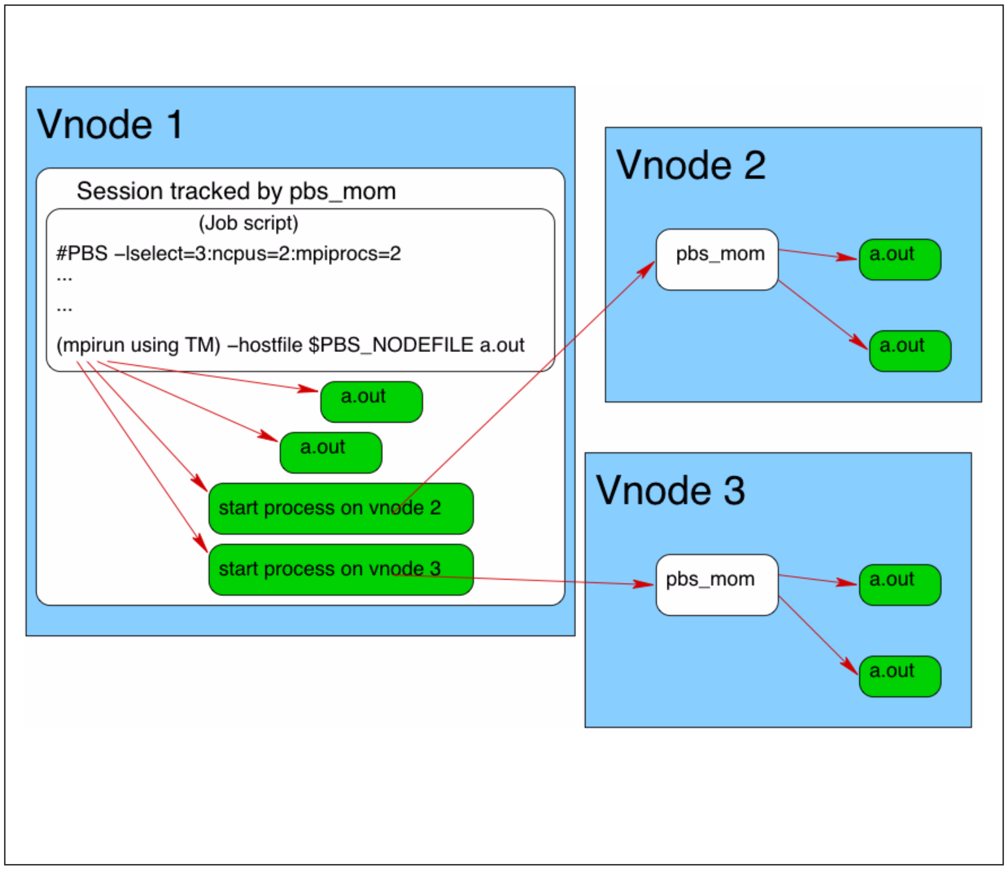
Figure 10-5: PBS knows about processes on vnodes 2 and 3, because `pbs_attach` tells those MoMs which processes belong to which jobs



10.14.3 Starting Processes Under MPIs Employing the TM Interface

The following figure illustrates how processes are started on sister vnodes when using an MPI that employs the TM interface:

Figure 10-6: PBS knows about processes on vnodes 2 and 3, because the TM interface talks directly to `pbs_mom`, and `pbs_mom` starts the processes on vnodes 2 and 3



10.15 Limit Enforcement with MPI

PBS can enforce the following for a job using MPI:

- Per-process limits via `setrlimit(2)` on sister vnodes
  - The `setrlimit` process limit can be enforced only when using an MPI that employs the TM interface directly, which is Open MPI only (and LAM MPI, which is deprecated)
- Limits set via MoM parameters, e.g. cpuburst and cpuaverage, on sister vnodes
  - PBS can enforce these limits using any integrated MPI
- Job-wide limits such as cput, mem
  - PBS can enforce job-wide limits using any integrated MPI

Once a process is started, process limits cannot be changed.

10.16 Restrictions and Caveats for MPI Integration

- Be sure to wrap the correct instance of the MPI. See section 10.10.1, “Wrap the Correct Instance”, on page 458
- Some applications write scratch files to a temporary location in `tmpdir`. The location of `tmpdir` is host-dependent. If you are using an MPI that is not integrated with the PBS TM interface, and your application needs scratch space, the location of `tmpdir` for the job should be consistent across execution hosts. You can specify the root for `tmpdir` in the MoM's $tmpdir configuration parameter. PBS sets the job's TMPDIR environment variable to the temporary directory it creates for the job.

11 Configuring PBS for Cray

11.1 Support for Shasta

PBS runs on Shasta exactly as it does on standard Linux machines. The only information in this chapter that applies to Shasta is contained within this section (Section 11.1, "Support for Shasta"). Each compute node behaves like a standard Linux machine, and runs one MoM. By default, each compute node is represented by one vnode. When you create vnodes on Shasta, use the host shortname as the vnode name.

11.1.1 Shasta Is Different from XC

If you are used to PBS on Cray XC machines, working with Shasta is different. Configuring PBS on Shasta is the same as on a standard Linux machine. You can ignore all of the Cray XC instructions in the rest of this chapter. For example:

- Batch mode and state do not apply
- Special Cray built-in resources do not apply to Shasta
- You don't need to set vntype
- You don't need node_fail_requeue to be zero
- The PBS_alps_inventory_check hook is not used for Shasta
- You don't need vnode_pool
- Hyperthreads are the same as on a standard Linux machine

11.1.1.1 Not Supported on Shasta

- Suspend/resume is not supported on Shasta
- Power awareness is not supported on Shasta

11.1.2 Hook for PBS on Shasta

On Shasta, PBS uses a built-in hook called *PBS_cray_atom*, which runs for execjob_begin and execjob_end events. The hook notifies the Cray when each job starts, and when each job should be deleted. This hook should be enabled by default, but we recommend making sure that it is.

If the hook alarms while running for the execjob_begin event (POST and DELETE), the vnode(s) where the hook was running are marked offline.

If the hook alarms while running for the execjob_end event (DELETE), the hook rejects the action. The default timeout for this hook is 300 seconds.

11.1.2.1 Shasta Hook Configuration File

The configuration file for the PBS_cray_atom hook is formatted as a JSON object. Here is the default configuration file:

```
{
    "post_timeout": 30,
    "delete_timeout": 30,
    "unix_socket_file": "/var/run/jacsd/jacsd.sock"
}
```

11.1.2.1.i Configuration File Parameters

"post_timeout"

Time limit for *POST* requests.

Units: *seconds*

Format: *float*

Default: *30 seconds*

"delete_timeout"

Time limit for *DELETE* requests.

Units: *seconds*

Format: *float*

Default: *30 seconds*

"unix_socket_file"

Path to the `UNIX` socket file to be used for authentication.

Format: *string*

Default: *"/var/run/jacsd/jacsd.sock"*

11.1.3 Responding to Node Health

On Shasta, Cray tasks take care of marking nodes unavailable or available. If Cray tasks decide that node health is not acceptable, Cray tasks will bring down the PBS MoM on that node. After you restore the node to usability, you must restart the MoM. If there are running jobs, use the `pbs_mom -p` option in order to preserve and track running jobs. See "Impact of Stop-Restart on Running Linux Jobs" on page 169 in the PBS Professional Installation & Upgrade Guide.

11.2 Configuring PBS for Cray XC Series

PBS provides features designed to support the Cray XC series. The rest of the chapter describes the special behavior of PBS on Cray XC systems only.

11.3 Introduction to PBS on Cray XC

PBS provides support for Cray XC systems by providing the following:

- PBS automatically defines vnodes for Cray XC compute nodes
- PBS automatically sets resources and attributes for vnodes representing Cray XC nodes
- PBS automatically creates custom resources that correspond to Cray XC resources
- Cray XC users can submit jobs through PBS using the PBS select and place statements.

11.4 Relationship of PBS Vnodes to Cray XC Nodes

PBS represents each login node as a vnode. A compute node is represented as a single vnode. A PBS MoM runs on each login node; this MoM manages the vnodes representing the compute nodes associated with the login node. On systems with multiple login nodes, each MoM on each login node manages every compute node. When this is the case, each compute node is reported by more than one login node. The Mom attribute of a vnode representing a compute node contains the hostname of each login node reporting the compute node. Each hostname is the FQDN or the short name of the reporting login node, depending on whatever is returned by the DNS.

11.4.1 How PBS Handles Changes in Cray XC Inventory

11.4.1.1 Reporting Changes in Vnode List in Cray XC

If a previously-reported vnode is no longer reported when the vnode list is created, because it is no longer available in the vnode definition file and the inventory, it is missing from the vnode list. The server marks missing vnodes as *stale*.

PBS provides a Boolean MoM configuration option that allows you to specify whether MoM tells the server that a vnode is missing. When the $vnodedef_additive MoM configuration option in `PBS_HOME/mom_priv/config` is *True*, MoM does not tell the server that any vnodes are missing. This means that the server does not mark missing vnodes as *stale*. When $vnodedef_additive is *False*, MoM tells the server that vnodes are missing, and the server marks the missing vnodes as *stale*. The default value for $vnodedef_additive for a MoM managing a Cray XC is *False*. The default value for other systems is *True*.

When a compute node goes down and the ALPS inventory no longer reports it, the vnode is marked *stale* once PBS queries for the inventory. If you bring the compute node back up, you can HUP the MoM in order to make the vnode usable by PBS. Alternatively, if PBS fails to make a Cray XC reservation, MoM will re-read the inventory and re-create the vnode list. A vnode is marked *stale* when any of the MoMs that reported the vnode stop reporting it.

The state of a vnode representing a compute node that is managed by more than one login node is not changed by a MoM going down, unless all of its MoMs are down. A vnode representing a compute node is marked *down* when all of the MoMs that manage the vnode are *down*.

11.4.1.2 When MoMs Report Conflicting Information in Cray XC

When more than one MoM reports information about a vnode, and the information conflicts, PBS uses the most recent information.

11.4.1.3 Vnode Resources on Stale Vnodes in Cray XC

If the ALPS inventory no longer reports information for a vnode, and the vnode is not defined in a vnode definition file, all resource and attribute information for that vnode is removed or set to zero, and the vnode is marked *stale*.

If the ALPS inventory no longer reports information for a vnode, but the vnode is defined in a vnode definition file, the vnode's attributes and resources retain their settings and the vnode is not marked *stale*.

11.4.1.4 Periodically Re-reading ALPS Inventory in Cray XC

PBS comes shipped with a built-in hook that periodically checks to see whether the inventory is consistent across ALPS and PBS. If it is not, it HUPs a MoM on a login node so that PBS has a current copy of the ALPS inventory. This hook is named *PBS_alps_inventory_check*. By default, this hook runs every 300 seconds; you can change the frequency by setting the hook's freq attribute:

```
#qmgr -c "set pbshook <hook name> freq=<new frequency>"
```

11.5 Requirements for Cray XC

- For a compute node to be managed by the PBS MoM, the node must be in batch mode, and in state *UP*.

11.6 Restrictions for Cray XC

- A Cray XC compute node cannot be used by more than one application at the same time.
- PBS does not report cput or mem for jobs running on a Cray XC compute node.

11.7 Resources, Parameters, etc. for Cray XC

PBS provides built-in and custom resources for the Cray XC. PBS also provides some built-in resources for all platforms, but these resources have specific uses on the Cray XC.

11.7.1 Resources for Cray XC

accelerator
accelerator_memory
accelerator_model
energy
eoe
naccelerators
PBScrayhost
PBScraylabel_<label name>
PBScraynid
PBScrayorder
vntype

See “Resources Built Into PBS” on page 267 of the PBS Professional Reference Guide.

11.7.2 Scheduler Attributes for Cray XC

do_not_span_psets
only_explicit_psets

11.7.3 MoM Configuration Options for Cray XC

$alps_client
$alps_release_jitter
$alps_release_timeout <timeout>
$alps_release_wait_time
pbs_accounting_workload_mgmt <value>
$vnodedef_additive

11.8 Automatic Configuration for Cray XC

11.8.1 Vnode List Creation for Cray XC

You must create a vnode for each login node, but PBS automatically creates the vnodes representing compute nodes. PBS creates a list of vnodes by reading the Cray XC inventory and any vnode definition files. PBS automatically creates one vnode to represent each Cray XC compute node. All NUMA nodes in a compute node are represented by the same vnode. PBS does this automatically when any of the following happens:

- Startup of the MoM
- The MoM is HUPed
- PBS queries the Cray XC for the inventory (e.g., when PBS fails to confirm a Cray XC reservation)
- PBS times out on trying to release an ALPS request.

11.8.2 Automatic Vnode Attribute and Resource Settings for Cray XC

PBS automatically sets the values of certain vnode attributes and resources. Vnode attribute and resource settings are derived from values returned in the inventory, according to the following rules:

resources_available.accelerator
: Set to *True* when this vnode's host has at least one accelerator in state *UP*.

resources_available.accelerator_memory
: Set to the value of basil_accelerator_gpu.memory.

resources_available.accelerator_model
: Set to the value of basil_accelerator_gpu.family.

resources_available.naccelerators
: Number of Accelerator entries for the host that are in state *UP*.

resources_available.host
: Values of node's mpp_host and node_id are concatenated.

Format: *<mpp_host>_<node_id>*

Example: Given a compute node where mpp_host = *examplehost* and node_id = *8*, resources_available.host is set to *examplehost_8*.

resources_available.PBScrayhost

On CLE 3.0 and higher, set to value of mpp_host

resources_available.PBScraylabel_<label name>

For the label on a compute node, PBS creates a custom Boolean resource, and sets it to *True* on the vnode representing that compute node. The format for the name of this resource is *PBScraylabel_<label>*. For example, if the label is *Blue*, then the name of the Boolean resource is *PBScraylabel_Blue*.

resources_available.PBScraynid

The value of PBScraynid is set to the value of node_id for this compute node.

resources_available.PBScrayorder

Set to the position in the Cray XC node list of the associated node. If this vnode's associated node was *n*th in the node list, the value of PBScrayorder is *n*.

resources_available.PBScrayseg

Not used.

resources_available.vntype

On compute nodes, set to *cray_compute*

On internal login nodes, set to *cray_login*

Mom vnode attribute

This is the canonical hostname of the login node where MoM runs.

Name of vnode

Value of node's mpp_host and node_id are concatenated.

Format: *<mpp_host>_<node_id>*

Example: Given node_id = *8* and mpp_host = *examplehost*, the vnode name is *examplehost_8*.

sharing vnode attribute

Set to *force_exclhost*

11.8.3 Automatic MoM Parameter Settings for Cray XC

$alps_release_jitter <maximum jitter>

Cray XC only. PBS sends requests to ALPS to release a finished job at intervals specified by the sum of $alps_release_wait_time and a randomly generated value between zero and *maximum jitter*, in seconds.

Format: *Float*

Default: 0.12 seconds

$alps_release_timeout <timeout>

Specifies the amount of time that PBS tries to release an ALPS request before giving up. We recommend that the value for this parameter be greater than the value for suspectbegin.

Format: Seconds, specified as positive integer.

Default: *600* (10 minutes)

$alps_release_wait_time <wait time>

Cray XC only. PBS sends requests to ALPS to release a finished job at intervals specified by the sum of *wait time* and a randomly generated value between zero and the maximum specified in $alps_release_jitter, in seconds.

Format: *Float*

Default: 0.4 seconds

$vnodedef_additive MoM configuration option

PBS automatically sets the value of the $vnodedef_additive MoM configuration option to *False* on any MoM on a login node. See section 11.7.3, “MoM Configuration Options for Cray XC”, on page 477.

11.8.4 Default Scheduler Attribute Settings for Cray XC

do_not_span_psets

This attribute is set to *False* by default. See section 11.7.2, “Scheduler Attributes for Cray XC”, on page 477.

11.9 Recommended Manual Configuration for Cray XC

11.9.1 Configuring Vnode Names on Cray XC

You can use the PBS_MOM_NODE_NAME configuration parameter in `/etc/pbs.conf` to tell MoM what name was used to create the vnode at the server.

11.9.1.1 Requirements for PBS_MOM_NODE_NAME on Cray XC

You can use any resolvable host name for a vnode name when you create a vnode at the server, if you use the PBS_MOM_NODE_NAME configuration parameter to tell MoM about the name that was used to create the vnode at the server.

MoM accepts only a PBS_MOM_NODE_NAME that is known to the resolver of the "`hosts`" map; for example, it appears somewhere in `/etc/hosts` on the execution host, is mentioned in an NIS map, or is a name known to DNS servers, possibly after adding a domain to the search list. If the name cannot be resolved, MoM will refuse to start.

You cannot use dots in PBS_MOM_NODE_NAME.

11.9.1.2 When to Use PBS_MOM_NODE_NAME on Cray XC

You may need to use a name for your parent vnode that is different from the output of the `hostname` command, for reasons such as the following:

- You want vnodes named after their function in the complex, not an accidental hostname that may refer to physical placement of the node. Frequently when that hardware host is not booted, another node with another official hostname needs to assume those functions
- The hostname is maintained by a cluster manager but is a private name that may be unknown to the PBS server or other execution nodes, while the alias is actually a globally valid name
- Name resolution is inconsistent on the complex, i.e. the same name refers to different IP addresses on different hosts in the cluster, or the canonicalized name is different on different hosts

The name you specify in PBS_MOM_NODE_NAME can then be used consistently on the server, in Version 2 configuration files, and in hooks, regardless of the event type; pbs.get_local_nodename() in hooks will return this name, which always matches the name of the parent vnode of the execution host.

Note that it is possible, in some clusters, for PBS_LEAF_NAME and PBS_MOM_NODE_NAME to be associated with different interfaces and IP addresses on the execution host.

11.9.1.3 Avoid Problems with Vnode Naming on Cray XC

If you use a name different from the output of the hostname command to create a vnode, and you don't specify it in PBS_MOM_NODE_NAME, this can create problems when Version 2 configuration files or execution event hooks are used.

- Version 2 configuration files need to use the MoM parent vnode name to change attributes of the parent vnode, but the server knows the parent vnode by another name
- When an exechost_startup or exechost_periodic hook operates on the vnode_list[], the vnode_list[] will contain the vnode named after its local hostname and not the name used on the server to create the vnode, and the vnode_list[] (with its different naming) will be propagated to the server

Both these problems may render the original vnode created on the server stale (and replaced by a vnode created using MoM's view of the parent vnode name), which also means that resources set using `qmgr` on the server will be lost, since they will be set on the stale vnode and not on the vnode MoM created to replace it.

Hooks will face additional problems:

- Vnode naming in pbs.event().vnode_list[] will be inconsistent in different hook events, since a vnode_list[] created locally by MoM will use different naming from that for a vnode_list[] created through the job's exec_vnode and exec_host attributes (which are set by the scheduler and the server)
- In exechost_startup and exechost_periodic hooks, the vnode_list[] does not contain a full representation of the vnode on the server, since not all attributes and resources are propagated; it will be impossible to correctly fetch the missing resources by querying the server, since the vnode will be called differently in pbs.event().vnode_list[] and pbs.server().vnodes
- It will be very hard to determine which portion of a job's exec_vnode attribute corresponds to the local host in hooks, since pbs.get_local_nodename() will return the node's hostname and exec_vnode will use the vnode name used on the server

11.9.2 Set Scheduling Parameters for Cray XC

- If your server/scheduler runs on a non-CLE machine, add the vntype resource to the "`resources:`" line in `<sched_priv directory>/sched_config`. If your server/scheduler runs on a CLE machine, this happens automatically.
- We recommend that you add the naccelerators resource to the "`resources:`" line in `<sched_priv directory>/sched_config`.
- If you want the scheduler to honor the following resources, add them as well:

  PBScrayhost

  PBScraynid

  accelerator_memory

  accelerator_model
- Do **not** add the following resources to the "`resources:`" line:

  PBScrayorder

  nchunk

11.9.2.1 Caveats for Replacing Resources Used for Gating for Cray XC

- There is no support for resources_min.nchunk and resources_max.nchunk. If set, their behavior is undefined.
- If you wish to set resources_min.mpiprocs or resources_max.mpiprocs, you must make sure that mpiprocs can be counted for each job chunk. If the job did not request mpiprocs with each chunk, the job must inherit `mpiprocs = 1` for each chunk.

  Set default_chunk.mpiprocs to 1 on the server:

  ```
  Qmgr: s s default_chunk.mpiprocs = 1
  ```

11.9.3 Keeping Jobs Within One Host for Cray XC

To prevent jobs from being scheduled across multiple Cray XC hosts, you must limit jobs to a single value for PBScray-host. Do the following:

- Set node_group_enable to *True*:

  ```
  Qmgr: s s node_group_enable=True
  ```
- Set node_group_key to *PBScrayhost*:

  ```
  Qmgr: s s node_group_key=PBScrayhost
  ```
- Set do_not_span_psets to *True*

  ```
  Qmgr: set sched <scheduler name> do_not_span_psets=true
  ```

If a job requests more resources than can be supplied from a single host, and the job does not specify a value for PBScrayhost, the job is scheduled across multiple Cray XC systems. To prevent this from happening, you can set the do_not_span_psets scheduler attribute to *True*, and add *PBSCrayhost* to node_group_key. See section 11.7.2, "Scheduler Attributes for Cray XC", on page 477.

11.9.4 Allowing Scheduling on Nearby Vnodes on Cray XC

To help the scheduler place each job requiring more than one vnode on vnodes that are close to each other, make the scheduler sort the vnodes based on their values for PBScrayorder. The vnodes will be listed in the order that their nodes are listed in the Cray XC inventory. To do this, specify the following in `<sched_priv directory>/config`:

```
node_sort_key: "PBScrayorder LOW"
```

11.9.5 Allowing Users to Request Useful Groups of Nodes on Cray XC

Job submitters can use select and place to request the groups of vnodes they want. However, you must provide the tools. Users may need to group their nodes by the certain criteria, for example:

- Certain nodes are fast nodes
- Certain nodes share a required or useful characteristic
- Some combination of nodes gives the best performance for an application

For these cases, you can do either of the following:

- Create custom resources, and set them on each vnode so that the important characteristics of the vnode can be requested. For example, if a vnode is fast, create a custom string resource called "*speed*" and set it to *fast* on that vnode.
- Label each node with its important characteristics. For example, if a node is both fast and best for App1, give it two labels, *fast*, and *BestForApp1*. PBS creates custom Boolean resources called *PBScraylabel_<label name>* and sets them to *True* on the appropriate vnodes.

11.9.6 Allowing Users to Request Login Node Groups on Cray XC

If users need to request groups of both esLogin nodes and internal login nodes, do the following:

1. Create a new string value for the vntype resource, for example *cray_compile*.
2. Use `qmgr` to set the value for vntype on the vnodes representing esLogin nodes:

   ```
   qmgr -c "set node esLogin resources_available.vntype+="cray_compile"
   ```

3. Use `qmgr` to add *cray_compile* to the vnodes representing internal login nodes. (resources_available.vntype is automatically set to *cray_login*.)

   ```
   qmgr -c "set node internal_Login resources_available.vntype +="cray_compile""
   ```

If you use `pbsnodes -av` to check resources_available.vntype for internal_Login, it now looks like this:

```
resources_available.vntype=cray_login,cray_compile
```

11.9.7 Set ALPS Reservation Release Timeout on Cray XC

The $alps_release_timeout <timeout> parameter specifies the amount of time that PBS tries to release an ALPS reservation before giving up. After this amount of time has passed, PBS stops trying to release the ALPS reservation, the job exits, and the job's resources are released. PBS sends a HUP to the MoM so that she rereads the ALPS inventory to get the current available ALPS resources.

You can set the amount of time that PBS waits between sending release requests to ALPS via the $alps_release_wait_time <wait time> and $alps_release_jitter <maximum jitter> MoM parameters. PBS generates a random value between zero and the value of $alps_release_jitter, and adds it to the value of $alps_release_wait_time, to determine how long to wait from one request to the next.

We recommend that you set the value for the $alps_release_timeout MoM parameter to a value greater than the value of the suspectbegin Cray XC node health variable. You want to allow the Cray XC node health check to reach its timeout before PBS gives up on trying to release the reservation.

The default for $alps_release_timeout is 600 seconds.

11.9.8 Enable Local Copy on Cray XC

If your site has disabled the use of remote operation functions ("r" commands) and output cannot be returned for jobs running on compute nodes, enable the use of the `cp` command by adding $usecp to the `$PBS_HOME/mom_priv/config` file on each login node.

11.9.9 Prevent Jobs from Being Requeued on Cray XC

We recommend setting the node_fail_requeue server attribute to *0* (zero) for Cray X* series machines. Why? There are three main cases where node_fail_requeue comes into play:

- Network failure between server and primary execution host MoM

  This is what node_fail_requeue >*0* helps with the most, since both the MoM and job processes are still running, so it acts as a buffer to allow the network failure to correct itself before action is taken on the job.
- Primary `pbs_mom` process crashes

  With node_fail_requeue set to a value >*0*, job processes on the Cray XC execution hosts continue to run and the ALPS reservation for the requeued job persists. This leads to PBS getting out of sync with ALPS (ALPS would not free the reservation that the requeued job was using), but PBS sees the resources as free since the job was requeued. The ALPS/PBS sync issue is handled properly by the remaining MoMs re-reading the ALPS inventory and seeing that these resources are unavailable. So we wind up wasting resources in this case. It is possible that the task completing on the Cray XC compute nodes from the original requeued job would still be of value to the job submitter.
- Primary `pbs_mom` host failure (e.g., someone tripped over the power cord)

  With node_fail_requeue set to a value >*0*, job processes continue to run on the Cray XC compute nodes under ALPS, though the running job script disappears upon job requeue. We run into the same case as when `pbs_mom` crashes.

In summary, with node_fail_requeue set to *0* on a Cray XC, the first case is still handled properly since jobs are not requeued due to a temporary network outage between the server and MoM on the login node. The second and third cases do not result in having the computation tasks running on two sets of Cray XC compute nodes (since PBS can't clean them up without the MoM that crashed). This is probably what you want.

For these jobs anything that the job was supposed to do after the `aprun` command in the job script does not occur, but the results from the number crunching would still be available.

11.10 Improving Server/MoM Inventory Performance for Cray XC

You can use the vnode attribute named *vnode_pool* to reduce the communication traffic between server and MoMs.

The vnode_pool attribute allows just one MoM, instead of all, to report inventory upon startup. This allows faster startup and less network communication between the server and the non-reporting MoMs. You use the attribute to tell PBS which MoMs report the same set of vnodes. PBS sees all login nodes with the same setting for vnode_pool as being part of the same Cray XC. Set this attribute to a different value for each Cray XC.

The type is int, and the Python type is int. The default value is zero, i.e. disabled. To enable the feature, set the attribute to any value greater than zero.

The vnode_pool vnode attribute can be set for each login node on a Cray XC running a MoM reporting the compute node inventory for the same Cray XC system. If you set this attribute for one of the MoMs reporting the same inventory, you must set it for all. Set the attribute to the same value on each of these nodes.

If one of the inventory-reporting MoMs goes down, PBS chooses another to report the inventory.

11.10.1 Setting the vnode_pool Attribute on Cray XC

- The vnode_pool attribute can be set only by a PBS Manager, and only in a vnode creation command. Format:

  Qmgr: create node <parent vnode name> vnode_pool=<value>

For example, if you have four login nodes running MoMs reporting the same compute node inventory, set vnode_pool at each of those vnodes to *1*.

- This attribute cannot be set or altered once the vnode is created; the attribute must be set during vnode creation.
- Do not define this attribute in a vnode definition file. To do so will give unspecified results.
- Do not attempt to set this attribute on a non-Cray machine. Setting the attribute on a non-Cray is unsupported and will result in undefined behavior.

11.10.2 Logging for Cray XC

11.10.2.1 MoM Log Messages Related to vnode_pool on Cray XC

- Recorded when a non-inventory-reporting MoM in a vnode pool is sent a Hello message by the Server:

  `"Hello (no inventory required) from server at <server address>"`

  Log level: PBSEVENT_SYSTEM

11.10.2.2 Server Log Messages Related to vnode_pool on Cray XC

- Recorded when a node is created or being recovered from the database and the specified vnode_pool value is negative or equal to zero:

  `"invalid vnode_pool provided"`

  Log level: PBSEVENT_ADMIN
- Recorded when an attempt is made to set or alter vnode_pool on an existing node:

  `"Unsupported actions for vnode_pool"`

  Log level: PBSEVENT_ADMIN
- Recorded when a MoM is first reporting her nodes to the server, and the vnode_pool appears in a vnode definition file:

  `"Error <error code> setting attribute vnode_pool in update for vnode <name>"`

  Log level: PBSEVENT_SYSTEM
- Recorded when a MoM sends either an IS_UPDATE or IS_UPDATE2 message to the Server and the sending: `pbs_mom` is in a vnode pool

  `"POOL: IS_UPDATE<x> received"`

  Log level: PBSEVENT_DEBUG4
- Recorded when an update of the database failed when updating the Mom attribute of a vnode:

  `"write_single_node_mom_attr, Failed to update 'Mom' attribute"`

  Log level: PBSEVENT_ERROR
- Recorded when the inventory-reporting MoM is set, including each time the inventory-reporting MoM changes:

  `"Setting inventory_mom for vnode_pool <x> to <Mom name>"`

  Log level: PBSEVENT_DEBUG
- Recorded when a MoM is added to a vnode pool:

  `"Mom <Mom name> added to vnode_pool <x>"`

  Log level: PBSEVENT_DEBUG3
- Recorded when a node is created or being recovered from the database:

  `"vnode_pool value is <x>"`

Log level: PBSEVENT_DEBUG3

- Recorded during MoM creation when a MoM is being added to a vnode pool:

  ```
  "POOL: cross linking <x> vnodes from <mom>"
  ```

  Log level: PBSEVENT_DEBUG4

11.11 Synchronizing PBS with ALPS Inventory on Cray XC

PBS comes shipped with a built-in periodic hook that regularly checks to see whether PBS is in sync with the ALPS inventory. If it is not, it HUPs the MoM on the first login node so that PBS has a current copy of the ALPS inventory.

By default, the hook is enabled on Cray X* series machines, and disabled on all other platforms. The hook runs as Administrator.

This hook is named *PBS_alps_inventory_check*.

By default, this hook runs every 300 seconds; you can change the frequency by setting the hook's freq attribute:

```
#qmgr -c "set pbshook PBS_alps_inventory_check freq=<new frequency>"
```

The timeout for the hook is 90 seconds.

The hook distinguishes multiple Cray XCs associated with a single PBS server by means of the PBScrayhost resource. Each MoM that runs the inventory hook (there will be as many of these MoMs as there are discrete Cray XC systems) will only attempt to inventory its own nodes.

The hook handles the case where there are nodes other than cray_login and cray_compute nodes on a server. It also allows a site to set the vntype resource on these nodes to some other string besides "*cray_compute*" or "*cray_login*". If the hook is running on such a node, it knows that it cannot process the inventory.

The hook ignores "*offline*" nodes for inventory purposes. If a cray_login node is "*offline*", it will be ineligible to be the MoM that runs the inventory hook. If a cray_compute node is "*offline*", then it may be either present or absent in the ALPS inventory without causing a SIGHUP and inventory reread. This allows a site to offline a compute node in PBS to prevent it from being scheduled without having to disable it in ALPS.

11.11.1 Prerequisites for Cray XC

The hook requires that the name of the cray_login parent vnode resolves to one of the addresses of the node it's running on.

11.12 Support for Xeon Phi on Cray XC

11.12.1 Creating Xeon Phi Vnodes on Cray XC

PBS Professional 2021.1.2 supports Xeon Phi nodes on the Cray XC running CLE 6.0. PBS automatically creates one vnode per Xeon Phi node, and assigns that Xeon Phi node to that vnode. PBS queries the Cray XC for information about the Xeon Phi nodes and automatically sets the following values for the vnode:

- The current_aoe attribute
- The hbmem resource
- The vntype resource to *cray_compute*

11.12.1.1 PBS Vnodes and Segments or NUMA Nodes on Cray XC

Regardless of the number of segments or NUMA nodes per Xeon Phi node, PBS creates one vnode per Xeon Phi node.

11.12.1.2 Indicating Current AOE on Cray XC

PBS indicates the current AOE for each vnode by setting the value of the current_aoe attribute to the concatenated returned values of numa_cfg and hbm_cache_pct. So for example if numa_cfg is *a2a* and hbm_cache_pct is *0*, the value of current_aoe is *a2a_0*. PBS queries BASIL for values for numa_cfg and hbm_cache_pct.

Valid values for numa_cfg: a2a, snc2, snc4, hemi, quad

Valid values for hbm_cache_pct: 0, 25, 50, 100

11.12.1.3 Indicating High-bandwidth Memory on Cray XC

This version of PBS automatically sets the value of resources_available.hbmem to the value of hbm_size_mb returned by BASIL.

11.12.1.4 Validating Xeon Phi Model in Request on Cray XC

You can use a queuejob hook to validate the Xeon Phi model a user requests for a job.

A Xeon Phi model has acceptable values with either of the following:

- No AOE is requested
- Valid values for 'numa_cfg' and 'hbm_cache_pct

11.12.1.4.i Example queuejob Hook for Validating Xeon Phi Models on Cray XC

```
import pbs

e = pbs.event()
j = e.job

try:
    knl_model = j.Resource_List['aoe']
    if knl_model is None:
        res_spec = j.Resource_List['select']
        if res_spec is not None:
            for s in str(res_spec).split('+')[0].split(':'):
                if s[:4] == 'aoe=':
                    knl_model = s.partition('=')[2]
                    break
    if knl_model is None:
        e.accept()
    else
        pbs.logmsg(pbs.LOG_DEBUG, "Job requested knl_model '%s'" % str(knl_model))
        numa_cfg = str(knl_model).split('_')[0]
        hbm_cache_pct = str(knl_model).split('_')[1]
        if num_cfg not in ['a2a', 'snc2', 'snc4', 'hemi', 'quad'] or hbm_cache_pct not in ['0',
    '25', '50', '100']:
            e.reject("Invalid knl_model requested '%s'" % str(knl_model))
except SystemExit:
    pass
except:
    e.reject("%s hook failed with %s. Please contact Admin" % (e.hook_name, sys.exc_info()[:2]))
```

11.12.2 Configuring Xeon Phi Vnodes on Cray XC

11.12.2.1 Configuration Instructions on Cray XC

You must set the value of resources_available.aoe for each Xeon Phi vnode. You can use the "admin helper" script in Chapter 11, "Using Xeon Phi Configuration Script on Cray XC", on page 487.

In order to use the Xeon Phi AOE, you need to set capmc permissions and make sure that capmc initialization succeeded. Contact Cray for this information.

We recommend setting the scheduler's provision_policy configuration parameter to *avoid_provision* because provisioning a new memory model is time-consuming.

11.12.2.2 Using Xeon Phi Configuration Script on Cray XC

We've included below an example of an "admin helper" configuration script called pbs_config_knl_nodes.py that sets resources_available.aoe on each Xeon Phi vnode.

We recommend that you do the following:

1. Edit the configuration script so that the server name is correct
2. Run the script at the server host

   The script produces a list of `qmgr` commands.
3. Feed the output of the script into `qmgr`

11.12.2.3 Xeon Phi Configuration Script Contents for Cray XC

The Xeon Phi configuration script is called `pbs_config_knl_nodes.py`. Here are the contents:

```
import json
import xml.etree.ElementTree as ET
import os
import sys
import subprocess
from string import join
import socket

# server_name = socket.gethostname()
server_name = 'perch'
capmc_dir = '/opt/cray/capmc/default/bin'
apbasil_dir = '/opt/cray/alps/6.1.3-43.3/bin'
basil_req = '<BasilRequest protocol="1.7" method="QUERY" type="SYSTEM"></BasilRequest>'
basil_req_file = '/tmp/pbs_system_query.xml'
cmd1 = ['capmc', 'get_numa_capabilities']
cmd2 = ['capmc', 'get_mcdram_capabilities']
cmd3 = ['apbasil']


# Generate list from numbers
def generate_number_list(number_str):
    tmp_list = number_str.split(',')
    num_list = []
    for item in tmp_list:
        tmp_val = None
        if '-' in item:
        try:
                lower,upper = item.split('-')
                tmp_val = range(int(lower),int(upper)+1)
        num_list += tmp_val
            except ValueError:
            print "Invalid string: ", item
        except:
            print "Something was not right with: ", item
        else:
            try:
                tmp_val = int(item)
        num_list.append(tmp_val)
            except NameError:
                print "Invalid integer: ", item
            except:
                print "Something was not right with: ", item
    # Return the list of numbers list
    return num_list


# Add capmc_dir to path
os.environ['PATH'] = capmc_dir + ":" + apbasil_dir + ":" + os.environ['PATH']

# capmc commands to configure the knl nodes
tmp_file = open(basil_req_file, 'w')
tmp_file.write(basil_req)
tmp_file.close()


# identify the available numa settings
numa_cap = {}
process = subprocess.Popen(cmd1,stdout=subprocess.PIPE,stderr=subprocess.PIPE)
output,err = process.communicate()
knl_numa= json.loads(output)

for item in knl_numa['nids']:
    numa_cap[item['nid']] = item['numa_cfg']


# identify the available mcdram settings
mcdram_cap = {}
process = subprocess.Popen(cmd2,stdout=subprocess.PIPE,stderr=subprocess.PIPE)
output,err = process.communicate()
knl_mcdram = json.loads(output)
for item in knl_mcdram['nids']:
    mcdram_cap[item['nid']] = item['mcdram_cfg']


# identify the current node settings for mcdram and numa cfg
tmp_file = open(basil_req_file)
process = subprocess.Popen(cmd3,stdin=tmp_file,stdout=subprocess.PIPE,stderr=subprocess.PIPE)
output,err = process.communicate()
tmp_file.close()
root = ET.fromstring(output)
node_sets = {}
set_cnt = 0
for child in root.iter('Nodes'):
    nodes = generate_number_list(child.text.strip())
    node_sets[set_cnt] = {}
    node_sets[set_cnt]['attribs'] = child.attrib
    node_sets[set_cnt]['nids'] = nodes
    set_cnt += 1
```

```
# Loop through the node sets and identify which ones are knls
key_list = []
for key in node_sets:
    if 'attribs' in node_sets[key]:
        if node_sets[key]['attribs']['numa_cfg'] == "":
            key_list.append(key)

for key in key_list:
    node_sets.pop(key, None)

#print "-" * 80
for key in node_sets:
    #print key, node_sets[key]['nids']
    current_model = node_sets[key]['attribs']['numa_cfg']
    current_state = node_sets[key]['attribs']['hbm_cache_pct']
    current_aoe = current_model + "_" + current_state

    # Loop through the nodes that have Xeon Phis and setup them up for provisioning in PBS
    for nid in node_sets[key]['nids']:

        aoe_list = []
        models = ''
        states = ''
        if nid in numa_cap:
            models = numa_cap[nid].split(',')
        if nid in mcdram_cap:
            states = mcdram_cap[nid].split(',')
        for model in models:
            for state in states:
                try:
                    int(state)
                    aoe_list.append("%s_%s" % (model,state))
                except:
                    pass
        print "set node %s_%d_0 resources_available.aoe='%s'" % (server_name, nid,
    join(aoe_list,','))
        print "set node %s_%d_0 provision_enable = True" % (server_name, nid)
```

11.13 Using Hyperthreading on Cray XC

PBS supports hyperthreading on Cray X* series systems using ALPS. On a Cray X* series system using ALPS, PBS assigns values to vnode resources according to the inventory returned from ALPS. PBS sets resources_available.ncpus to the number of compute unit elements returned in the XML inventory. This allows PBS to make ALPS reservations for the compute units of a node, and get all of the hyperthreads associated with those compute units.

For a job to use hyperthreading, the job submitter puts a request for hyperthreading in the `aprun` call in the job script.

You can help job submitters use hyperthreaded vnodes by labeling them with a custom resource.

You can opt to limit the value reported for ncpus to cores only, not hyperthreads, when using cgroups. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

11.13.1 References for Hyperthreading on Cray XC

Check the *Cray Programming Environment User Guide* for Cray's advice on using CPUs and compute units.

11.14 Viewing Cray XC Information

11.14.1 Listing Vnodes on Cray XC

Each vnode appears only once in the output of any command that lists all vnodes, such as `pbs_statnode()`, `pbsnodes -av`, or `qmgr -c "list nodes @default"`.

11.14.2 Contents of Vnode Mom Attribute on Cray XC

When multiple login nodes are defined, each vnode representing a compute node lists every reporting login node in its Mom attribute. The Mom attribute lists multiple fully-qualified host names in a comma-separated list format.

For example, MoM1 reports compute nodes with node_id 1 through 4, and MoM2 reports compute nodes with node_id 3 through 6. In this case, the vnodes representing compute nodes with node_id 1 and 2 list MoM1 in the Mom attribute, vnodes representing compute nodes with node_id 3 and 4 list MoM1 and MoM2 in the Mom attribute, and vnodes representing compute nodes with node_id 5 and 6 list MoM2 in the Mom attribute.

11.14.3 Viewing Vnode Information on Cray XC

Each vnode's jobs attribute lists the jobs that have processes executing on that vnode. Jobs launched from an internal login node, requesting a vntype of *cray_compute* only, are not listed in the internal login node's vnode's jobs attribute. Jobs that are actually running on a login node, which requested a vntype of *cray_login*, do appear in the login node's vnode's jobs attribute.

You can view vnode attributes using the `pbsnodes -av` command.

If esLogin and internal login nodes are grouped by adding a string such as *cray_compile* to the vntype resource, the `pbs_rstat -F` command shows the following:

```
    resources_available.vntype=cray_login,cray_compile
```

11.14.4 Effect on Jobs of Stopping and Starting Vnodes on Cray XC

If a job is launched from a login node, and the MoM goes down, the impact on the job depends on the command-line options specified when the MoM is restarted.

If a job is launched from a login node, and the login node goes down, the job does not continue to run.

If there are multiple login nodes, and one login node or its MoM goes down, jobs that were launched from other login nodes are not affected.

11.14.5 Resource Accounting on Cray XC

On CLE 5.2, Comprehensive System Accounting (CSA) runs on the compute nodes, under the control of the Cray XC system. PBS performs resource accounting on the login nodes, under the control of their MoMs.

11.14.5.1 Using Comprehensive System Accounting on Cray XC

If CSA is enabled, PBS can request the kernel to write user job accounting data to accounting records. These records can then be used to produce reports for the user.

If PBS finds the CSA shared object libraries, and CSA is enabled, PBS can cause a workload management record to be written for each job. If MoM is configured for CSA support, MoM can issue CSA workload management record requests to the kernel. The kernel writes workload management accounting records associated with the PBS job to the system-wide process accounting file. The default for this file is `/var/csa/day/pacct`.

11.14.5.2 CSA Configuration Parameter on Cray XC

pbs_accounting_workload_mgmt <value>

MoM configuration parameter. Controls whether CSA accounting is enabled. The name does not start with a dollar sign. If set to "*1*", "*on*", or "*true*", CSA accounting is enabled. If set to "*0*", "*off*", or "*false*", CSA accounting is disabled. Values are case-insensitive. Default: "*true*"; enabled.

11.14.5.3 Requirements for CSA on Cray XC

PBS supports CSA on Cray XC machines running CLE 5.2. CSA requires CSA support Linux kernel modules.

On the supported platforms, the PBS MoM is CSA-enabled. If CSA workload management and user job accounting are available, PBS can use them.

11.14.5.4 Configuring MoM for CSA on Cray XC

CSA support is specified in the `pbs_accounting_workload_mgmt` line in MoM's Version 1 configuration file. CSA support is enabled by default; you must explicitly disable it if you want it disabled. If the `pbs_accounting_workload_mgmt` line is absent, CSA is still enabled.

To disable CSA support, modify `$PBS_HOME/mom_priv/config`, by setting `pbs_accounting_workload_mgmt` to *false*, *off*, or *0*.

To enable CSA support, either remove the `pbs_accounting_workload_mgmt` line, or set it to *true*, *on*, or *1*.

After modifying the MoM config file, either restart `pbs_mom` or send it SIGHUP.

11.14.5.5 Enabling Kernel CSA Support on Cray XC

In order for CSA user job accounting and workload management accounting requests to be acted on by the kernel, you need to make sure that the parameters CSA_START and WKMG_START in the `/etc/csa.conf` configuration file are set to "*on*" and that the system reflects this. You can check this by running the command:

```
csaswitch -c status
```

To set CSA_START to *"on"*, use the command:

```
csaswitch -c on -n csa
```

To set WKMG_START to *"on"*, use:

```
csaswitch -c on -n wkmg
```

Alternatively, you can use the CSA startup script `/etc/init.d/csa` with the desired argument (*on*/*off*); see the system's man page for `csaswitch` and how it is used in the `/etc/init.d/csa` startup script.

11.15 Resource Restrictions and Deprecations for Cray XC

The mpp* resources are removed.

The following are not supported, and if set, behavior is undefined.

resources_min.nchunk

resources_max.nchunk.

11.16 Caveats and Advice for Cray XC

11.16.1 Processes Not Suspended on Cray XC

On CLE 5.2UP03, if you are using preemption via suspend/resume, you may see that after a SWITCH request, ALPS continues to start new applications, so that the system is never ready for PBS to suspend job processes. The system can go from RUNNING to EMPTY to RUNNING.

11.16.2 Creating MoM Directories on Cray XC

If you start PBS with PBS_START_MOM = 0 for the first time, PBS does not create MoM directories on that host. If you want to use the machine as an execution host (running a MoM on it), set *PBS_START_MOM* = 1, run `pbs_habitat`, then start MoM.

11.16.3 Error Messages in MoM Logs on Cray XC

There are two circumstances where you may see error messages in the MoM logs:

1. The first circumstance is benign. PBS is trying to release a reservation, and PBS gets acknowledgement when ALPS stops recognizing the reservation. ALPS has canceled the reservation that PBS was trying to cancel. We get the following message:

   ```
   "ALPS error: apsched: No entry for resId <reservation ID>"
   ```

2. In the second circumstance, a node is busy or unavailable, resulting in these messages:

   ```
   "Node;BASIL;ERROR: ALPS error: apsched: resource temporarily unavailable"
   "Node;alps_request_parent;TRANSIENT BASIL error from BACKEND: ERROR: ALPS error: apsched:
      resource temporarily unavailable"
   "Transient MPP reservation error on create."
   ```

   When PBS is trying to make a reservation on a node that has become unavailable, this is benign. MoM will update her vnode information and be able to run jobs.

   Very rarely, these messages can be seen when there is a problem that requires action, for example, when Node Health Checker takes longer than the value of $alps_release_timeout. In this case, set the value of $alps_release_timeout to be greater than the time Node Health Checker requires. Unless you are seeing held jobs, this is probably not what is happening.

11.16.4 Configure Cray XC MoMs According to Rules

Because the vnode sharing attribute must be set using the `pbs_mom -s insert` command, it is not recommended to set the sharing attribute on a Cray XC vnode.

11.16.5 Suspending and Resuming Jobs on Cray XC

On Cray X* series systems, PBS can suspend one or more jobs in order to run a higher priority job.

11.16.5.1 Caveats and Restrictions

- Suspend and resume are supported on Cray XC systems with an Aries interconnect and newer Cray X* series systems
- Suspend and resume are not supported on Cray XC systems with a Gemini interconnect
- On Cray X* series systems, the suspended low priority job and the high priority job must fit into the Cray compute node's memory
- Cray X* series systems can have a maximum number of co-resident jobs on a compute node. See the Cray documentation for more details.
- On a Cray X* series system, a job that requests exclusive access (i.e. `-lplace=excl`) to a node cannot be suspended.

11.16.5.2 Default Behavior on Cray XC

The restrict_res_to_release_on_suspend server attribute is set to *ncpus* by default on Cray X* series systems. This attribute is set in the `pbs_habitat` script which runs when PBS is started for the first time after an install or upgrade.

During suspension of a job PBS releases only ncpus on Cray XC machines.

11.16.5.3 Configuring Suspend and Resume on Cray XC

On Cray X* series systems, PBS issues a request to ALPS to switch an ALPS reservation IN for resume or OUT for suspend.

In order to use suspend and resume on a Cray X* series, you must modify ALPS configuration files. Please refer to Cray's *System Administration Guide* for more details about using suspend and resume on Cray X* series.

You can update the restrict_res_to_release_on_suspend server attribute and add more resources to it. We do not recommend removing ncpus from the list of resource names on Cray X* series systems. See section 5.9.6.2, “Job Suspension and Resource Usage”, on page 252.

11.16.5.4 Errors on Cray XC

If ALPS fails to switch a reservation from suspend to resume or resume to suspend, PBS returns the error code 15222 via the `pbs_sigjob()` IFL call. The `qsig` command prints the following error message when ALPS fails to switch a reservation:

```
"qsig: Switching ALPS reservation failed <job id>"
```

11.16.6 Vnode Definition Files Not Recommended on Cray XC

Using vnode definition files on a Cray XC is not recommended. Use `qmgr` where possible instead.

Any attribute and resource settings for a specific vnode in a vnode definition file cause PBS to believe that that vnode is still usable. If PBS reads the Cray XC inventory, and a vnode is not listed in the inventory, but it is listed in a vnode definition file, the vnode is not marked as *stale*. This will cause a problem when the scheduler tries to schedule jobs onto this vnode.

If you create a vnode definition file for a vnode that has more than one MoM, you must make sure that the files are consistent on all of the MoMs that manage the vnode.

Settings in a vnode definition file override those from inventory. Settings in `qmgr` override both vnode definition files and inventory. Be careful not to overwrite information from the inventory when creating a vnode definition file. For example, if the vntype resource for a vnode is set to *cray_login* when PBS reads the inventory, and it is set to *cray_compile* in a vnode definition file, the value for vntype becomes *cray_compile* only.

11.16.7 Use Correct Name When Creating Vnode on Cray XC

When creating a vnode to represent a login node, use the short name returned by the `gethostname` command on the login node. For example, if `gethostname` returns *HostA*, do the following:

```
Qmgr: create node HostA
```

If you create a vnode with a different name from the short name returned by gethostname, the following happens:

- MoM creates a vnode whose name is the short name returned by `gethostname`
- The vnode you created is not recognized by MoM, and is marked *stale*

Do not use the IP address for the vnode name.

11.16.8 Deleting Vnodes on Cray XC

You can delete a parent vnode only if no other vnodes list this vnode in their Mom attributes. In order to delete a parent vnode which is listed in another vnode's Mom attribute, you must first delete the vnode with this vnode in its Mom attribute.

After removing a vnode that is managed by more than one MoM, you must HUP all of the managing MoMs, otherwise the vnode is not marked *stale* by the server.

11.16.9 Do Not Make Vnode Definitions Additive on Cray XC

On a Cray XC MoM, the $vnodedef_additive parameter in `PBS_HOME/mom_priv/config` is set to *False* or 0 by default. Do not unset or change the setting of the $vnodedef_additive parameter.

11.16.10 Do Not Use `configrm` on Cray XC

It is not recommended to use the `configrm` `pbs_tclsh` call.

11.16.11 Using Gating Values As Defaults on Cray XC

For most resources, if the job does not request the resource, and no server or queue defaults are set, the job inherits the maximum gating value for the resource. If this is set at the queue, the queue value of resources_max.<resource name> is used. If this is set only at the server, the job inherits the value set at the server.

11.16.12 Marking Cray XC Vnodes Offline

You can use the `qmgr` command to individually mark each vnode representing a compute node offline. This is independent of the vnodes representing login nodes.

11.16.13 Do Not Use PBS-reserved Resource Names on Cray XC

Do not create resources with names that could be used by PBS to create a Cray XC resource equivalent. For example, do not create a resource with the name *PBScraylabel_small*.

11.16.14 Fewer Chunks for Shorter Scheduling Cycle on Cray XC

The more chunks in each translated job request, the longer the scheduling cycle takes. Jobs that request a value for ncpus effectively direct PBS to use the size of ncpus as the value for ncpus for each chunk, thus dividing the number of chunks by ncpus.

Example 11-1: Comparison of larger vs. smaller chunk size and the effect on scheduling time:

Submit job with chunk size 1 and 8544 chunks:

```
qsub -lselect=8544:ncpus=1 job
```

Job's Resource_List:

```
Resource_List.ncpus = 8544
Resource_List.place = free
Resource_List.select = 8544:vntype=cray_compute
Submit_arguments = -lselect=8544:ncpus=1 job
```

Scheduling took 6 seconds:

```
12/05/2011 16:46:10;0080;pbs_sched;Job;23.example;Considering job to run
12/05/2011 16:46:16;0040;pbs_sched;Job;23.example;Job run
```

To speed up scheduling, you may want to write a submission hook that assigns each job a value for ncpus. We recommend that this value be the value for ncpus for a vnode or for a compute node.

11.16.14.1 Caveats

If you are on a heterogeneous system, forcing ncpus to be set for all requests can cause jobs to wait for particular vnodes and their associated resources, where these jobs would have been able to run across many different-sized vnodes.

Instead, you can use a job submission hook that rejects jobs that don't request values for ncpus.

11.16.15 No cput or mem for Compute Node Jobs on Cray XC

PBS does not report cput or mem for jobs running on a Cray XC compute node.

11.16.16 Set PATH Correctly on Cray XC

PATH must be included in the pbs_environment file. The PATH value is passed on to batch jobs. To maintain security, it is important that PATH be restricted to known, safe directories. Do not include "." in PATH.

11.17 Errors and Logging on Cray XC

11.17.1 Creating Custom Resources on Cray XC

When a custom resource is created for a Cray XC vnode, the server logs a message containing the resource name and type, and the vnode name. This is logged at event class 0x080.

If a custom resource can't be created, the following error message is printed in the server log:

```
error: resource <name> for vnode <name> cannot be defined
```

11.17.2 Job Requests More Than Available on Cray XC

If do_not_span_psets is set to *True*, and a job requests more resources than are available in one placement set, the following happens:

- The job's comment is set to the following:
  ```
  "Not Running: can't fit in the largest placement set, and can't span placement sets"
  ```
- The following message is printed to the scheduler's log:
  ```
  "Can't fit in the largest placement set, and can't span placement sets"
  ```

11.17.3 Invalid Cray XC Requests

It is possible to create a select and place statement that meets the requirements of PBS but not of the Cray XC. The Cray XC width and depth values cannot be calculated from ncpus and mpiprocs values. For example, if ncpus is 2 and mpiprocs is 4, the depth value is calculated by dividing ncpus by mpiprocs, and is one-half. This is not a valid depth value for Cray XC. When a select statement does not meet Cray XC requirements, and the Cray XC reservation fails, the following error message is printed in MoM's log, at log level 0x080:

```
Fatal MPP reservation error preparing request
```

11.17.4 Unequal ompthreads and ncpus on Cray XC

If the value of ompthreads does not match the value of ncpus when PBS is constructing exec_vnode for a job, the following is printed in the MoM log, at event class 0x080:

```
"ompthreads <value> does not match ncpus <value>"
```

12 Support for HPE

12.1 Briefly, How PBS Manages Cpusets

As of version 2020.1, PBS uses the standard MoM on HPE machines, and uses the cgroups hook to manage cpusets on HPE machines. See Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

PBS automatically examines the topology of the machine, and creates child vnodes to represent subsets of the machine. PBS also organizes the machine's vnodes into placement sets. When PBS runs a job on an HPE execution host, the cgroups hook creates the cpuset in which the job runs, and destroys the cpuset after the job is finished.

12.2 Cpusets and Vnodes

The PBS MoM represents a machine as a set of vnodes. Each vnode is visible via commands such as `pbsnodes`. Each vnode must have its own logical memory pool, so you get one vnode per logical memory pool. All of the vnodes on one multi-vnode host are managed by one instance of `pbs_mom`.

A cpuset is a group of CPUs and memory nodes around which an inescapable wall has been placed. The OS manages a cpuset so that processes executing within the cpuset are typically confined to use only the resources defined by the cpuset.

12.3 Requirements for Managing Cpusets

If you want PBS to manage the cpusets on a machine:

- Use the cgroups hook
- You must use a supported version of HPE MPI
- You use the PBS start/stop script to start MoM instead of `pbs_mom`

12.4 Where to Use Cpusets

Use PBS to manage your cpusets wherever you want jobs to be fenced into their own CPUs and memory. This can also be useful on other machines, such as the HPE 8600, depending on the individual machine.

12.5 Settings for sharing Attribute

The cgroups hook sets the sharing attribute for each vnode as follows:

- On MC990X and Superdome Flex, the hook sets the sharing attribute for the parent vnode to *default_shared*
- On MC990X and Superdome Flex, the hook sets the sharing attribute for all other vnodes to *default_shared*
- On 8600, the hook sets the sharing attribute for each vnode to *default_shared*

12.5.1 Creating Vnodes

We recommend using the cgroups hook to manage the machine and create any child vnodes. If you use the cgroups hook, do not create vnodes via a Version 2 configuration file. However, if you are not using the cgroups hook, you can create your vnode definitions by hand. You can have MoM create any child vnodes via a Version 2 configuration file. See section 3.3, "Creating Vnodes", on page 40.

12.5.1.1 Caveats for Creating Vnodes

Do not attempt to create more than one vnode per logical memory pool. Your jobs will not run correctly.

12.5.2 Configuring Vnodes

If necessary, you can modify child vnodes created by the hook, by using an exechost_startup hook or via a Version 2 configuration file. See section 3.4, "Configuring Vnodes", on page 43.

12.6 Comprehensive System Accounting

PBS support for CSA on HPE systems is no longer available. The CSA functionality for HPE systems has been **removed** from PBS.

13 Support for NEC SX-Aurora TSUBASA

13.1 Vnodes for NEC SX-Aurora TSUBASA

The basic hardware unit for NEC SX-Aurora TSUBASA is a *vector host* (a standard x86 server) connected to a set of accelerators called *vector engines* (VEs) via optional PCIe. The unit can consist of one or more NUMA nodes. Each unit uses one or more host channel adapters to communicate with other units and with the rest of the world.

The increasing order of communication overhead is first within a vector engine, then between vector engines via a shared PCIe, then between vector engines via PCIes on a common vector host, and finally between vector engines on separate vector hosts.

PBS creates topology-aware vnodes by grouping each PCIe with its associated vector host and vector engines together into one vnode. If there is no PCIe, PBS groups the vector host and its VEs into a vnode. A NUMA node without its own PCIe is in its own vnode.

PBS automatically creates vnodes to represent the host topology when you start PBS on execution hosts after the built-in PBS_sx_aurora hook is enabled.

PBS tries to do topology-aware scheduling by grouping job processes on vector engines in a way that produces the lowest communication overhead. When a job requests vector engines, PBS tries to assign vector engines from a single vnode to minimize communication overhead between vector engines.

For how to request resources on NEC SX-Aurora TSUBASA, see "Submitting Jobs to NEC SX-Aurora TSUBASA", on page 199 of the PBS Professional User's Guide.

13.2 Terminology

HCA

Host channel adapter. Network interconnect used by vnode. Each vector host can have one or more HCAs.

Vector engine, VE

Accelerator associated with vector host. Executes parallel and/or vectorized numeric operations.

Vector host, VH

Standard x86 server. Performs tasks such as I/O.

VE offloading

Main operations that take place on the vector host offload parallel and/or vectorized numeric operations to vector engines. In offloading, NEC MPI launches processes on the VH, and those processes then launch other job processes on VEs assigned to the job. See "Using VE Offloading", on page 204 of the PBS Professional User's Guide.

13.3 Resources for SX-Aurora TSUBASA

nves

Host-level consumable integer. Allows you to specify the number of vector engines per chunk. PBS sets the available VEs on a vnode in resources_available.nves. The default for resources_available.nves is number of VEs attached to the PCIe. The out-of-the-box default value for a job request is zero; PBS assigns a value of zero unless the administrator has set the value otherwise.

nhcas

Chunk-level non-consumable integer. When requested in a job chunk, PBS sets _NEC_HCA_LIST_IO and _NEC_HCA_LIST_MPI environment variables accordingly for that chunk. When not requested for a chunk, PBS sets _NEC_HCA_LIST_IO and _NEC_HCA_LIST_MPI to include all HCAs on a host.

ve_mem

Job-wide string. Used for reporting the maximum memory on vector engines used by job.

ve_cput

Job-wide string. Used for reporting the total CPU time, in seconds, on vector engines used by job.

ncpus

PBS sets the value of resources_available.ncpus on each vnode to (#CPUs on whole host / #vnodes on host) - #VEs on vnode. One CPU per VE is reserved for the VEOS daemon.

mem

PBS sets the value of resources_available.mem on each vnode by dividing the memory of the whole host equally among the vnodes on the host.

13.4 Configuring PBS for NEC SX-Aurora TSUBASA

1. Make sure that the PBS server and MoM daemons are installed and started. See “Installing via RPM on Linux Systems” on page 23 in the PBS Professional Installation & Upgrade Guide.
2. Enable the PBS_sx_aurora hook:
   ```
   sudo /opt/pbs/bin/qmgr -c "set pbshook PBS_sx_aurora enabled=True"
   ```
3. Optional: the default frequency for the hook is 20 seconds. You can set the frequency for the PBS_sx_aurora hook in seconds:
   ```
   sudo /opt/pbs/bin/qmgr -c "set pbshook PBS_sx_aurora freq=<frequency>"
   ```
4. Create the custom resource nves for requesting and managing VEs:
   ```
   sudo /opt/pbs/bin/qmgr -c "c r nves type= long,flag=nhm"
   ```
5. Add the custom nves resource to the `{PBS_HOME}/sched_priv/sched_config` resources: line:
   ```
   resources: "ncpus, mem, arch, host, vnode, aoe, eoe, nves"
   ```
6. HUP the scheduler(s):
   ```
   kill -HUP <scheduler PID>
   ```
7. Create the custom resource nhcas for managing HCAs:
   ```
   sudo /opt/pbs/bin/qmgr -c "c r nhcas type= long,flag=hm"
   ```
8. Create the custom resources ve_cput and ve_mem for accounting:
   ```
   sudo /opt/pbs/bin/qmgr -c "c r ve_cput type=long, flag=h"
   sudo /opt/pbs/bin/qmgr -c "c r ve_mem type=size, flag=h"
   ```
9. Recommended: sort your vnodes first by nves, then by ncpus. Replace the default node_sort_key in `{PBS_HOME}/sched_priv/sched_config` with the following:
   ```
   node_sort_key: "nves HIGH unused"
   node_sort_key: "ncpus HIGH unused"
   ```
10. Set NEC-specific environment variables for all hosts. Set the following in each host's `{PBS_HOME}/pbs_environment` file:
    ```
    NMPI_LAUNCHER_EXEC={PBS_EXEC}/bin/pbs_tmrsh
    NMPI_TTY_COMPAT=ON
    ```
11. Restart PBS so that the PBS_sx_aurora hook can create vnodes on all hosts in the cluster:
    ```
    sudo systemctl restart pbs
    ```

13.5 Debugging on NEC SX-Aurora TSUBASA

- To see all the DEBUG and INFO messages logged by the hook, increase the log level by setting the $logevent parameter to *4095* (0xffffffff) in the MoM's configuration file, `PBS_HOME/mom_priv/config`.
- If you need to detect failed devices faster, you can change the hook's frequency. The frequency is specified in seconds. The default hook frequency is 20 seconds. You can set the frequency for the PBS_sx_aurora hook:
  ```
  sudo /opt/pbs/bin/qmgr -c "set pbshook PBS_sx_aurora freq=<frequency>"
  ```

13.6 Suspending and Resuming Jobs

On the SX-Aurora TSUBASA, partial process swapping (PPS) means copying part of the memory on VEs being used by VE processes onto memory on the VH (the PPS buffer), then later copying the PPS buffer on the VH back to memory on the VEs.

PPS allows high-priority jobs to run before current lower-priority VE processes finish, by suspending and swapping out those lower-priority processes, then resuming the swapped-out VE processes after the high-priority jobs finish.

Swapping out a VE process means copying part of the memory area being used by the VE process onto the PPS buffer, and freeing the memory area so that other, higher-priority, VE processes can use it.

Swapping in a VE process means copying the memory area in the PPS buffer used for the swapped-out VE process back to memory on the VE.

When PBS runs a higher-priority job by swapping out a lower-priority job, it does the following:

1. Suspend the execution of VE processes and VH processes belonging to the lower priority job
2. Swap out the VE processes of the lower-priority job, using SX-Aurora TSUBASA interfaces
3. Run the higher-priority job
4. After completion of the higher-priority job, swap the VE processes of the lower-priority job back
5. Resume the execution of the lower-priority job

13.7 Job Accounting on NEC SX-Aurora TSUBASA

When PBS writes accounting records, PBS records nves in both Resource_List.nves and resources_assigned.nves. PBS also writes ve_mem and ve_cput as part of the value of the job's resources_used attribute.

14 Managing Jobs

14.1 Routing Jobs

You can route jobs to various places and by various criteria. You can reject submission of jobs that request too much of a given resource. You can force jobs into the correct queues. You can have all jobs submitted to a routing queue, then route them to the correct execution queues. You can use peer scheduling to have jobs executed at other PBS complexes. You can use hooks to move jobs. For information on routing jobs, see section 4.9.39, “Routing Jobs”, on page 207.

14.2 Limiting Number of Jobs Considered in Scheduling Cycle

If you limit the number of jobs in execution queues, you can speed up the scheduling cycle. You can set an individual limit on the number of jobs in each queue, or a limit at the server, and you can apply these limits to generic and individual users, groups, and projects, and to overall usage. You specify this limit by setting the queued_jobs_threshold queue or server attribute. See section 5.15.1.9, “How to Set Limits at Server and Queues”, on page 299.

If you set a limit on the number of jobs that can be queued in execution queues, we recommend that you have users submit jobs to a routing queue only, and route jobs to the execution queue as space becomes available. See section 4.9.39, “Routing Jobs”, on page 207.

14.3 Allocating Resources to Jobs

You can make sure that jobs request or inherit any resources required to manage those jobs. If a job does not request a resource, you can make sure that the resource is allocated to the job anyway.

In order for limits to be effective, each job must request each limited resource. For a complete description of how limits work, see section 5.15, “Managing Resource Usage”, on page 290.

You can create custom resources specifically to allocate them to jobs. These resources can be visible, alterable, and requestable by users, or invisible, unalterable, and unrequestable, or visible but unalterable and unrequestable. For instructions on creating invisible or unrequestable resources, see section 5.14.2.3.vi, “Resource Permission Flags”, on page 262.

You can alter a job's resource request using the following methods:

- You can set defaults for resources at the server or at each queue. This way, you can have jobs inherit specific values for the resources by routing them to special queues, where they inherit the defaults. For how jobs inherit resources, see section 5.9.4, “Allocating Default Resources to Jobs”, on page 249. For how to specify default resources, see section 5.9.3, “Specifying Job Default Resources”, on page 247.

For how resource defaults change when a job is moved, see section 5.9.4.3, "Moving Jobs Between Queues or Servers Changes Defaults", on page 250.

- You can use a hook to assign a specific resource value to a job, if a job requests the wrong value for a resource. For how to use a hook to assign a resource to a job, see the PBS Professional Hooks Guide. For examples of using hooks to assign resources to jobs, see *PBS Professional Plugins (Hooks) Guide*.
- You can use the `qalter` command to change a job's resource request. For how to use the qalter command, see "qalter" on page 128 of the PBS Professional Reference Guide.
- You can set default arguments the `qsub` command via the default_qsub_arguments server attribute. For how to use default arguments to `qsub`, see "Server Attributes" on page 283 of the PBS Professional Reference Guide.

14.3.1 Viewing Resources Allocated to a Job

14.3.1.1 The exec_vnode Attribute

The exec_vnode attribute displayed via `qstat` shows the resources allocated from each vnode for the job.

The exec_vnode line looks like:

```
exec_vnode = (<vnode name>:ncpus=W:mem=X)+(<vnode name>:ncpus=Y:mem=Z)
```

For example, a job requesting

```
-l select=2:ncpus=1:mem=1gb+1:ncpus=4:mem=2gb
```

gets an exec_vnode of

```
exec_vnode =  (VNA:ncpus=1:mem=1gb)+(VNB:ncpus=1:mem=1gb) +(VNC:ncpus=4:mem=2gb)
```

Note that the vnodes and resources required to satisfy a chunk are grouped by parentheses. In the example above, if two vnodes on a single host were required to satisfy the last chunk, the exec_vnode might be:

```
exec_vnode = (VNA:ncpus=1:mem=1gb)+(VNB:ncpus=1:mem=1gb)
    +(VNC1:ncpus=2:mem=1gb+VNC2:ncpus=2:mem=1gb)
```

Note also that if a vnode is allocated to a job because the job requests an arrangement of *exclhost*, only the vnode name appears in the chunk. For example, if a job requesting

```
-l select 2:ncpus=4 -l place = exclhost
```

is placed on a host with 4 vnodes, each with 4 CPUs, the exec_vnode attribute looks like this:

```
exec_vnode = (VN0:ncpus=4)+(VN1:ncpus=4)+(VN2)+(VN3)
```

14.3.1.2 The schedselect Attribute

The resources allocated from a vnode are only those specified in the job's schedselect attribute. This job attribute is created internally by starting with the select specification and applying any server and queue default_chunk resource defaults that are missing from the select statement. The schedselect job attribute contains only vnode-level resources. The exec_vnode job attribute shows which resources are allocated from which vnodes. See "Job Attributes" on page 330 of the PBS Professional Reference Guide.

14.3.1.3 Resources for Requeued Jobs

When a job is requeued due to an error in the prologue or initialization, the job's exec_host and exec_vnode attributes are cleared. The only exception is when the job is checkpointed and must be rerun on the exact same system. In this case, the exec_host and exec_vnode attributes are preserved.

14.4 Grouping Jobs By Project

14.4.1 PBS Projects

In PBS, a project is a way to organize jobs independently of users and groups. A project is a tag that identifies a set of jobs. Each job's project attribute specifies the job's project. Each job can be a member of up to one project.

Projects are not tied to users or groups. One user or group may run jobs in more than one project. For example, user Bob runs JobA in ProjectA and JobB in ProjectB. User Bill runs JobC in ProjectA. User Tom runs JobD in ProjectB. Bob and Tom are in Group1, and Bill is in Group2.

14.4.2 Assigning Projects to Jobs

A job's project can be set in the following ways:

- At submission, using the `qsub -P` option; see "qsub" on page 214 of the PBS Professional Reference Guide
- After submission, via the `qalter -P` option; see "qalter" on page 128 of the PBS Professional Reference Guide
- Via a hook; see the PBS Professional Hooks Guide

14.4.3 Managing Resource Use by Project

PBS can apply limits to the amount of resources used by jobs in projects, or the number of queued and running jobs belonging to projects. See section 5.15.1, "Managing Resource Usage By Users, Groups, and Projects, at Server & Queues", on page 290.

14.4.4 Managing Jobs by Project

You can arrange for the jobs belonging to a project to run on designated hardware; see section 4.4.4, "Allocating Resources by User, Project or Group", on page 82. You can also run jobs belonging to a project in designated time slots; see section 4.4.6, "Scheduling Jobs into Time Slots", on page 86. For more information on routing by project, see section 4.9.39, "Routing Jobs", on page 207.

14.4.5 Viewing Project Information

Each job's project, if any, is specified in its project attribute. To see the value of this attribute, use the `qstat -f` option. See "qstat" on page 198 of the PBS Professional Reference Guide.

14.4.6 Selecting Jobs by Project

You can select jobs according to their project using the `qselect -P` option. See "qselect" on page 187 of the PBS Professional Reference Guide.

14.4.7 Default Project Value

The default value for a job's project attribute is "*_pbs_project_default*". Any job submitted without a specified value for the project attribute is given the default value. If you explicitly set the value to "*_pbs_project_default*", the server prints a warning message saying that the value has been set to the default. If you unset the value of the attribute in a hook, the value becomes the default value. Using `qalter -P ""` sets the value to the default.

14.4.8 Error Messages

When a job would exceed a limit by running, the job's comment field is set to an error message. See "Run Limit Error Messages" on page 389 of the PBS Professional Reference Guide.

14.5 Job Prologue and Epilogue

As of 2020.1, the prologue and epilogue are **deprecated**.

You can run a site-supplied script or program before and/or after each job runs. This allows initialization or cleanup of resources, such as temporary directories or scratch files. The script or program that runs before the job is the *prologue*; the one that runs after the job is the *epilogue*.

The primary purpose of the prologue is to provide a site with some means of performing checks prior to starting a job. The epilogue can be used to requeue a checkpointed job. See section 9.3.7.3, "Requeueing via Epilogue", on page 431.

If you have any execjob_prologue hooks, they supersede the prologue, and run when the prologue would run, and if you have any execjob_epilogue hooks, they supersede the epilogue, and run when the epilogue would run.

If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

You can run a shell script as your prologue or epilogue, or you can use an execjob_prologue and/or execjob_epilogue hook to do the work. If you already have a shell script prologue and/or epilogue, you can run each via an appropriate execjob_prologue or execjob_epilogue hook. We show how to do this in section 14.5.2, "Using Hooks for Prologue and Epilogue", on page 514.

14.5.1 Using Shell Scripts for Prologue and Epilogue

Only one prologue and one epilogue may be used per PBS server. The same prologue and/or epilogue runs for every job in the complex.

Each script may be either a shell script or an executable object file.

14.5.1.1 When Shell Prologue and Epilogue Run

The prologue runs before the job is executed. The epilogue runs after the job terminates, including normal termination, job deletion while running, error exit, or even if `pbs_mom` detects an error and cannot completely start the job. If the job is deleted while it is queued, then neither the prologue nor the epilogue is run. If the job is discarded while running, for example when the server loses contact with the MoM, the epilogue does not run.

If a prologue or epilogue script is not present, MoM continues in a normal manner.

14.5.1.2 Where Shell Prologue and Epilogue Run

When multiple vnodes are allocated to a job, these scripts are run only by the MoM on the primary execution host.

The prologue runs with its current working directory set to `PBS_HOME/mom_priv`, regardless of the setting of the sandbox job attribute.

The epilogue runs with its current working directory set to the job's staging and execution directory. This is also where the job shell script is run.

14.5.1.3 Shell Prologue and Epilogue Location

Both the prologue and the epilogue must reside in the `PBS_HOME/mom_priv` directory.

14.5.1.4 Shell Prologue and Epilogue Requirements

In order to be run, the script must adhere to the following rules:

- The script must be in the `PBS_HOME/mom_priv` directory
- The prologue must have the exact name "prologue" under Linux, or "prologue.bat" under Windows
- The epilogue must have the exact name "epilogue" under Linux, or "epilogue.bat" under Windows
- The script must be written to exit with one of the zero or positive exit values listed in section 14.5.1.12, "Shell Prologue and Epilogue Exit Codes", on page 513. The negative values are set by MoM
- Under Linux, the script must be owned by root, be readable and executable by root, and cannot be writable by anyone but root
- Under Windows, the script's permissions must give "Full Access" to the local Administrators group on the local computer

14.5.1.5 Shell Prologue and Epilogue Environment Variables

The prologue and epilogue run with the following set in their environment:

- The contents of the `pbs_environment` file
- The PBS_JOBDIR environment variable

TMPDIR is not set in the prologue environment or the epilogue environment.

14.5.1.6 Shell Prologue and Epilogue Permissions

Both the prologue and epilogue are run under root on Linux, or under an Admin-type account on Windows, and neither is included in the job session.

14.5.1.7 Shell Prologue and Epilogue Arguments

The prologue is called with the following arguments:

Table 14-1: Arguments to Prologue

Argument	Description
argv[1]	Job ID
argv[2]	User name under which the job executes
argv[3]	Group name under which the job executes

The epilogue is called with the following arguments:

Table 14-2: Arguments to Epilogue

Argument	Description
argv[1]	Job ID
argv[2]	User name under which the job executes
argv[3]	Group name under which the job executes
argv[4]	Job name
argv[5]	Session ID
argv[6]	Requested built-in resources (job's Resource_List)
argv[7]	List of resources used (job's resources_used) gathered from the primary execution host only
argv[8]	Name of the queue in which the job resides
argv[9]	Account string, if one exists
argv[10]	Exit status of the job

14.5.1.8 Shell Epilogue Argument Caveats

Under Windows and with some Linux shells, accessing argv[10] in the epilogue requires a shift in positional parameters. To do this, the script must do the following:

1. Call the arguments with indices 0 through 9
2. Perform a shift /8
3. Access the last argument using %9%

For example:

```
cat epilogue
> #!/bin/bash
>
> echo "argv[0] = $0" > /tmp/epiargs
> echo "argv[1] = $1" >> /tmp/epiargs
> echo "argv[2] = $2" >> /tmp/epiargs
> echo "argv[3] = $3" >> /tmp/epiargs
> echo "argv[4] = $4" >> /tmp/epiargs
> echo "argv[5] = $5" >> /tmp/epiargs
> echo "argv[6] = $6" >> /tmp/epiargs
> echo "argv[7] = $7" >> /tmp/epiargs
> echo "argv[8] = $8" >> /tmp/epiargs
> echo "argv[9] = $9" >> /tmp/epiargs
> shift
> echo "argv[10] = $9" >> /tmp/epiargs
```

14.5.1.9 Standard Input to Shell Prologue and Epilogue

Both scripts have standard input connected to a system-dependent file. The default for this file is `/dev/null`.

14.5.1.10 Standard Output and Error for Shell Prologue and Epilogue

The standard output and standard error of the scripts are connected to the files which contain the standard output and error of the job. There is one exception: if a job is an interactive PBS job, the standard output and error of the epilogue is pointed to `/dev/null` because the pseudo-terminal connection used was released by the system when the job terminated.

14.5.1.11 Shell Prologue and Epilogue Timeout

When the scheduler runs a job, it waits until the prologue has ended. To prevent an error condition within the prologue or epilogue from delaying PBS, MoM places an alarm around the script's/program's execution. The default value is *30 seconds*. If the alarm timeout is reached before the script has terminated, MoM will kill the script. The alarm value can be changed via the $prologalarm MoM configuration parameter. See section 9.6.6, “Prologue & Epilogue Running Time”, on page 449.

14.5.1.12 Shell Prologue and Epilogue Exit Codes

Normally, the prologue and epilogue programs should exit with a zero exit status. The prologue and epilogue should be written to exit with one of the zero or positive values listed here. When there is a problem with the script, MoM sets the exit value to one of the negative values. Exit status values and their impact on the job are listed in the following table:

Table 14-3: Prologue and Epilogue Exit Codes

Exit Code	Meaning	Prologue	Epilogue
-4	The script timed out (took too long).	The job will be requeued.	Ignored
-3	The `wait(2)` call waiting for the script to exit returned with an error.	The job will be requeued	Ignored
-2	The input file to be passed to the script could not be opened.	The job will be requeued.	Ignored
-1	The script has a permission error, is not owned by root, and/or is writable by others than root.	The job will be requeued.	Ignored
0	The script was successful.	The job will run.	Ignored
1	The script returned an exit value of *1*.	The job will be aborted.	Ignored
>1	The script returned a value greater than one.	The job will be requeued.	Ignored
2	The script returned a value of *2*.	The job will be requeued.	If the job was checkpointed under the control of PBS, the job is requeued.

MoM records in her log any case of a non-zero prologue or epilogue exit code, at event class 0x0001.

14.5.1.13 Shell Prologue and Epilogue Limitations and Caveats

- Consider having your epilogue write a lock file so that it can detect whether it is being run more than once for a job.
- You must exercise great caution in setting up the prologue to prevent jobs from being flushed from the system.
- Interactive-batch jobs cannot be requeued if the epilogue exits with a non-zero status. When this happens, these jobs are aborted.
- The prologue and epilogue cannot be used to modify the job environment or to change limits on the job.
- If any execjob_prologue hooks exist, they are run, and the prologue is not run.
- If any execjob_epilogue hooks exist, they are run, and the epilogue is not run.
- If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead.

14.5.2 Using Hooks for Prologue and Epilogue

You can run execjob_prologue and execjob_epilogue hooks to do whatever setup and cleanup you need before and after jobs run. Note that these hooks supersede the shell prologue and epilogue and prevent them from running. See "execjob_prologue: Event Just Before Execution of Top-level Job Process" on page 97 in the PBS Professional Hooks Guide, and "execjob_epilogue: Event Just After Killing Job Tasks" on page 104 in the PBS Professional Hooks Guide.

However, you can run your shell prologue and epilogue using execjob_prologue and execjob_epilogue hooks, and we provide an example hook called `run_pelog_shell.py`. The hook is included in `$PBS_EXEC/unsupported`. as `run_pelog_shell.py`, along with its configuration file, `run_pelog_shell.ini`. You can see the contents at "execjob_prologue and execjob_epilogue Hook Examples" on page 266 in the PBS Professional Hooks Guide.

You can use this hook when the execjob_prologue and execjob_epilogue events are used in other hooks, such as the cgroups hook, and you still want to run the classic prologue and epilogue scripts we describe in section section 14.5.1, "Using Shell Scripts for Prologue and Epilogue", on page 510. Additionally, the hook introduces parallel prologue and epilogue shell scripts.

On the primary execution host (the first host listed in PBS_NODEFILE), the standard naming convention of 'prologue' and 'epilogue' apply. Parallel prologues and epilogues use the naming conventions 'pprologue' and 'pepilogue', respectively, but run only on the secondary execution hosts. On Windows, parallel prologues and epilogues expect a '.bat' extension, which results in 'pprologue.bat' and 'pepilogue.bat'. This hook does the normal checks PBS does to start a prologue, such as permissions, etc., for UNIX. This hook also allows you to use a parallel prologue/epilogue (pprologue/pepilogue).

Parallel prologues will not run until a task associated with the job (i.e. via `pbs_attach`, `pbs_tmrsh`) begins on the secondary execution hosts. Parallel epilogues run only if the prologue ran successfully on the primary execution host. Only the primary execution host will have a value for resources_used in epilogue argument $7.

We assume the same requirements as listed for prologues/epilogues for running all types of prologue and epilogue shell scripts in section 14.5.1.4, "Shell Prologue and Epilogue Requirements", on page 511.

By default, parallel prologue/epilogue is set to *False*. To enable parallel behavior, edit the configuration file and set ENABLE_PARALLEL to *True*.

The hook kills the prologue/epilogue 5 seconds before the hook_alarm timeout. At this point the job is requeued/deleted depending on the value of DEFAULT_ACTION. The hook_alarm time defaults to 30 seconds, giving the prologue/epilogue approximately 25 seconds to complete.

14.5.2.1 Installing Prologue and Epilogue Hooks

You could create a single hook that runs on both the execjob_prologue and the execjob_epilogue events, but to ensure execution order we separate them into the individual events by creating two separate hooks that use the same hook script.

Edit `run_pelog_shell.ini` to make configuration changes, then create and import the hook as we show here.

As root, run the following:

```
qmgr << EOF
create hook run_prologue_shell
set hook run_prologue_shell event = execjob_prologue
set hook run_prologue_shell enabled = true
set hook run_prologue_shell order = 1
set hook run_prologue_shell alarm = 35
import hook run_prologue_shell application/x-python default run_pelog_shell.py
import hook run_prologue_shell application/x-config default run_pelog_shell.ini

create hook run_epilogue_shell
set hook run_epilogue_shell event = execjob_epilogue
set hook run_epilogue_shell enabled = true
set hook run_epilogue_shell order = 999
set hook run_prologue_shell alarm = 35
import hook run_epilogue_shell application/x-python default run_pelog_shell.py
import hook run_epilogue_shell application/x-config default run_pelog_shell.ini
EOF
```

Any further configuration changes to `run_pelog_shell.ini` require re-importing the file to both hooks:

```
qmgr << EOF
import hook run_prologue_shell application/x-config default run_pelog_shell.ini
import hook run_epilogue_shell application/x-config default run_pelog_shell.ini
EOF
RERUN=14
DELETE=6
DEBUG=False
```

We show the defaults for the following constants in `run_pelog_shell.ini`. We show the contents of the file in "execjob_prologue and execjob_epilogue Hook Examples" on page 266 in the PBS Professional Hooks Guide. You can set them `to` match site preferences:

```
ENABLE_PARALLEL=False
VERBOSE_USER_OUTPUT=False
DEFAULT_ACTION=RERUN
TORQUE_COMPAT=False
```

14.6 Linux Shell Invocation

When PBS starts a job, it invokes the user's login shell, unless the user submitted the job with the `-S` option. PBS passes the job script, which is a shell script, to the login process.

PBS passes the name of the job script to the shell program. This is equivalent to typing the script name as a command to an interactive shell. Since this is the only line passed to the script, standard input will be empty to any commands. This approach offers both advantages and disadvantages:

14.6.1 Advantages

- Any command which reads from standard input without redirection will get an EOF.
- The shell syntax can vary from script to script. It does not have to match the syntax for the user's login shell. The first line of the script, even before any #PBS directives, should be

  #!/shell

  where *shell* is the full path to the shell of choice, `/bin/sh, /bin/csh, ...`

  The login shell will interpret the `#!` line and invoke that shell to process the script.

14.6.2 Disadvantages

- An extra shell process is run to process the job script.
- If the script does start with a `#!` line, the wrong shell may be used to interpret the script and thus produce errors.
- If a non-standard shell is used via the -S option, it will not receive the script, but its name, on its standard input.

14.7 When Job Attributes are Set

The attributes of a job are set at various points in the life of the job. For a description of each job attribute, see "Job Attributes" on page 330 of the PBS Professional Reference Guide.

14.7.1 Job Attributes Set By qsub Command

Before the job is passed to the server, the `qsub` command sets these job attributes, in this order:

1. Attributes specified as options on the command line
2. Attributes specified in #PBS directives within the job script
3. Job attributes specified in the default_qsub_arguments server attribute
4. If the following job attributes have not already been set, they are set as follows:
   - Job_Name: set to the file name of the job script, or to "*STDIN*" if the script is entered via standard input
   - Checkpoint: set to "*u*" for unspecified.
   - Hold_Types: set to "*n*"
   - Join_Path: set to "*n*"
   - Keep_Files: set to "*n*"
   - Mail_Points: set to "*a*" for abort
   - Priority: set to *0* (zero)
   - Rerunnable: set to *True*
   - run_count: can be set by job submitter
   - Variable_List: the `qsub` command sets the following variables and appends them to the existing value of Variable_List: PBS_O_HOME, PBS_O_LANG, PBS_O_LOGNAME, PBS_O_PATH, PBS_O_MAIL, PBS_O_SHELL, PBS_O_WORKDIR, PBS_O_TZ, and PBS_O_SYSTEM
   - Submit_arguments: set to any submission arguments on the command line

14.7.2 Job Attributes Set at Server

When the job is passed from the qsub command to the server, the raw job information is available to any job submission hooks, which can alter the information. Once the job is at the server, the server sets the following attributes:

- Job_Owner: set to <username>@<submission host name>
- Variable_List: the following are added to the job's Variable_List attribute: PBS_O_QUEUE, PBS_O_HOST
- Output_Path: if not yet specified, the Output_Path attribute is set
- Error_Path: if not yet specified, the Error_Path attribute is set
- Rerunable: if the job is interactive, the Rerunable attribute is set to *False*
- run_count: incremented each time job is run
- project: if unset, the project attribute is set to "*_pbs_project_default*".
- Read-only attributes: the server sets the job's read-only attributes; see "Job Attributes" on page 330 of the PBS Professional Reference Guide
- Resource_List: adjusted to include inherited resources specified in the queue and server Resources_Default attributes, if those resources are not yet in the list
- Comment set when job is sent for execution or rejected; see section 14.7.3.1, "Comment Set When Running Job", on page 517

14.7.3 Attributes Changed by Operations on Jobs

14.7.3.1 Comment Set When Running Job

Before the server sends the job to an execution host, the server sets the job's comment to "Job was sent for execution at <time> on <execvnode>".

After the server gets a confirmation from the MoM, the server updates the job's comment to "Job run at <time> on <execvnode>".

If the MoM rejects the job, the server changes the job comment to "Not Running: PBS Error: Execution server rejected request".

14.7.3.2 Attributes Changed When Moving Job

If you move a job to a different queue or server, any default resources from the current queue or server are removed, and new defaults are inherited. See section 5.9.4.3, "Moving Jobs Between Queues or Servers Changes Defaults", on page 250. For information on the qmove command, see "qmove" on page 173 of the PBS Professional Reference Guide.

14.7.3.3 Attributes Changed When Altering Job

When the qalter command is used to alter a job, the changes to the job are changes to the equivalent job attributes. See "qalter" on page 128 of the PBS Professional Reference Guide.

14.7.3.4 Attributes Changed When Requeueing or Rerunning a Job

When a job is requeued or rerun, its exec_vnode and/or exec_host attributes may be changed. The job may end up running on different vnodes. See "qrerun" on page 179 of the PBS Professional Reference Guide.

Each time a job is run, its run_count attribute is incremented by the server.

14.7.3.5 Attributes Changed by Holding or Releasing a Job

When a job is held using the `qhold` command, or released using the `qrls` command:

- The Hold_Types attribute reflects the change
- The job_state attribute may be changed

See "Job Attributes" on page 330 of the PBS Professional Reference Guide and "qhold" on page 148 of the PBS Professional Reference Guide.

14.7.3.6 Attributes Changed by Suspending or Resuming a Job

When a job is suspended or resumed using the `qsig` command, the job's job_state attribute reflects the change in state. See "qsig" on page 193 of the PBS Professional Reference Guide.

14.8 Job Termination

A job can be terminated for the following reasons:

- You or the submitter can use `qdel` to kill the job
- The job can be preempted and requeued
- The job can go over a limit and be killed
- The job is submitted to a routing queue, and can never be routed (accepted by a destination queue)
- The server is restarted and the job cannot be recovered
- The job specifies a dependency that fails or is terminated
- The job is killed by a signal

14.8.1 Normal Job Termination

When there is no $action terminate script and a running job is terminated, via the `qdel <job ID>` command, because of a server shutdown, or because the job has exceeded a limit, PBS waits for a configurable amount of time between sending a SIGTERM and a SIGKILL signal to the job. The amount of time is specified in the kill_delay queue attribute. The default value for this attribute is *10 seconds*. PBS takes the following steps.

For a single-vnode job:

1. PBS sends the job a SIGTERM
2. PBS waits for the amount of time specified in the kill_delay queue attribute
3. PBS sends the job a SIGKILL

For a multi-vnode job:

1. The primary execution host MoM sends a SIGTERM to all processes on the primary execution host
2. If any of the processes of the top task of the job are still running, PBS waits a minimum of *kill_delay* seconds
3. The primary execution host MoM sends a SIGKILL to all remaining job processes on the primary execution host
4. The subordinate MoMs send a SIGKILL to all their processes belonging to this job

14.8.2 Using the `qdel` Command to Terminate a Job

You can delete a job using the `qdel` command. See “qdel” on page 141 of the PBS Professional Reference Guide.

`qdel <job ID>`

If there is an $action terminate script, it is used to terminate the job.

If there is no $action terminate script, the SIGTERM-delay-SIGKILL sequence described in section 14.8.1, “Normal Job Termination”, on page 518 is used to terminate the job.

This command does not terminate provisioning jobs.

`qdel -Wforce <job ID>`

If MoM is reachable, MoM sends the job a SIGKILL signal, and files are staged out. If MoM is unreachable, the server discards the job. The job may or may not continue to run on the execution host(s).

This command terminates provisioning jobs.

14.8.3 Killing Job Processes

If you need to kill job processes, you can use the `printjob` command to find the job's session ID, and then kill those processes. See “printjob” on page 126 of the PBS Professional Reference Guide.

14.8.4 Hooks and Job Termination

If you qdel a job, any execjob_preterm hooks run on all the hosts allocated to a job. On the primary execution host, the hook executes when the job receives a signal from the server for the job to terminate. On a sister host, this hook executes when the sister receives a request from the primary execution host MoM to terminate the job, just before the sister signals the task on this host to terminate.

The execjob_preterm hook does not run for any other job termination. For example, it does not run on a `qrerun` or when a job goes over its limit.

See "execjob_preterm: Event Just Before Killing Job Tasks" on page 103 in the PBS Professional Hooks Guide.

14.8.5 Configuring Site-specific Job Termination

The default behavior of PBS is for MoM to terminate a job under the following circumstances:

- The job's usage of a resource exceeds the limit requested
- The job is deleted by the server on shutdown
- The job is deleted via the `qdel` command

MoM normally uses `SIGTERM`, waits for the amount of time specified in the queue's kill_delay attribute, then issues a `SIGKILL`. See section 14.8, “Job Termination”, on page 518.

You may want PBS to run your own job termination script in place of the normal action. The termination script is run in place of a `SIGTERM`. The termination script runs only on the primary execution host. After the top job process is terminated, a `KILL` signal is sent to any other job processes running on other hosts.

You can define the desired termination behavior by specifying the script you want to run in the $action terminate parameter in the Version 1 configuration file. The $action terminate parameter takes this form:

$action terminate <timeout> ! <path to script> [args]

Where

<timeout> is the time, in seconds, allowed for the script to complete. A value of *zero* (*0*) indicates infinite time is allowed for the script to run.

<path to script> is the path to the script. If it is a relative path, it is evaluated relative to the `PBS_HOME/mom_priv` directory.

<args> are optional arguments to the script. Values for *<args>* may be any string not starting with a percent sign ("*%*").

Arguments with a percent sign, making up any of the following keywords, are replaced by MoM with the corresponding value:

Table 14-4: $action terminate Keywords

Keyword	Value Used by MoM
%jobid	Job ID
%sid	Session ID of task (job)
%uid	Execution UID of job
%gid	Execution GID of job
%login	Login name associated with UID
%owner	Job owner in form *name@host*
%auxid	Auxiliary ID (system-dependent)

14.8.5.1 Requirements for Termination Script

The script should exit with a value of *zero* when the job is terminated successfully. If the script exits successfully (with a zero exit status and before the time-out period), PBS does not send any signals or attempt to terminate the job. It is the responsibility of the termination script in this situation to ensure that the job has been terminated.

The script should exit with a non-zero value if the job was not successfully terminated. If the script exits with a non-zero exit status, the job is sent `SIGKILL` by PBS.

If the script does not complete in the time-out period, it is aborted and the job is sent `SIGKILL`.

14.8.5.2 Examples of Configuring Termination

Linux:

Example 14-1: To use a 60-second timeout, run `PBS_HOME/mom_priv/endjob.sh,` and pass the job's session ID, user ID, and PBS jobs ID to the script:

```
$action terminate 60 !endjob.sh %sid %uid %jobid
```

Example 14-2: To use an infinite timeout, run the system `kill` command with the signal *13*, and pass the job's session ID:

```
$action terminate  0 !/bin/kill -13 %sid
```

Windows:

Example 14-3: To use a 60-second timeout, run `endjob.bat,` and pass the job's session ID, user ID, and PBS jobs ID to the script:

```
$action terminate 60 !endjob.bat %sid %uid %jobid
```

Example 14-4: To use an infinite timeout, run the `pbskill` command, and pass the job's session ID:

```
$action terminate  0 !"C:/Program Files/PBS Pro/exec/bin/pbskill" %sid
```

14.8.5.3 Caveats and Restrictions on Termination

Under Windows, *<path to script>* must have a "`.bat`" suffix since it will be executed under the Windows command prompt `cmd.exe`. If the *<path to script>* specifies a full path, be sure to include the drive letter so that PBS can locate the file. For example, `C:\winnt\temp\terminate.bat`. The script must be writable by no one but an Administrator-type account.

14.8.6 Killing Jobs with a Signal

You or the job owner can kill a job by sending a kill signal to a job via `qsig`.

If a job is terminated via a signal while it is in the process of being sent to the execution host, the following happens:

- PBS writes a server log message:
  `Job;<job ID>;Terminated on signal <signal number>`
- The job is requeued
- If `qrun` is used to run the job, `qrun` does not set the job's comment

14.9 Job Exit Status Codes

The exit status of a job may fall in one of three ranges, listed in the following table:

Table 14-5: Job Exit Status Ranges

Exit Status Range	Reason	Description
X < 0	The job could not be executed	See Table 14-6, "Job Exit Codes," on page 522
0 <=X < 128	Exit value of shell or top process	This is the exit value of the top process in the job, typically the shell. This may be the exit value of the last command executed in the shell or the `.logout` script if the user has such a script (`csh`). The exit status of an interactive job is always recorded as 0 (zero), regardless of the actual exit status.
X >=128	Job was killed with a signal	This means the job was killed with a signal. The signal is given by X modulo 128 (or 256). For example an exit value of 137 means the job's top process was killed with signal 9 (137 % 128 = 9). The exit status values greater than 128 (or 256) indicate which signal killed the job. Depending on the system, values greater than 128 (or on some systems 256; see `wait(2)` or `waitpid(2)` for more information), are the value of the signal that killed the job. To interpret (or "decode") the signal contained in the exit status value, subtract the base value from the exit status. For example, if a job had an exit status of 143, that indicates the job was killed via a SIGTERM (e.g. 143 - 128 = 15, signal 15 is SIGTERM). See the `kill(1)` manual page for a mapping of signal numbers to signal name on your operating system.

The exit status of jobs is recorded in the PBS server logs and the accounting logs.

Negative exit status indicates that the job could not be executed. Negative exit values are listed in the table below:

Table 14-6: Job Exit Codes

Exit Code	Name	Description
0	*JOB_EXEC_OK*	Job execution was successful
-1	*JOB_EXEC_FAIL1*	Job execution failed, before files, no retry
-2	*JOB_EXEC_FAIL2*	Job execution failed, after files, no retry
-3	*JOB_EXEC_RETRY*	Job execution failed, do retry
-4	*JOB_EXEC_INITABT*	Job aborted on MoM initialization
-5	*JOB_EXEC_INITRST*	Job aborted on MoM initialization, checkpoint, no migrate
-6	*JOB_EXEC_INITRMG*	Job aborted on MoM initialization, checkpoint, ok migrate
-7	*JOB_EXEC_BADRESRT*	Job restart failed
-10	*JOB_EXEC_FAILUID*	Invalid UID/GID for job
-11	*JOB_EXEC_RERUN*	Job was rerun
-12	*JOB_EXEC_CHKP*	Job was checkpointed and killed
-13	*JOB_EXEC_FAIL_PASSWORD*	Job failed due to a bad password
-14	*JOB_EXEC_RERUN_ ON_SIS_FAIL*	Job was requeued (if rerunnable) or deleted (if not) due to a communication failure between the primary execution host MoM and a Sister
-15	JOB_EXEC_QUERST	Requeue job for restart from checkpoint
-16	JOB_EXEC_FAILHOOK_RERUN	Job execution failed due to hook rejection; requeue for later retry
-17	JOB_EXEC_FAILHOOK_DELETE	Job execution failed due to hook rejection; delete the job at end
-18	JOB_EXEC_HOOK_RERUN	A hook requested for job to be requeued
-19	JOB_EXEC_HOOK_DELETE	A hook requested for job to be deleted
-20	JOB_EXEC_RERUN_MS_FAIL	Job requeued because server couldn't contact the primary execution host MoM

14.9.1 Job Exit Status Between 0 and 128 (or 256)

This is the exit value of the top process in the job, typically the shell. This may be the exit value of the last command executed in the shell or the `.logout` script if the user has such a script (`csh`).

14.9.2 Job Exit Status >= 128 (or 256)

This means the job was killed with a signal. The signal is given by X modulo 128 (or 256). For example an exit value of 137 means the job's top process was killed with signal 9 (137 % 128 = 9).

The exit status values greater than 128 (or 256) indicate which signal killed the job. Depending on the system, values greater than 128 (or on some systems 256; see `wait(2)` or `waitpid(2)` for more information), are the value of the signal that killed the job.

To interpret (or "decode") the signal contained in the exit status value, subtract the base value from the exit status. For example, if a job had an exit status of 143, that indicates the job was killed via a SIGTERM (e.g. 143 - 128 = 15, signal 15 is SIGTERM). See the `kill(1)` manual page for a mapping of signal numbers to signal name on your operating system.

14.9.3 Logging Job Exit Status

The exit status of jobs is recorded in the PBS server logs and the accounting logs.

14.9.4 Exit Status of Interactive Jobs

The exit status of an interactive job is always recorded as 0 (zero), regardless of the actual exit status.

14.10 Rerunning or Requeueing a Job

You can re-run a job using the `qrerun` command. To re-run a job means to kill it, and requeue it in the execution queue from which it was run. See “qrerun” on page 179 of the PBS Professional Reference Guide.

14.10.1 Requeueing a Job on a Dead Node

Before you requeue a job on a node you know to be dead, use `qmgr` to mark the node as *Down*. When the node is marked *Down*, `qrerun` the job.

14.10.2 Output from a Re-run Job

When you re-run a job, the job's existing standard output and error files are copied back to the server host and stored in `PBS_HOME/spool`. They are then sent with the job to MoM when the job is again run. The output of a job that is re-run is appended to the output from prior runs of the same job.

14.10.3 Caveats for `qrerun`

- Jobs lose their queue wait time when they are requeued, including when they are checkpointed or requeued during preemption.

14.10.4 Requeueing Caveats

- When requeueing a job fails, for example because the queue does not exist, the job is deleted.
- If a job's run_count attribute is already at the limit (20), and you requeue the job, the job will be held the next time the scheduler tries to run it.

14.10.5 Caveats for Jobs Started by PBS

PBS attempts to run a job a certain number of times before placing a hold on the job. You cannot prevent a job from being held after this number of attempts. You must explicitly release the hold.

14.11 Job IDs

14.11.1 Format of Job IDs

Job Identifier

<sequence number>[.<server name>][@<server>]

Job Array Identifier

Job array identifiers are a sequence number followed by square brackets:

<sequence number>[][.<server name>][@<server>]

Example:

1234[]

Note that some shells require that you enclose a job array ID in double quotes.

14.11.2 Range of IDs

The largest allowed value for a job ID or job array ID is set in the max_job_sequence_id server attribute. Minimum allowed is *9999999.* Maximum allowed is *999999999999.* After this has been reached, job IDs start again at zero.

14.11.3 Job IDs and Moving Jobs

If a job is qmoved from one server to another, the job's ID does not change.

14.11.4 Job IDs and Requeueing and Checkpoint/Restart

If a job is requeued without being checkpointed, or checkpointed and requeued, it keeps its original job ID.

14.12 Where to Find Job Information

Information about jobs is found in `PBS_HOME/server_priv/jobs` and `PBS_HOME/mom_priv/jobs`.

14.12.1 Deleted Jobs

If PBS tries to requeue a job and cannot, for example when the queue doesn't exist, the job is deleted.

14.12.2 Failed Jobs

Once a job has experienced a certain number of failures, PBS holds the job.

14.12.3 Job Information When Server is Down

When the PBS server is down, you can use the `pbs_dataservice` command to start the PBS data service by hand, and then run the `printjob` command at the server host. See "pbs_dataservice" on page 61 of the PBS Professional Reference Guide and "printjob" on page 126 of the PBS Professional Reference Guide.

14.12.4 Job Information on Execution Host

You can use the `printjob` command to look at job information on the execution host. See "printjob" on page 126 of the PBS Professional Reference Guide.

14.13 Job Directories

PBS jobs use two kinds of directories:

- The job's job's *staging and execution directory*, into which input files are staged, and from which output files are staged. It is also the current working directory for the job script, for tasks started via the `pbs_tm()` API, and for the epilogue.
- The job's *temporary directory*, where the job can create scratch files if necessary. The root of this directory is specified in the $tmpdir MoM configuration parameter. PBS creates the temporary directory, then sets the TMPDIR job environment variable to the path of the temporary directory. The job can then use this environment variable.

14.13.1 Staging and Execution Directories for Job

A job's *staging and execution directory* is the directory to which input files are staged, and from which output files are staged. It is also the current working directory for the job script, for tasks started via the `pbs_tm()` API, and for the epilogue.

For multi-host jobs, PBS stages files to and from the primary execution host only. The job submitter specifies files and directories to be staged via the job's stagein and stageout attributes, which have this format:

execution_path@[storage_host:]storage_path

The *execution_path* is the path to the staging and execution directory. On stagein, *storage_path* is the path where the input files normally reside, and on stageout, *storage_path* is the path where output files will end up.

Make sure that each execution host can provide an area for staging and execution directories for jobs.

14.13.1.1 Using Job-specific Staging and Execution Directories

Each PBS user may submit several jobs at once, and each job may need to have data files staged in or out. To prevent collisions, PBS can create a job-specific staging and execution directory for each job.

If all users on a host have home directories, PBS can create the staging and execution directories for each job in the job submitters' home directories. If users do not have home directories, you can designate a directory for the task by setting the $jobdir_root MoM parameter to that location.

Whether or not PBS creates job-specific staging and execution directories for a job is controlled by the job's sandbox attribute:

- If the job's sandbox attribute is set to *PRIVATE*, PBS creates a staging and execution directory for each job, in the location specified by the $jobdir_root MoM parameter. If the $jobdir_root parameter is unset, PBS creates job-specific staging and execution directories in the job submitter's home directory.
- If the job’s sandbox attribute is set to *HOME* or is unset, PBS does not create job-specific staging and execution directories. Instead PBS uses the job submitter's home directory.

Using the server's default_qsub_arguments attribute, you can specify the default for the sandbox attribute for all jobs. By default, the sandbox attribute is not set.

The submitter can set the sandbox attribute via `qsub`, for example:

```
qsub -Wsandbox=PRIVATE
```

The `-Wsandbox` option to `qsub` overrides default_qsub_arguments. The job's sandbox attribute cannot be altered while the job is executing.

14.13.1.2 Using Shared Directories for Staging and Execution

Using a shared directory for job staging and execution is a little more complicated when nodes are released early from a job. Normally each MoM on a sister node that is being released cleans up its own files upon release. However, if the directory is shared, you need to prevent those sister MoM(s) from prematurely cleaning up job files before the job has finished. This is an issue whether or not the directory is the user home directory. You take care of this by specifying whether the directory is shared via the $jobdir_root MoM parameter:

- When staging and execution directories are to be created in a shared (e.g. NFS) directory specified in `$jobdir_root`, set the *shared* directive after the directory name:

  $jobdir_root <directory name> shared
- If job submitter home directories are shared, tell MoM:

  $jobdir_root PBS_USER_HOME shared

14.13.1.3 Examples of Setting Location for Creation of Staging and Execution Directories

To tell PBS to create job staging and execution directories created under `/r/shared`, so that each job gets `/r/shared/<job-specific directory>`, put the following line in MoM's configuration file:

```
$jobdir_root /r/shared
```

To tell PBS to use `/scratch` when it is a shared directory:

```
$jobdir_root /r/shared shared
```

To tell PBS to use shared submitter home directories:

```
$jobdir_root PBS_USER_HOME shared
```

To tell PBS to use non-shared submitter home directories, leave the $jobdir_root parameter blank.

14.13.1.4 Options, Attributes and Environment Variables Affecting Staging

PBS sets the environment variable PBS_JOBDIR to the pathname of the staging and execution directory on the primary execution host. PBS_JOBDIR is added to the job script process, any job tasks created by the `pbs_tm()` API, the prologue and epilogue, and the MoM $action scripts.

The job's jobdir attribute is read-only, and is also set to the pathname of the staging and execution directory on the primary execution host. You can view the jobdir attribute via the `-f` option to `qstat`.

The following table lists the options, attributes, etc., affecting staging:

Table 14-7: Options, Attributes, Environment Variables, etc., Affecting Staging

Option, Attribute, Environment Variable, etc.	Effect

MoM's $jobdir_root parameter	Directory under which PBS creates job-specific staging and execution directories. Defaults to user's home directory if unset. If $jobdir_root is unset, the user's home directory must exist. If $jobdir_root is set but does not exist when MoM starts, MoM will abort. If $jobdir_root is set but does not exist when MoM tries to run a job, MoM will kill the job. Permissions on the directory specified in this option must be *1777*.
	When you set `$jobdir_root` to a shared (e.g. NFS) directory, tell MoM it is shared by setting the *shared* directive after the directory name:
	$jobdir_root <directory name> shared
	If the user home directories are shared, tell MoM they are shared:
	$jobdir_root PBS_USER_HOME shared
	Otherwise sister MoMs can prematurely delete files and directories when nodes are released. This is because when sister nodes are released, those sister MoMs would normally clean up their own files upon release, but this could cause problems in a shared directory. So if $jobdir_root or submitter home directories are shared, you need to tell the sister MoMs not to do the cleanup, and let the primary execution host MoM clean up when the job is finished.
	Example of using a shared non-submitter-home directory:
	`$jobdir_root /r/shared shared`
	Example of using shared submitter home directories:
	`$jobdir_root PBS_USER_HOME shared`
	Example of a non-shared directory:
	`$jobdir_root /scratch/foo`

MoM's $usecp parameter	Tells MoM where to look for files in a shared file system; also tells MoM that she can use the local copy agent for these files.
Job's sandbox attribute	Determines whether PBS creates staging and execution directories for this job. If value is *PRIVATE*, PBS creates directories under the location specified in the MoM $jobdir_root configuration option or in the submitter's home directory. If value is *HOME* or is unset, PBS uses the user's home directory for staging and execution. User-settable per-job via `qsub -W` or through a PBS directive.
Job's stagein attribute	Sets list of files or directories to be staged in. User-settable per job via `qsub -W`. Format: *execution_path@[storage_host:]storage_path* The *execution_path* is the path to the staging and execution directory. On stagein, *storage_path* is the path where the input files normally reside.

Table 14-7: Options, Attributes, Environment Variables, etc., Affecting Staging

Option, Attribute, Environment Variable, etc.	Effect
Job's stageout attribute	Sets list of files or directories to be staged out. User-settable per job via `qsub -W`. Format: *execution_path@[storage_host:]storage_path* The *execution_path* is the path to the staging and execution directory. On stageout, *storage_path* is the path where output files will end up.
Job's jobdir attribute	Set to pathname of staging and execution directory on primary execution host. Read-only; viewable via `qstat -f`.
Job's Keep_Files attribute	Determines whether output and/or error files remain on execution host. User-settable per job via `qsub -k` or through a PBS directive. If the Keep_Files attribute is set to *o* and/or *e* (output and/or error files remain in the staging and execution directory) and the job's sandbox attribute is set to *PRIVATE*, standard out and/or error files are removed when the staging and execution directory is removed at job end along with its contents. If direct write for files is specified via the `-d` suboption to the `-k` argument, files are not removed. See "Keeping Output and Error Files on Execution Host", on page 44 of the PBS Professional User's Guide.
Remove_Files attribute	Specifies whether standard output and/or standard error files are automatically removed (deleted) upon job completion.
Job's PBS_JOBDIR environment variable	Set to pathname of staging and execution directory on primary execution host. Added to environments of job script process, `pbs_tm` job tasks, prologue and epilogue, and MoM $action scripts.
Job's TMPDIR environment variable	Location of job-specific scratch directory.
PBS_RCP string in `pbs.conf`	Location of `rcp` command
PBS_SCP string in `pbs.conf`	Location of `scp` command; setting this parameter causes PBS to first try `scp` rather than `rcp` for file transport.
Server's default_qsub_arguments attribute	Can contain a default for job's sandbox (and other) attributes.

14.13.1.5 Getting Information About the Job Staging and Execution Directory

You can check the value of the job's jobdir attribute via `qstat` or the equivalent API while a job is executing. The value of jobdir is not retained if a job is rerun; it is undefined whether jobdir is visible or not when the job is not executing.

14.13.1.6 Staging and Execution Directory Caveats

- If the user home directory is NFS mounted, and you want to use `sandbox=PRIVATE`, then root must be allowed write privilege on the NFS filesystem on which the users' home directories reside.
- You should not depend on any particular naming scheme for the new directories that PBS creates for staging and execution. The pathname to each directory on each node may be different, since each depends on the corresponding MoM's $jobdir_root or user home directory.
- The directory specified in MoM's $jobdir_root parameter must have permissions set to *1777*.
- Beware shared staging directories:

  When you set $jobdir_root to a shared (e.g. NFS) directory, tell MoM it is shared by setting the *shared* directive after the directory name:

  $jobdir_root <directory name> shared

  If the user home directory is shared, tell MoM it is shared:

  $jobdir_root PBS_USER_HOME shared

  Otherwise sister MoMs can prematurely delete files and directories when nodes are released. This is because when sister nodes are released, those sister MoMs would normally clean up their own files upon release, but this could cause problems in a shared directory. So if $jobdir_root or submitter home directories are shared, you need to tell the sister MoMs not to do the cleanup, and let the primary execution host MoM clean up when the job is finished.

14.14 The Job Lifecycle

14.14.1 Sequence of Events for Start of Job

This is the order in which events take place on an execution host at the start of a job:

1. Application licenses are checked out
2. Any job-specific staging and execution directories are created:
   - PBS_JOBDIR and job's jobdir attribute are set to pathname of staging and execution directory
   - Files are staged in

     PBS evaluates `execution_path` and `storage_path` relative to the staging and execution directory given in PBS_JOBDIR. PBS stages files to the primary execution host only. Staging is done as the job owner.

     PBS uses local file transfer mechanisms where possible. For remote file transfers, PBS uses the mechanism you specify. See section 15.6, “Setting File Transfer Mechanism”, on page 561.
3. Temporary scratch directories (TMPDIRs) are created

   For each host allocated to the job, PBS creates a job-specific temporary scratch directory for this job. The root of TMPDIR is set by MoM to the value of MoM's $tmpdir configuration parameter. PBS sets TMPDIR to the pathname of the job-specific temporary scratch directory. This directory is for the use of the job, not PBS. This directory and its contents are removed when the job is finished.

   The recommended TMPDIR configuration is to have a separate, local directory on each host. If the temporary scratch directory cannot be created, the job is killed.
4. The job's cpusets are created
5. The prologue is executed

The MoM's prologue is run on the primary host as root, with the current working directory set to `PBS_HOME/mom_priv` and with PBS_JOBDIR set in its environment.

6. The job script is executed

   PBS runs the job script on the primary host as the user. PBS also runs any tasks created by the job via the `pbs_tm()` API as the user. The job script and tasks are executed with their current working directory set to the job's staging and execution directory, and with PBS_JOBDIR and TMPDIR set in their environment. The job attribute jobdir is set to the pathname of the staging and execution directory on the primary host.

14.14.2 Sequence of Events for End of Job

This is the order in which events generally take place at the end of a job:

7. The job script finishes
8. The epilogue is run

   PBS runs MoM's epilogue script on the primary host as root. The epilogue is executed with its current working directory set to the job's staging and execution directory, and with PBS_JOBDIR set in its environment.

9. The obit is sent to the server
10. Any specified file staging out takes place, including `stdout` and `stderr`

    When PBS stages files out, it evaluates `execution_path` and `storage_path` relative to PBS_JOBDIR. Files that cannot be staged out are saved in `PBS_HOME/undelivered`. PBS stages files out from the primary execution host only. Staging is done as the job owner.

    PBS uses local file transfer mechanisms where possible. For remote file transfers, PBS uses the mechanism you specify. See section 15.6, “Setting File Transfer Mechanism”, on page 561.

    When the job is done, PBS writes the final job accounting record and purges job information from the server's database.

    - If PBS created job-specific staging and execution directories for the job, it cleans up at the end of the job. If no errors are encountered during stageout and all stageouts are successful, the staging and execution directory and all of its contents are removed, on all execution hosts.
    - Files to be staged out are deleted all together, only after successful stageout of all files. If any errors are encountered during stageout, no files are deleted on the primary execution host, and the execution directory is not removed.
    - If PBS created job-specific staging and execution directories on secondary execution hosts, those directories and their contents are removed at the end of the job, regardless of stageout errors. If these directories are shared, only the MoM on the primary execution host does the cleanup. If the directories are not shared, those directories are cleaned up by the sister MoMs.
    - If PBS did not create job-specific staging and execution directories, files that are successfully staged out are deleted immediately, without regard to files that were not successfully staged out.

11. Files staged in or out are removed

The job's `stdout` and `stderr` files are created directly in the job's staging and execution directory on the primary execution host. See "Managing Output and Error Files", on page 40 of the PBS Professional User's Guide.

- If PBS creates job-specific staging and execution directories and the submitter uses `qsub -k` without the `-d` sub-option (direct write to final destination), the `stdout` and `stderr` files are **not** automatically copied out of the staging and execution directory at job end; they are deleted when the directory is automatically removed.
- If PBS does not create job-specific staging and execution directories and the submitter uses `qsub -k`, standard out and/or standard error files are retained in the submitter's home directory on the primary execution host instead of being returned to the submission host, and are not deleted after job end.

12. PBS removes all temporary scratch directories (TMPDIRs), along with their contents.
13. Any job-specific staging and execution directories are removed
14. Job files are deleted
15. Application licenses are returned to pool
16. The job's cpusets are destroyed

14.15 Managing Job History

14.15.1 Introduction

PBS Professional can provide job history information, including what the submission parameters were, whether the job started execution, whether execution succeeded, whether staging out of results succeeded, and which resources were used.

PBS can keep job history for jobs which have finished execution, were deleted, or were moved to another server.

You can configure whether PBS preserves job history, and for how long, by setting values for the job_history_enable and job_history_duration server attributes.

14.15.2 Definitions

Moved jobs

Jobs which were moved to another server

Finished jobs

Jobs whose execution is done, for any reason:

- Jobs which finished execution successfully and exited
- Jobs terminated by PBS while running
- Jobs whose execution failed because of system or network failure
- Jobs which were deleted before they could start execution

History jobs

Jobs which will no longer execute at this server:

- Moved jobs
- Finished jobs

14.15.3 Job History Information Preserved by PBS

PBS can keep all job attribute information, including the following kinds of job history information:

- Submission parameters
- Whether the job started execution
- Whether execution succeeded
- Whether staging out of results succeeded
- Which resources were used

PBS keeps job history for the following jobs:

- Jobs that are running at another server
- Jobs that have finished execution
- Jobs that were deleted
- Jobs that were moved to another server

14.15.4 Period When PBS Preserves Job History

PBS preserves history for the specified history duration beginning from the time a job finishes or is deleted.

After the duration has expired, PBS deletes the job history information and it is no longer available.

14.15.5 Configuring Job History Management

To configure job history, you enable it and you set the job history duration. You configure PBS to manage job history using the following server attributes:

job_history_enable

Enables or disables job history management. Setting this attribute to *True* enables job history management.

Format: Boolean.

Default: *False*

job_history_duration

Specifies the length of time that PBS will keep each job's history.

Format: duration: [[hours:]minutes:]seconds[.milliseconds]

Default: *Two weeks* (336:00:00)

14.15.5.1 Enabling Job History

To enable job history management, set the server's job_history_enable attribute to *True*:

```
Qmgr: set server job_history_enable=True
```

14.15.5.2 Setting Job History Duration

To set the length of time that job history is preserved, set the server's job_history_duration attribute to the desired duration:

```
Qmgr: set server job_history_duration=<duration>
```

If the job history duration is set to *zero*, no history is preserved.

If job history is enabled and job history duration is unset, job history information is kept for the default 2 weeks.

14.15.6 Changing Job History Settings

14.15.6.1 Disabling Job History

If job history is being preserved, and you unset the job_history_enable server attribute, PBS deletes all job history information. This information is no longer available.

14.15.6.2 Enabling Job History

If job history is not being preserved, and you set the job_history_enable server attribute, PBS begins preserving job history information for any jobs that are queued or running.

14.15.6.3 Modifying Job History Duration

Every job's history duration is set to the current value of the job_history_duration server attribute.

Example 14-5: Reducing job history duration:

The value of job_history_duration was "00:10:00" when a job finished execution. After 2 minutes, you change the duration to "00:06:00". This job's history is kept for a total of 6 minutes.

Example 14-6: Increasing job history duration:

The value of job_history_duration was "00:10:00" when a job finished execution. After 8 minutes you change the duration to "00:30:00". This job's history is kept for a total of 30 minutes.

Example 14-7: Increasing job history duration:

The value of job_history_duration was "00:10:00" when a job finished execution. After 11 minutes you change the duration to "00:30:00". This job's history is kept for a total of 10 minutes. The job's history is deleted after it is kept for 10 minutes.

14.15.7 Backward Compatibility

To have PBS behave as it did before the job history management feature was introduced, disable job history management. Do one of the following:

- Set the server's job_history_enable attribute to *False*:
  ```
  Qmgr: set server job_history_enable=False
  ```
- Unset the server's job_history_enable attribute:
  ```
  Qmgr: unset server job_history_enable
  ```
- Set the value of the server's job_history_duration attribute to *zero*, by doing one of the following:
  ```
  Qmgr: set server job_history_duration=0
  Qmgr: set server job_history_duration=00:00
  Qmgr: set server job_history_duration=00:00:00
  ```

14.15.8 Logging Moved Jobs

Jobs can be moved to another server for one of the following reasons:

- Moved for peer scheduling
- Moved via the `qmove` command
- Job was submitted to a routing queue, then routed to a destination queue at another server

When a job is moved, the server logs the event in the server log and the accounting log. The server log messages are logged at log level 0x0008.

Format for the server log file:

```
7/08/2008 16:17:38;0008;Server@serverhost1;Job; 97.serverhost1.domain.com;Job moved to
    destination: workq@serverhost2
```

Format for the accounting log entry:

```
7/08/2008 16:17:38;M;97.serverhost1.domain.com;destination=workq@serverhost2
```

Record type: *M* (moved job)

14.15.9 Deleting Moved Jobs and Job Histories

You can use the `qdel -x` option to delete job histories. This option also deletes any specified jobs that are queued, running, held, suspended, finished, or moved. When you use this, you are deleting the job and its history in one step. If you use the `qdel` command without the `-x` option, you delete the job, but not the job history, and you cannot delete a moved or finished job. See "qdel" on page 141 of the PBS Professional Reference Guide.

14.15.10 Job History Caveats

- Enabling job history requires additional memory for the server. When the server is keeping job history, it needs 8kb-12kb of memory per job, instead of the 5kb it needs without job history. Make sure you have enough memory: multiply the number of jobs being tracked by this much memory. For example, if you are starting 100 jobs per day, and tracking history for two weeks, you're tracking 1400 jobs at a time. On average, this will require 14.3M of memory.
- If the server is shut down abruptly, there is no loss of job information. However, the server will require longer to start up when keeping job history, because it must read in more information.

14.16 Environment Variables

The settings in `$PBS_HOME/pbs_environment` are available to user job scripts. You must HUP the MoM if you change the file. This file is useful for setting environment variables for `mpirun` etc. For a list of environment variables used by PBS, see "PBS Environment Variables" on page 401 of the PBS Professional Reference Guide.

14.17 Adjusting Job Running Time

14.17.1 Shrink-to-fit Jobs

PBS allows you or the job submitter to adjust the running time of a job to fit into an available scheduling slot. The job's minimum and maximum running time are specified in the min_walltime and max_walltime resources. PBS chooses the actual walltime. Any job that requests min_walltime is a **shrink-to-fit** job.

For a complete description of using shrink-to-fit jobs, see section 4.9.42, "Using Shrink-to-fit Jobs", on page 213.

14.18 Managing Number of Run Attempts

PBS has a built-in limit of 21 for the number of times the server can try to run a job or subjob. When the job or subjob goes over this limit, it gets a System hold. The number of tries is recorded in the job or subjob's run_count attribute. The run_count attribute starts at zero, and the job or subjob is held when run_count goes above 20. When a subjob's run_count attribute goes above 20, it and its parent job array get a System hold. You can use `qrls` on the parent array to release the parent array and indirectly release the subjobs. See "qrls" on page 181 of the PBS Professional Reference Guide.

Job submitters can set a non-negative value for run_count on job submission, and can use `qalter` to raise the value of run_count. A PBS Manager or Operator can use `qalter` to raise or lower the value of run_count.

14.19 Managing Amount of Memory for Job Scripts

By default, starting with version 13.1, PBS limits the size of any single job script to 100MB. You can set a different limit using the jobscript_max_size server attribute. The format for this attribute is *size*, and the units default to bytes. You can specify the units. For example:

```
Qmgr: set server jobscript_max_size = 10mb
```

Job script size affects server memory footprint. If a job submitter wants to use a really big script, they can put it in shared storage and call it from a short script, or they can run a small job script that stages in the big script, then calls it.

14.20 Allowing Interactive Jobs on Windows

1. Make sure that file and printer sharing is enabled. This is off by default.
2. Make sure that the ephemeral port range in your firewall is open on both the submission and execution hosts. Check your OS documentation for the correct range.
3. Make sure that IPC$ share is enabled. You should be able to run the following command from the submission host:

   ```
    net use \\<execution_host>\IPC$
   ```

   The output should look like this:

   ```
   > net use \\myhost\IPC$
   c:\Users\pbsuser>net use \\myhost\IPC$
   Local name
   Remote name        \\myhost\IPC$
   Resource type      IPC
   Status             Disconnected
   # Opens            0
   # Connections      1
   The command completed successfully.
   ```

14.20.1 Configuring PBS for Remote Viewer on Windows

Job submitters can run interactive GUI jobs so that the GUI is connected to the primary execution host for the job. The job submitter runs a GUI application over a remote viewer. On Windows, PBS supports any remote viewer, such as Remote Desktop or X.

You can specify the remote viewer that PBS will use by setting a pbs.conf parameter on each submission host. See section 14.20.2, "Specifying Remote Viewer at Submission Hosts", on page 536.

On an execution host that will launch a GUI application for an interactive job, MoM must run in a LocalSystem account. See section 14.20.3, "Configuring MoM to Run in LocalSystem Account on Windows", on page 536.

A password is usually required when a Remote Desktop client tries to connect to an execution host. However you can configure Single Sign-on for Remote Desktop using the current login at the client host. See section 14.20.4, "Configuring Single Sign-on for Remote Desktop on Windows", on page 537.

14.20.2 Specifying Remote Viewer at Submission Hosts

You can specify which remote viewer PBS should use when a job submitter runs a GUI job remotely. On each submission host, set the PBS_REMOTE_VIEWER parameter in pbs.conf to point to the remote viewer you want, or to a script that launches the desired remote viewer. If this parameter is unset, PBS uses the native Windows Remote Desktop client as the remote viewer. The line in pbs.conf should have this form:

```
PBS_REMOTE_VIEWER = <remote viewer client>
```

Example 14-8: Using the remote desktop client as the remote viewer:

```
PBS_REMOTE_VIEWER=mstsc /v
```

Example 14-9: Using the VNC viewer client as the remote viewer:

```
PBS_REMOTE_VIEWER=vncviewer.exe
```

Example 14-10: Launching a remote viewer via a script:

```
PBS_REMOTE_VIEWER=launch_remote_viewer.bat
```

14.20.3 Configuring MoM to Run in LocalSystem Account on Windows

On an execution host that will launch a GUI application for an interactive job, MoM must run in a LocalSystem account. To run MoM in a LocalSystem account, take the following steps:

1. Log in as administrator
2. Open `services.msc`
3. Right-click on the `pbs_mom` service and open "*properties*"
4. In the "*Log on*" tab, select "*Local System Account*"
5. Check "*Allow service to interact with desktop*"
6. Click *OK*

14.20.4 Configuring Single Sign-on for Remote Desktop on Windows

14.20.4.1 Configuring Submission Hosts for Single Sign-on

You can configure single sign-on using domain or local group policy. Follow these steps:

1. Log on to your local machine as an administrator
2. Start the Group Policy Editor:

   ```
   gpedit.msc
   ```
3. Navigate to "*Computer Configuration\Administrative Templates\System\Credentials Delegation*"
4. Double-click the "*Allow Delegating Default Credentials*" policy
5. Enable the policy
6. Click on the "*Show*" button to get to the list of servers
7. Add "TERMSRV/<server name>" to the server list.
8. You can add any number of server names to the list. A server name can be a hostname or an IP address. You can use one wildcard (*) per name. To store credentials for everything, use just a wildcard.
9. Confirm your changes by clicking on the "*OK*" button until you get back to the main Group Policy Object Editor dialog.
10. Repeat steps 3 through 7 for the following policies:
    a. "*Allow Delegating Default Credentials with NTLM-only Server Authentication*"
    b. "*Allow Delegating Saved Credentials with NTLM-only Server Authentication*"
    c. "*Allow Delegating Saved Credentials*"
11. In the Group Policy editor, navigate to *Computer Configuration* -> *Administrative Templates* -> *Windows Components* -> *Remote Desktop Services* -> *Remote Desktop Connection Client*
12. For the entry labeled "*Do not allow passwords to be saved*", change to *Disabled*
13. Force the policy to be refreshed immediately on the local machine. Run the following at a command prompt:

    ```
    gpupdate /force
    ```

14.20.4.2 Configuring Execution Hosts for Single Sign-on

The PBS execution host is the Remote Desktop server.

If the execution host is a Windows server, for example Windows Server 2008 R2, follow these steps:

1. Start Server Manager
2. Expand *Roles*->*Remote Desktop Services* and select *RD Session Host Configuration*
3. In the right pane in *Connections*, right-click *RDP-TCP Connection Name* and choose *Properties*
4. On the *Log on Settings* tab make sure "*Always prompt for password*" is unchecked
5. On the *General* tab choose the *Security* layer: *Negotiate* or *SSL (TLS 1.0)*
6. Click *OK*

If the execution host is not a Windows server, follow these steps:

1. Open the Group Policy Editor:

   `gpedit.msc`

2. Navigate to *Computer Configuration->Administrative Templates->Windows Components->Remote Desktop Services->Remote Desktop Session Host->Security*
3. Set "*Always prompt for password upon connection*" to "*Disabled*"

14.21 Releasing Unneeded Vnodes from Jobs

If you want to prevent unnecessary resource usage, you can release unneeded hosts or vnodes from jobs. You can use the `pbs_release_nodes` command or the release_nodes_on_stageout job attribute:

- You can use the `pbs_release_nodes` command at the command line, or submitters can use it or in their job scripts to release vnodes when the command is issued. You can use this command to release specific vnodes that are not on the primary execution host, or all vnodes that are not on the primary execution host. You can also use it to release all hosts or vnodes except for what you specify, which can be either a count of hosts to keep, or a select specification describing the vnodes to keep. You cannot use the command to release vnodes on the primary execution host. See “pbs_release_nodes” on page 93 of the PBS Professional Reference Guide.
- You can set the job's release_nodes_on_stageout attribute to *True* so that PBS releases all of the job's vnodes that are not on the primary execution host when stageout begins. You must set the job's stageout attribute as well. See “Job Attributes” on page 330 of the PBS Professional Reference Guide.
- You can use the default_qsub_arguments server attribute to specify that all jobs are submitted with release_nodes_on_stageout set by default.

For details, see "Releasing Unneeded Vnodes from Your Job", on page 128 of the PBS Professional User’s Guide.

14.21.1 Caveats and Restrictions for Releasing Vnodes

- The job must specify a stageout parameter in order to release vnodes on stageout. If the job does not specify stageout, release_nodes_on_stageout has no effect.
- You can release only vnodes that are not on the primary execution host. You cannot release vnodes on the primary execution host.
- The job must be running (in the *R* state).
- The `pbs_release_nodes` command is not supported on vnodes tied to Cray X* series systems (vnodes whose vntype has the "cray_" prefix).
- If cgroups support is enabled, and `pbs_release_nodes` is called to release some but not all the vnodes managed by a MoM, resources on those vnodes are released.
- If a vnode on a multi-vnode host is assigned exclusively to a job, and the vnode is released, the job will show that the vnode is released, but the vnode will still show as assigned to the job in `pbsnodes -av` until the other vnodes on that host have been released. If a vnode on a multi-vnode machine is not assigned exclusively to a job, and the vnode is released, it shows as released whether or not the other vnodes on that host are released.
- If you specify release of a vnode on which a job process is running, that process is terminated when the vnode is released.

14.22 Tolerating Vnode Faults

PBS lets you allocate extra vnodes to a job so that the job can successfully start and run even if some vnodes fail. See section 9.5, “Vnode Fault Tolerance for Job Start and Run”, on page 436.

14.23 Managing Job Array Behavior

You can set a limit on the number of simultaneously running subjobs from any one array job by setting the job's max_run_subjobs attribute, either via `qalter -Wmax_run_subjobs=<new value> <job ID>`, or in a queuejob or modifyjob hook.

You can set a limit on the size of job arrays, either at the server, via the server max_array_size attribute, or at each queue, via the server max_array_size attribute.

Note that the `qrun` command overrides the limit on the number of simultaneously running subjobs for an array job set in the max_run_subjobs job attribute.

14.24 Recommendations

We recommend that as much as possible, you avoid huge numbers of jobs and subjobs. We recommend consolidating jobs where possible.

15 Administration

This chapter covers information on the maintenance and administration of PBS, and is intended for the PBS administrator. Topics covered include starting and stopping PBS, event logging, and accounting.

15.1 The PBS Configuration File

During the installation of PBS Professional, the installation script creates a configuration file named `pbs.conf`. This configuration file controls which daemons are to run on the local system, the directory tree location, and various runtime configuration options. Each host in a complex should have its own `pbs.conf` file.

15.1.1 Location of Configuration File

The configuration file is located in one of the following:

Linux:

```
/etc/pbs.conf
```

Windows:

```
[PBS Destination Folder]\pbs.conf
```

where `[PBS Destination Folder]` is the path specified when PBS is installed on the Windows platform, for example:

```
C:\Program Files\PBS\pbs.conf
```

or

```
C:\Program Files (x86)\PBS\pbs.conf
```

You can set the value of PBS_CONF_FILE in your environment in order to specify an alternate location for `pbs.conf`.

15.1.2 Format of Configuration File

Each line in the `/etc/pbs.conf` file gives a value for one parameter, or is a comment, or is blank. The order of the elements is not important.

15.1.2.1 Specifying Parameters

When you specify a parameter value, do not include any spaces in the line. Format for specifying a parameter value:

<parameter>=<value>

For example, to specify a value for PBS_START_MOM on the local host:

```
PBS_START_MOM=1
```

15.1.2.2 Comment Lines in Configuration File

You can comment out lines you are not using. Precede a comment with the hashmark ("#"). For example:

```
#This is a comment line
```

15.1.3 Example of Configuration File

The following is an example of a `pbs.conf` file for a host which is to run the server, the scheduler, and a MoM. The server runs on the host named Host1.ExampleDomain.

```
PBS_EXEC=/opt/pbs/M.N.P.S
PBS_HOME=/var/spool/PBS
PBS_START_SERVER=1
PBS_START_MOM=1
PBS_START_SCHED=1
PBS_SERVER=Host1.ExampleDomain
```

15.1.4 Contents of Configuration File

The `/etc/pbs.conf` file contains configuration parameters for PBS. The following table describes the parameters you can use in the `pbs.conf` configuration file:

Table 15-1: Parameters in `pbs.conf`

Parameter	Description
PBS_AUTH_METHOD	Specifies default authentication method and library to be used by PBS. Used only at authenticating client. Case-insensitive. Default value: *resvport* To use `MUNGE`, set to *munge*
PBS_BATCH_SERVICE_PORT	Port on which server listens. Default: 15001
PBS_BATCH_SERVICE_PORT_DIS	DIS port on which server listens.
PBS_COMM_LOG_EVENTS	Communication daemon log mask. Default: *511*
PBS_COMM_ROUTERS	Tells a `pbs_comm` the location of the other `pbs_comms.`
PBS_COMM_THREADS	Number of threads for communication daemon.
PBS_REMOTE_VIEWER	Specifies remote viewer client. If not specified, PBS uses native Remote Desktop client for remote viewer. Set on submission host(s). Supported on Windows only.
PBS_CORE_LIMIT	Limit on corefile size for PBS daemons. Can be set to an integer number of bytes or to the string "unlimited". If unset, core file size limit is inherited from the shell environment.
PBS_DATA_SERVICE_PORT	Used to specify non-default port for connecting to data service. Default: 15007

Table 15-1: Parameters in `pbs.conf`

Parameter	Description
PBS_ENCRYPT_METHOD	Specifies method and library for encrypting and decrypting data in client-server communication. Used only at authentication client side. Case-insensitive. To use TLS encryption in client-server communication, set this parameter to *tls*. No default; if this is not set, PBS does not encrypt or decrypt data.
PBS_ENVIRONMENT	Location of `pbs_environment` file.
PBS_EXEC	Location of PBS `bin` and `sbin` directories.
PBS_HOME	Location of PBS working directories.
PBS_LEAF_NAME	Tells endpoint what hostname to use for network. The value does not include a port, since that is usually set by the daemon. By default, the name of the endpoint's host is the hostname of the machine. You can set the name where an endpoint runs. This is useful when you have multiple networks configured, and you want PBS to use a particular network. The server only queries for the canonicalized address of the MoM host, unless you let it know via the Mom attribute; if you have set PBS_LEAF_NAME in `/etc/pbs.conf` to something else, make sure you set the Mom attribute at vnode creation. TPP internally resolves the name to a set of IP addresses, so you do not affect how `pbs_comm` works.
PBS_LEAF_ROUTERS	Location of endpoint's `pbs_comm` daemon(s).
PBS_LOCALLOG=<value>	Enables logging to local PBS log files. Valid values: 0: no local logging 1: local logging enabled Only available when using `syslog`.
PBS_LOG_HIGHRES_TIMESTAMP	Controls whether daemons on this host log timestamps in microseconds. Default timestamp log format is *HH:MM:SS*. With microsecond logging, format is *HH:MM:SS:XXXXXX*. Does not affect accounting log. Not applicable when using `syslog`. Overridden by environment variable of the same name. Valid values: *0*, *1*. Default: *0* (no microsecond logging)
PBS_MAIL_HOST_NAME	Used in addressing mail regarding jobs and reservations that is sent to users specified in a job or reservation's Mail_Users attribute. Optional. If specified, must be a fully qualified domain name. Cannot contain a colon (":"). For how this is used in email address, see section 2.2.2, “Specifying Mail Delivery Domain”, on page 22.
PBS_MANAGER_SERVICE_PORT	Port on which MoM listens. Default: 15003
PBS_MOM_HOME	Location of MoM working directories.

Table 15-1: Parameters in pbs.conf

Parameter	Description
PBS_MOM_NODE_NAME	Name that MoM should use for parent vnode, and if they exist, child vnodes. If this is not set, MoM defaults to using the non-canonicalized hostname returned by `gethostname()`. If you use the IP address for a vnode name, set `PBS_MOM_NODE_NAME=<IP address>` in `pbs.conf` on the execution host. Dots are not allowed in this parameter unless they are part of an IP address.
PBS_MOM_SERVICE_PORT	Port on which MoM listens. Default: 15002
PBS_OUTPUT_HOST_NAME	Host to which all job standard output and standard error are delivered. If specified in `pbs.conf` on a job submission host, the value of PBS_OUTPUT_HOST_NAME is used in the host portion of the job's Output_Path and Error_Path attributes. If the job submitter does not specify paths for standard output and standard error, the current working directory for the `qsub` command is used, and the value of PBS_OUTPUT_HOST_NAME is appended after an at sign ("@"). If the job submitter specifies only a file path for standard output and standard error, the value of PBS_OUTPUT_HOST_NAME is appended after an at sign ("@"). If the job submitter specifies paths for standard output and standard error that include host names, the specified paths are used. Optional. If specified, must be a fully qualified domain name. Cannot contain a colon (":"). See "Delivering Output and Error Files" on page 60 in the PBS Professional Administrator's Guide.
PBS_PRIMARY	Hostname of primary server. Used only for failover configuration. Overrides PBS_SERVER_HOST_NAME. If you set PBS_LEAF_NAME on the primary server host, make sure that PBS_PRIMARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_PRIMARY matches the hostname of the server host.
PBS_RCP	Location of `rcp` command if `rcp` is used.
PBS_SCHEDULER_SERVICE_PORT	Port on which default scheduler listens. Default value: 15004
PBS_SCHED_THREADS	Maximum number of scheduler threads. Scheduler automatically caps number of threads at the number of cores (or hyperthreads if applicable), regardless of value of this variable. Overridden by `pbs_sched -t` option and PBS_SCHED_THREADS environment variable. Default: 1
PBS_SCP	Location of `scp` command if `scp` is used; setting this parameter causes PBS to first try `scp` rather than `rcp` for file transport.

Table 15-1: Parameters in `pbs.conf`

Parameter	Description
PBS_SECONDARY	Hostname of secondary server. Used only for failover configuration. Overrides PBS_SERVER_HOST_NAME. If you set PBS_LEAF_NAME on the secondary server host, make sure that PBS_SECONDARY matches PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on the server host, make sure that PBS_SECONDARY matches the hostname of the server host.
PBS_SERVER	Hostname of host running the server. Cannot be longer than 255 characters. If the short name of the server host resolves to the correct IP address, you can use the short name for the value of the PBS_SERVER entry in `pbs.conf`. If only the FQDN of the server host resolves to the correct IP address, you must use the FQDN for the value of PBS_SERVER. Overridden by PBS_SERVER_HOST_NAME and PBS_PRIMARY.
PBS_SERVER_HOST_NAME	The FQDN of the server host. Used by clients to contact server. Overridden by PBS_PRIMARY and PBS_SECONDARY failover parameters. Overrides PBS_SERVER parameter. Optional. If specified, must be a fully qualified domain name. Cannot contain a colon (":"). See "Contacting the Server" on page 60 in the PBS Professional Administrator's Guide.
PBS_START_COMM	Set this to *1* if a communication daemon is to run on this host.
PBS_START_MOM	Default is *0*. Set this to *1* if a MoM is to run on this host.
PBS_START_SCHED	**Deprecated**. Set this to *1* if default scheduler is to run on this host. Overridden by scheduler's scheduling attribute.
PBS_START_SERVER	Set this to *1* if server is to run on this host.
PBS_SUPPORTED_AUTH_METHODS	Specifies supported authentication methods for client-server communication. Used by authenticating server (PBS server, scheduler, MoM, or comm); ignored at client. Case-insensitive. If this parameter is set, PBS accepts only the methods listed. Format: comma-separated list of authentication methods. Default value: *resvport* Example: *munge,GSS*

Table 15-1: Parameters in pbs.conf

Parameter	Description
PBS_SYSLOG=<value>	Controls use of `syslog` facility under which the entries are logged. Valid values: 0: no syslogging 1: logged via LOG_DAEMON facility 2: logged via LOG_LOCAL0 facility 3: logged via LOG_LOCAL1 facility ... 9: logged via LOG_LOCAL7 facility
PBS_SYSLOGSEVR=<value>	Filters `syslog` messages by severity. Valid values: 0: only LOG_EMERG messages are logged 1: messages up to LOG_ALERT are logged ... 7: messages up to LOG_DEBUG are logged
PBS_TMPDIR	Location of temporary files/directories used by PBS components.

For information on how to use the `pbs.conf` file when configuring PBS for failover, see section 9.2.5.2, "Configuring the pbs.conf File for Failover", on page 411.

15.1.5 Configuration File Caveats and Recommendations

- Each parameter in `pbs.conf` can also be expressed as an environment variable.
- Environment variables override `pbs.conf` parameter settings.
- When you change a setting in a `pbs.conf` file, you must restart the daemon that reads the file.
- If you specify a location for `PBS_HOME` in the shell environment, make sure that this agrees with that specified in `pbs.conf`.
- Do not change a hostname without updating the corresponding Version 2 configuration file.
- Use a name for the server in the PBS_SERVER variable in the `pbs.conf` file that is not longer than 255 characters. If the short name for the server resolves to the correct host, you can use this in `pbs.conf` as the value of PBS_SERVER. However, if the fully-qualified domain name is required in order to resolve to the correct host, then this must be the value of the PBS_SERVER variable.
- If you set PBS_LEAF_NAME on a primary or secondary server host, make sure that PBS_PRIMARY and PBS_SECONDARY match PBS_LEAF_NAME on the corresponding host. If you do not set PBS_LEAF_NAME on a server host, make sure that PBS_PRIMARY and PBS_SECONDARY match the hostnames of the server hosts.
- The server only queries for the canonicalized address of the MoM host, unless you let it know via the Mom attribute; if you have set PBS_LEAF_NAME in `/etc/pbs.conf` to something else, make sure you set the Mom attribute at vnode creation.
- Do not include shell-style comments in the configuration file.
- When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

15.2 Environment Variables

PBS sets environment variables for different purposes: some variables are used by the daemons, commands, and jobs, and some environment variables are set individually for each job. Each parameter in pbs.conf can also be expressed as an environment variable. Environment variables override pbs.conf parameters.

15.2.1 Environment Variables For Daemons, Commands, and Jobs

The PBS installer creates an environment file called `pbs_environment`. This file is used by the daemons, commands, and jobs:

- Each PBS daemon initializes its environment using this environment file
- Several commands use environment variables to determine things like the name of the default server. The environment file is useful for setting environment variables for `mpirun`, etc.
- Jobs inherit the contents of this environment file before they acquire settings from `.profile` and `.login` files. Job scripts can use the environment variables set in the job's environment.

You can edit the environment file.

15.2.1.1 Contents of Environment File

When this file is created, it contains the following:

```
TZ=<local timezone, e.g. US/Pacific>
PATH=/bin:/usr/bin
```

For a list of PBS environment variables, see "PBS Environment Variables" on page 401 of the PBS Professional Reference Guide.

To support X forwarding, edit MoM's PATH variable to include the directory containing the `xauth` utility.

15.2.1.2 Location of Environment File

The PBS environment file is located here:

```
PBS_HOME/pbs_environment
```

15.2.1.3 Environment File Requirements

You must restart each daemon after making any changes to the environment file.

15.2.1.4 Editing Configuration Files Under Windows

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

15.2.2 Job-specific Environment Variables

For each job, the `qsub` command creates environment variables beginning with PBS_O_, and puts them in the job's environment. They are not written to `pbs_environment`. The server sets some of these environment variables if the `qsub` command does not set them.

For each job, the MoM on the primary execution host creates a file of the hosts to be used by the job. The node file is put in the job's environment, but the host list is not written to `pbs_environment`. The location of the node file is specified in the PBS_NODEFILE environment variable, which is set for the job only. See "The Job Node File", on page 77 of the PBS Professional User's Guide.

Some environment variables are set by commands. The PBS `mpiexec` script sets PBS_CPUSET_DEDICATED.

For a list of environment variables used and set by the `qsub` command, see "Environment Variables" on page 231 of the PBS Professional Reference Guide.

15.3 Event Logging

PBS provides event logging for the server, the scheduler, the communication daemon, and each MoM. You can use logfiles to monitor activity in the PBS complex.

15.3.1 PBS Events

The amount and type of output in the PBS event logfiles depends on the specified log filters for each component. Each PBS daemon can be directed to record only messages pertaining to certain levels of importance, called log levels. The specified log levels are logically "or-ed" to produce a mask representing the events to be logged by the daemon. The hexadecimal value for each log level is shown in Table 15-2, "PBS Events and Log Levels," on page 549. When events appear in the log file, they are tagged with their hexadecimal value, without a preceding "0x".

15.3.2 Event Logfiles

Each PBS daemon writes a separate event logfile. Each multisched writes its own logfile. By default, each daemon writes a file that has the current date as its name in the `PBS_HOME/<component>_logs` directory. The location of the logfile can be overridden with the -L option to each daemon's command. For example, to override the server's logfile location:

```
pbs_server -L <new path>
```

Whenever a new log file is opened, the daemon logs PBS_LEAF_NAME, PBS_MOM_NODE_NAME, and the hostname. The daemon also logs all network interfaces, listing each interface and all of the hostnames associated with that interface. In addition, it logs the PBS version and the build information.

Each daemon closes the day's log file and opens a new log file on the first message written after midnight. If no messages are written, the old log file stays open. Each daemon closes and reopens the same logfile when the daemon receives a SIGHUP.

Each daemon writes its version and build information to its event logfile each time it is started or restarted, and also when the logfile is automatically rotated out. The version and build information appear in individual records. These records contain the following substrings:

```
pbs_version = <PBSPro_stringX.stringY.stringZ.5-digit seq>
build = <status line from config.status, etc>
```

Example:

```
pbs_version = PBSPro_9.2.0.63106
build = '--set-cflags=-g -O0' --enable-security=KCRYPT ...
```

If the daemon cannot write to its log file, it writes the error message to the console. Some errors that appear before the daemon has backgrounded itself may appear on standard error.

The maximum number of characters in the message portion of a log entry is 4096.

15.3.3 Log Levels

PBS allows specification of the types of events that are logged for each daemon. Each type of log event has a different log level. All daemons use the same log level for the same type of event.

The following table lists the log level for each type of event.

Table 15-2: PBS Events and Log Levels

Name	Decimal	Hex	Event Description
PBSEVENT_ERROR	1	0x0001	Internal PBS errors
PBSEVENT_SYSTEM	2	0x0002	System (OS) errors, such as malloc failure
PBSEVENT_ADMIN	4	0x0004	Administrator-controlled events, such as changing queue attributes
PBSEVENT_JOB	8	0x0008	Job related events, e.g. submitted, ran, deleted
PBSEVENT_JOB_USAGE	16	0x0010	Job resource usage
PBSEVENT_SECURITY	32	0x0020	Security related events
PBSEVENT_SCHED	64	0x0040	When the scheduler was called and why
PBSEVENT_DEBUG	128	0x0080	Common debug messages
PBSEVENT_DEBUG2	256	0x0100	Debug event class 2
PBSEVENT_RESV	512	0x0200	Reservation-related messages
PBSEVENT_DEBUG3	1024	0x0400	Debug event class 3. Debug messages rarer than event class 2.
PBSEVENT_DEBUG4	2048	0x0800	Debug event class 4. Limit-related messages.

15.3.3.1 Specifying Log Levels

Each daemon uses an integer representation of a bit string to specify its log levels. The bit string can be decimal (or hexadecimal, for the MoM). Each daemon's log levels are specified in a a bit string that includes the events to be logged. You can specify each multisched's log levels individually.

For example, if you want the server to log all events except those at event classes 512, 1024, and 2048 (hex 0x0200, 0x0400, and 0x0800), you would use a log level of 511. This is 256 + 128 + 64 + 32 + 16 + 8 + 4 + 2 + 1. If you want to log events at event classes 1, 2, and 16, you would set the log level to 19.

The following table shows the log event parameter for each daemon:

Table 15-3: Daemon Log Event Specification Parameters

PBS	Parameter/ Attribute	Reference	How to Make Parameter Take Effect
Server	log_events attribute	"Server Attributes" on page 283 of the PBS Professional Reference Guide	Takes effect immediately with `qmgr`

Table 15-3: Daemon Log Event Specification Parameters

PBS	Parameter/ Attribute	Reference	How to Make Parameter Take Effect
MoM	$logevent parameter	"Contents of MoM Configuration File" on page 242 of the PBS Professional Reference Guide	Requires SIGHUP to MoM
Scheduler	log_events attribute	"Configuration Parameters" on page 252 of the PBS Professional Reference Guide	Takes effect immediately with `qmgr`
communi-cation	PBS_COMM_LOG_EVENTS parameter in `pbs.conf`	"Daemon Log Mask" on page 46 in the PBS Professional Installation & Upgrade Guide	Restart the communication dae-mon

When reading the PBS event logfiles, you may see messages of the form "Type 19 request received from PBS_Server...". These "type codes" correspond to different PBS batch requests. See "Request Codes" on page 397 of the PBS Professional Reference Guide.

15.3.3.1.i Specifying Server Log Events

You can specify the server's log events by setting the server's log_events attribute. The attribute is an integer representation of a bit string, where the integer includes all events to be logged. To set the value, use the `qmgr` command:

```
Qmgr: set server log_events = <value>
```

The new value takes effect immediately.

For example, to log only debug event class 3 (1024, or 0x0400) and internal PBS errors (1, or 0x0001), set the value to *1025* (1024 +1, or 0x0401). To include all events, set the value to *4095* or *-1*. The default value for this attribute is 511. It can be set by Operators and Managers only. See "Server Attributes" on page 283 of the PBS Professional Reference Guide.

You can set the server's log level when you start the server using `pbs_server -e <log level>`. Note that you can specify a hexadecimal value this way, but not via the server's log_events attribute. When you use the `-e <log level>` option to `pbs_server`, that sets the server's log_events attribute to the corresponding integer value.

15.3.3.1.ii Specifying MoM Log Events

Each MoM's log events are specified in the $logevent parameter in that MoM's configuration file `PBS_HOME/mom_priv/config`. The parameter is an integer representation of a bit string, where the integer includes all events to be logged. For example, to log only debug event class 3 (1024, or 0x0400) and internal PBS errors (1, or 0x0001), set the value to *1025* (1024 +1, or 0x0401). To set the value, add the $logevent line in `PBS_HOME/mom_priv/config`, then HUP the MoM. To include all events, set the value to *4095* (0xffffffff). The default value used by MoM is 975 (0x03cf). This parameter can be set by root only. See section 3.2, "Contents of MoM Configuration File", on page 242.

15.3.3.1.iii Specifying Scheduler Log Events

You can specify log events for the scheduler and for each multisched by setting each scheduler's log_events attribute. The attribute is an integer representation of a bit string, where the integer includes all events to be logged. To set the value, use the `qmgr` command:

```
Qmgr: set sched <scheduler name> log_events = <value>
```

The new value takes effect immediately.

For example, to log only debug event class 3 (1024, or 0x0400) and internal PBS errors (1, or 0x0001), set the value to *1025* (1024 +1, or 0x0401). To include all events, set the value to *4095* or *-1*. The default value for this attribute is 767. It can be set by Operators and Managers only. See “Scheduler Attributes” on page 300 of the PBS Professional Reference Guide.

15.3.3.1.iv Specifying Communication Daemon Log Events

The communication daemon's log events are specified in the PBS_COMM_LOG_EVENTS parameter in `/etc/pbs.conf`. This parameter is an integer representation of a bit string, where the integer includes all events to be logged. HUP the daemon after you set the parameter.

For example, to log only debug event class 3 (1024, or 0x0400) and internal PBS errors (1, or 0x0001), set the value to *1025* (1024 +1, or 0x0401). To include all events, set the value to *2047* (or *-1*). The default value for this attribute is 511 (0x1ff). See “Logging and Errors with TPP” on page 54 in the PBS Professional Installation & Upgrade Guide and "Contents of Configuration File” on page 542.

15.3.4 Event Logfile Format and Contents

15.3.4.1 Event Logfile Format

Each component event logfile is a text file with each entry terminated by a new line. The format of an entry is:

<logfile date and time>;<event code>;<server name>;<object type>;<object name>;<message>

- The *logfile date and time* field is a date and time stamp in the format:

  mm/dd/yyyy hh:mm:ss[.xxxxxx]

If microsecond logging is enabled, microseconds are logged using the *.xxxxxx* portion. Microseconds may be preceded by zeroes. Microsecond logging is controlled per host via the PBS_LOG_HIGHRES_TIMESTAMP configuration parameter or environment variable.

- The *event code* is a bitmask for the type of event which triggered the event logging. It corresponds to the bit position, 0 to n, of each log event in the event mask of the PBS component writing the event record. See section 15.3.1, “PBS Events”, on page 548 for a description of the event mask.
- The *server name* is the name of the server which logged the message. This is recorded in case a site wishes to merge and sort the various logs in a single file.
- `The` *object type* is the type of object which the message is about. All messages are associated with an *object type*. The following lists each possible *object type*:

Table 15-4: List of Event Logfile Object Types

Object Type	Usage
Svr	for server
Que	for queue
Job	for job
Req	for request
Fil	for file
Act	for accounting string
Node	for vnode or host
Resv	for reservation
Sched	for scheduler

- The *object name* is the name of the specific object.
- The *message* field is the text of the log message.

15.3.4.2 Scheduler Commands

These commands tell a scheduler why a scheduling cycle is being started. These commands appear in the server's logfile. Each has a decimal value, shown below. The following table shows commands from the server to a scheduler.

Table 15-5: Commands from Server to Scheduler

Value	Event Description
1	New job enqueued
2	Job terminated
3	Scheduler time interval reached
4	Cycle again after scheduling one job
5	Scheduling command from operator or manager
7	Configure
8	Quit (`qterm -s`)

Table 15-5: Commands from Server to Scheduler

Value	Event Description
9	Ruleset changed
10	Schedule first
11	A reservation's start time has been reached
12	Schedule a job (`qrun` command has been given)
13	Stopped queue is started
14	Job moved into local queue (queue at this server)
15	eligible_time_enable is turned on
16	PBS attempting to reconfirm degraded reservation

15.3.5 Logging Job Usage

PBS can log per-vnode cputime usage. The primary execution host MoM logs cputime in the format "hh:mm:ss" for each vnode of a multi-vnode job. The log level of these messages is 0x0100.

Under Linux, to append job usage to standard output for an interactive job, use a shell script for the epilogue which contains the following:

```
#!/bin/sh
tracejob -sl $1 | grep 'cput'
```

This behavior is not available under Windows.

15.3.6 Managing Log Files

15.3.6.1 Disk Space for Log Files

It is important not to run out of disk space for logging. You should periodically check the available disk space, and check the size of the log files PBS is writing, so that you know how fast you are using up disk space. Make sure that you always have more than enough disk space available for log files.

15.3.6.2 Dividing Up Log Files

You may wish to divide a day's logging up into more than one file. You may want to create a logfile that contains only the entries of interest. You can specify a file for a daemon's event log. See section 15.3.6.3, “Specifying Log File Path”, on page 554. The next sections describe how to break up your log files.

15.3.6.2.i Dividing Log Files on Linux

On Linux systems, all daemons close and reopen the same named log file when they are sent a SIGHUP. The process identifier (PID) of each daemon is available in its lock file in its home directory. You can move the current log file to a new name and send SIGHUP to restart the file using the following commands:

```
cd $PBS_HOME/<daemon>_logs
mv <current log file> <archived log file>
kill -HUP 'cat ../<daemon>_priv/<daemon>.lock'
```

15.3.6.2.ii Dividing Log Files on Windows

On Windows systems, you can rotate the event log files by stopping the service for which you want to rotate the logfile, moving the file, and then restarting that service. For example:

```
cd "%PBS_HOME%\mom_logs"
net stop pbs_mom
move <current log file> <archived log file>
net start pbs_mom
```

15.3.6.3 Specifying Log File Path

You may wish to specify an event logfile path that is different from the default path. Each daemon has an option to specify a different path for the daemon's event logfile. This option is the -L logfile option, and it is the same for all daemons. For example, to start the scheduler so that it logs events in `/scratch/my_sched_log`:

```
pbs_sched -L /scratch/my_sched_log
```

See the `pbs_server(8B)`, `pbs_sched(8B)`, and `pbs_mom(8B)` manual pages.

15.3.7 Extracting Logged Information

You can use the `tracejob` command to extract information from log files, such as why a job is not running or when a job was queued. The `tracejob` command can read both event logs and accounting logs. See the `tracejob(8B)` manual page.

15.3.8 Using the Linux `syslog` Facility

Each PBS component logs various event classes of information about events in its own log file. While having the advantage of a concise location for the information from each component, the disadvantage is that in a complex, the logged information is scattered across each execution host. The Linux syslog facility can be useful.

If your site uses the `syslog` subsystem, PBS may be configured to make full use of it. The following entries in `pbs.conf` control the use of `syslog` by the PBS components:

Table 15-6: Entries in `pbs.conf` for Using Syslog

Entry	Description
PBS_LOCALLOG=x	Enables logging to local PBS log files. Only possible when logging via `syslog` feature is enabled. 0 = no local logging 1 = local logging enabled
PBS_SYSLOG=x	Controls the use of syslog and syslog facility under which the entries are logged. If x is: *0* - no syslogging *1* - logged via `LOG_DAEMON` facility *2* - logged via `LOG_LOCAL0` facility *3* - logged via `LOG_LOCAL1` facility ... *9* - logged via `LOG_LOCAL7` facility
PBS_SYSLOGSEVR=y	Controls the severity level of messages that are logged; see `/usr/include/sys/syslog.h`. If y is: *0* - only LOG_EMERG messages are logged *1* - messages up to LOG_ALERT are logged ... *7* - messages up to LOG_DEBUG are logged

15.3.8.1 Caveats

- PBS_SYSLOGSEVR is used in addition to PBS's log_events mask which controls the class of events (job, vnode, ...) that are logged.
- If you use `syslog`, you cannot have daemons log events at microsecond resolution.

15.4 Managing Machines

15.4.1 Offlining Hosts and Vnodes

For using hooks to offline vnodes, see "Offlining Bad Vnodes" on page 66 in the PBS Professional Hooks Guide.

To offline an entire host, use the `pbsnodes` command. Use the name of the parent vnode, which is usually the name of the host:

```
pbsnodes -o <name of parent vnode>
```

All vnodes on this host are offlined.

To offline a single vnode, use the `qmgr` command, with the name of the vnode:

```
qmgr -c "set node foo[3] state=offline"
```

15.4.1.1 Caveats of Offlining

If you set a vnode with no running jobs *offline*, the server will not attempt to communicate with the vnode. Therefore, the server will not notice that the vnode is up until you clear the *offline* state. For example, a vnode that is both *down* and *offline* will not be marked up by the server until you clear the *offline* state.

15.4.2 Performing Maintenance on Powered-up Vnodes

15.4.2.1 Reserving Vnodes for Maintenance

You can create maintenance reservations using `pbs_rsub --hosts <host list>`. Maintenance reservations are designed to make the specified hosts available for the specified amount of time, regardless of what else is happening:

- You can create a maintenance reservation that includes or is made up of vnodes that are down or offline.
- Maintenance reservations ignore the value of a vnode's resv_enable attribute.
- PBS immediately confirms any maintenance reservation.
- Maintenance reservations take precedence over other reservations; if you create a maintenance reservation that overlaps an advance or standing job reservation, the overlapping vnodes become unavailable to the job reservation, and the job reservation is in conflict with the maintenance reservation. PBS looks for replacement vnodes; see "Reservation Fault Tolerance" on page 434 in the PBS Professional Administrator's Guide.

PBS will not start any new jobs on vnodes overlapping or in a maintenance reservation. However, jobs that were already running on overlapping vnodes continue to run; you can let them run or requeue them.

You cannot specify place or select for a maintenance reservation; these are created by PBS:

- PBS creates the reservation's placement specification so that hosts are assigned exclusively to the reservation. The placement specification is always the following:

  -lplace=exclhost
- PBS sets the reservation's resv_nodes attribute value so that all CPUs on the reserved hosts are assigned to the maintenance reservation. The select specification is always the following:

  -lselect=host=<host1>:ncpus=<number of CPUs at host1>+host=<host2>:ncpus=<number of CPUs at host2>+...

Maintenance reservations are prefixed with *M*. A maintenance reservation ID has the format:

M<sequence number>.<server name>

You cannot create a recurring maintenance reservation.

Creating a maintenance reservation does not trigger a scheduling cycle.

You must have manager or operator privilege to create a maintenance reservation.

15.4.2.2 Putting Vnodes into Maintenance State

You may want to perform maintenance on a vnode while it is powered up, but you don't want job processes running on it. You can suspend a job on a vnode and put the vnode into a *maintenance* state, where the scheduler will not start any new jobs on the vnode, using `qsig -s admin-suspend <job ID>`. You must suspend each job on the vnode; if you suspend only one, the rest will keep running. When you *admin-suspend* a job, all of the job's vnodes are put into the *maintenance* state, the job goes into the *S* state, and the job's processes are suspended.

Once the maintenance is finished, you can resume the *admin-suspend*ed jobs using `qsig -s admin-resume <job ID>`. The *admin-resume* signal directly resumes the job, without waiting for the scheduler. Once all of the vnode's jobs are *admin-resume*d, the vnode leaves the *maintenance* state.

You can see the list of jobs that were running on a vnode then *admin-suspend*ed in the maintenance_jobs vnode attribute. This attribute is a list of job IDs, and is readable only by managers.

15.4.2.2.i Resource Release on Suspension

When you *admin-suspend* a job, resources are released according to how you have configured the restrict_res_to_release_on_suspend server attribute; see section 5.9.6.2, "Job Suspension and Resource Usage", on page 252. However, no new jobs will run while the job is suspended.

15.4.2.2.ii Caveats for admin-suspend and admin-resume

- We recommend that before you *admin-suspend* any job, you disable scheduling and wait for the current scheduling cycle to finish. The scheduler queries vnode state only at the beginning of the scheduling cycle. If a vnode goes into the *maintenance* state after the start of the cycle, the scheduler could still schedule jobs onto that vnode.
- The *suspend* and *resume* signals are not interchangeable with the *admin-suspend* and *admin-resume* signals. For example, if a job is suspended via normal the *suspend* signal (`qsig -s suspend <job ID>`), it cannot be resumed with the *admin-resume* signal.

  Similarly, if a job is suspended with the *admin-suspend* signal, it cannot be resumed with the *resume* signal. Either request will be rejected with the following message:

  ```
  "Job can not be resumed with the requested resume signal"
  ```
- If there are multiple jobs on a vnode, we recommend using either *suspend* and *admin-suspend*, but not both. If you have a *suspend*ed job on a vnode that was in the *maintenance* state but is no longer, the scheduler could run jobs on the resources owned by the *suspend*ed job.
- If you want to perform maintenance on a vnode that has no jobs running on it, we recommend putting the vnode into the *offline* state before performing the maintenance.
- Any reservations on vnodes in the *maintenance* state are marked *degraded*. PBS searches for alternate vnodes for those reservations.
- Any vnode which had only *admin-suspend*ed subjobs will stay in the *maintenance* state after a server restart.

15.4.3 Changing Hostnames or IP Addresses

- Do not change a hostname without updating the corresponding Version 2 configuration file.
- Do not change the IP address or hostname of a machine in the complex while PBS is running. Stop PBS (server, scheduler, and MoMs), change the IP address, and restart PBS.

To change a hostname or IP address:

1. Make sure no jobs are running
2. Stop all PBS daemons
3. Make a backup of `PBS_HOME`
4. Change the hostname or IP address
5. If you are using the IP address as a vnode name, update PBS_MOM_NODE_NAME in `pbs.conf` on the execution host to the new IP address.
6. Restart all PBS daemons
7. If a host has a corresponding Version 2 configuration file, make sure that it is consistent with the new hostname
8. If you are running `nscd`, restart `nscd` on all hosts

15.4.4 Discovering Last Reboot Time of Server

Under Linux, you can find the timestamp of the most recent time PBS started up in `/var/tmp/pbs_boot_check`.

The permission of this file is set to 0644; only the PBS init script should modify this file. Do not modify this file. If you do so, you violate the configuration requirements of PBS.

This file is not available under Windows.

15.4.5 Changing Network Configuration

If you change any network configuration, restart the PBS daemons.

15.4.6 Replacing or Reimaging Nodes

When `PBS_HOME` is removed on a node by reimaging, etc., make sure that the server knows that there are no legitimate jobs on the node. Send each job `qsig -s SIGNULL` after the node is up again, which causes the server to contact the MoM and discover that any jobs are gone as far as MoM is concerned. The server then requeues and reruns any of MoM's gone jobs. Otherwise zombie jobs will ensure that no new jobs are scheduled to the node even after it's been reimaged.

MoM depends on its `PBS_HOME` to know which jobs are gone. When a node goes down on PBS complexes with either diskless nodes or nodes with integrated disk drives, sometimes the cluster manager will reimage the node before the complex reintegrates the node. In that case, `PBS_HOME` is gone, so MoM no longer knows about any jobs she was managing. The server will never get any updates or obits for those jobs, so they'll stay in state *R*.

If the reimaging process is longer than node_fail_requeue, the server will requeue the jobs, but your complex may use node_fail_requeue set to 0 for very good reasons, for example if there are Cray or HPE NUMA machines in the complex.

15.4.7 Restricting User Access to Execution Hosts

PBS provides a facility to prevent users who are not running PBS jobs from using machines controlled by PBS. You can turn this feature on by using the $restrict_user MoM directive. This directive can be fine-tuned by using the $restrict_user_exceptions and $restrict_user_maxsysid MoM directives. This feature can be set up host by host.

- A user requesting exclusive access to a set of hosts (via `place=excl`) can be guaranteed that no other user will be able to use the hosts assigned to his job, and PBS will not assign any unallocated resources on the vnode to another job.
- A user requesting non-exclusive access to a set of hosts can be guaranteed that no non-PBS users are allowed access to the hosts.
- A privileged user can be allowed access to the complex such that they can log into a host without having a job active.
- An abusive user can be denied access to the complex hosts.

The administrator can find out when users try to access hosts without going through PBS. The administrator can ensure that application performance is consistent on a complex controlled by PBS. PBS will also be able to clean up any job processes remaining after a job finishes running.

For a vnode with access restriction turned on:

- Any user not running a job who logs in or otherwise starts a process on that vnode will have his processes terminated.
- A user who has logged into a vnode where he owns a job will have his login terminated when the job is finished.
- When MoM detects that a user that is not exempt from access restriction is using the system, that user's processes are killed and a log message is output:

  ```
  01/16/2006 22:50:16;0002;pbs_mom;Svr;restrict_user;
  killed uid 1001 pid 13397(bash) with log event class PBSE_SYSTEM.
  ```

You can set up a list of users who are exempted from the restriction via the $restrict_user_exceptions directive. This list can contain up to 10 usernames.

Example 15-1: Turn access restriction on for a given node:

```
$restrict_user True
```

Example 15-2: Limit the users affected to those with a user ID greater than 500:

```
$restrict_user_maxsysid 500
```

Example 15-3: Exempt specific users from the restriction:

```
$restrict_user_exceptions userA, userB, userC
```

Note that a user who has a job running on a particular host will be able to log into that host.

15.4.7.1 Windows Restriction

The user access restriction feature is not supported on Windows.

15.5 Managing the Data Service

15.5.1 PBS Monitors Data Service

PBS monitors its connection to the data service. If the connection is broken (for example, because the data service is down), PBS tries to reestablish the connection. If necessary, PBS restarts the data service.

If failover is configured, and PBS cannot reestablish a connection, PBS quits.

If failover is not configured, PBS attempts to reestablish the connection until it succeeds.

When the server is stopped, it stops the data service.

15.5.2 Data Service Accounts

On Linux, PBS uses a PBS data service management account and an internal data service account. They are described here: "Create PBS Data Service Management Account" on page 23 in the PBS Professional Installation & Upgrade Guide.

15.5.3 Data Service Account Password

The default password for the internal data service account is a random password that is generated at installation, and which is known only to the PBS server.

15.5.3.1 Setting Data Service Account Name and Password

Changing the password is necessary only if you want to manually log into the database to check data or change something. Otherwise it is not necessary.

Use the `pbs_ds_password` command to change the password of the data service internal user account (not the PBS data service management account).

You can change the user account and/or password for the data service account using the `pbs_ds_password` command. Use this command if you need to change the user account or update the password for the data service account. You must be root or administrator to run the `pbs_ds_password` command. See “pbs_ds_password” on page 62 of the PBS Professional Reference Guide.

To change the data service account name:

```
pbs_ds_password -C <new user account>
```

To change the data service account password:

```
pbs_ds_password
```

15.5.3.2 Caveats

- When you specify a new name for the data service account, there must already be a data service management account with that name
- The account name cannot be changed while the data service is running.
- Do not delete `PBS_HOME/server_priv/db_password`. Doing so will prevent the `pbs_ds_password` command from being able to function.
- Do not change the data service password using any method other than the `pbs_ds_password` command.
- If you change the data service account after installing PBS, and then you want to upgrade PBS, you must change it back in order to perform the upgrade. After the upgrade, you can change it again. This is covered in the upgrading instructions.
- If you type in a password, make sure it does not contain restricted characters. The `pbs_ds_password` command generates passwords containing the following characters:

  0123456789abcdefghijklmnopqrstuvwxyzABCDEFGHIJKLMNOPQRSTUVWXYZ!@#$%^&()_+*

  When creating a password manually, do not use \ (backslash) or ‘ (backquote). This can prevent certain commands such as `pbs_server`, `pbs_ds_password`, and `printjob` from functioning properly, as they rely on connecting to the database. The format is also described in "PBS Password” on page 359.

15.5.4 Starting and Stopping the Data Service

PBS automatically starts and stops the data service. However, you can start, stop, or check the status of the PBS data service using the `pbs_dataservice` command. See “pbs_dataservice” on page 61 of the PBS Professional Reference Guide.

To start the data service:

```
pbs_dataservice start
```

To stop the data service:

```
pbs_dataservice stop
```

To get the status of the data service:

```
pbs_dataservice status
```

15.5.4.1 Caveats for Starting and Stopping Data Service

- **Do not** start or stop the data service using anything except the `pbs_dataservice` command. Start or stop the data service using only the `pbs_dataservice` command.
- The data service cannot be stopped while the PBS server is running.

15.5.5 Changing Data Service Port

You can change the port that the data service listens on by changing the setting of the PBS_DATA_SERVICE_PORT entry in `pbs.conf`.

15.5.5.1 Caveats

- The PBS daemons must not be running when the port is changed.
- The data service must not be running when the port is changed.

15.5.6 File Ownership

The files under `PBS_HOME/datastore` are owned by the data service user account.

15.6 Setting File Transfer Mechanism

15.6.1 File Transfer in PBS

If PBS finds `scp` in the system PATH at install time, it sets the PBS_SCP parameter in `pbs.conf` to the path to `scp`.

MoM does the work of transferring files, using the mechanism you specify. MoM transfers files when she stages them in or out for a job, and when she delivers output and error files. MoM always tries to determine whether the source and destination for a file transfer are both local. If they are, she uses the local copy mechanism (`/bin/cp` on Linux, and `xcopy` on Windows). You can use the $usecp MoM configuration parameter to tell MoM which local directories are mapped to mounted directories, so that she can use the local copy mechanism.

For remote copying, PBS uses `scp` or `rcp`. In most installations, PBS is configured to use `scp` by default; at installation PBS looks for `scp` in the system PATH, and if it finds `scp` in the system PATH, PBS sets PBS_SCP in `pbs.conf`. You can configure PBS to use `rcp` for remote copying. You can also tell PBS to use any script or command for remote file transfer, such as `rsync`, `gsiftp`, etc.; see section 15.6.3.3, "Configuring MoM to Use Different Flags, a Script, or a Different Command", on page 565.

PBS ships with a version of `rcp` called `pbs_rcp`. On Windows, PBS uses this version by default.

PBS does not impose limitations on the size of files being transferred. Any limitations are caused by the commands themselves. The `pbs_rcp` command should be as fast as other implementations of `rcp`.

15.6.1.1 Configuration Parameters Affecting File Transfer

You configure MoM's file transfer mechanisms using the following:

- Local copy: the $usecp MoM configuration parameter
- Remote copy: the PBS_SCP and PBS_RCP entries in `pbs.conf`

15.6.1.2 How MoM Chooses File Transfer Method

If MoM knows that she is performing a local file transfer, she uses her local copy mechanism.

If MoM is transferring a remote file, she chooses according to the following:

- If PBS finds `scp` in the system PATH at install time, it sets the PBS_SCP parameter in `pbs.conf` to the path to `scp`.
- If a command is specified in PBS_SCP, MoM uses the command specified in PBS_SCP.
- If a command is specified in PBS_RCP, and PBS_SCP is not defined, MoM uses the command specified in PBS_RCP.
- If no `pbs.conf` parameters are defined, MoM uses `pbs_rcp`.

15.6.1.2.i When Multiple Attempts Are Required

If necessary, MoM tries to transfer a file multiple times, with an increasing delay between each attempt:

- If MoM is using her local copy mechanism, she tries it up to four times
- If MoM is using the entry in PBS_SCP:
  - She first tries this, and if it fails, she tries `rcp`, `pbs_rcp`, or the entry in PBS_RCP if it is configured
  - She repeats this sequence four times
- If MoM is using `rcp`, `pbs_rcp`, or the entry in PBS_RCP, she tries it up to four times

15.6.1.3 Options Passed to File Transfer Commands

15.6.1.3.i Options Passed on Linux

MoM automatically uses these options on Linux:

Table 15-7: File Transfer Mechanism Options on Linux

Distance	Mechanism	Options
Remote	PBS_RCP entry, `rcp`, or `pbs_rcp`	`-rp`
Remote	PBS_SCP entry	`-Brvp`
Local	`/bin/cp`	`-rp`

15.6.1.3.ii Options Passed on Windows

MoM automatically uses these options on Windows:

Table 15-8: File Transfer Mechanism Options on Windows

Distance	Mechanism	Options
Remote	PBS_RCP entry, `rcp`, or `pbs_rcp`	`-E -r`
Remote	PBS_SCP entry	`-Brv`
Local	`xcopy`	`/e/i/q/y`

15.6.2 Configuring MoM for Local Copy

MoM uses her local copy mechanism whenever she knows she will perform a local copy. To tell her which directories can be treated as local, specify the mappings between local and mounted directories in MoM's $usecp configuration parameter.

15.6.2.1 Configuring the $usecp MoM Parameter

This tells MoM where to look for files in a shared file system, so that she can use the local copy agent for these files. This is useful when you have common mount points across execution hosts.

Format:

$usecp <hostname>:<source directory> <destination directory>

You can use a wildcard ("*") as the first element only, to replace *hostname*.

MoM uses a local copy mechanism to transfer files when staging or delivering output, under the following circumstances:

- The destination is a network mounted file system
- The source and destination are both on the local host
- The *source directory* can be replaced with the *destination directory* on *hostname*

You can map multiple directories. Use one line per mapping.

You must HUP MoM after making this change.

15.6.2.1.i Linux and $usecp

MoM uses `/bin/cp` for the local copy mechanism on Linux.

Format:

$usecp <hostname>:<source directory> <destination directory>

Use trailing slashes on both the source and destination directories.

Example 15-4: Configuring $usecp on Linux:

```
$usecp *:/home/ /home/
$usecp *.example.com:/home/ /home/
$usecp *:/home/user/ /home/user/
$usecp *:/data/ /data/
$usecp HostA:/users/work/myproj/ /sharedwork/proj_results/
```

15.6.2.1.ii Windows and $usecp

MoM uses `xcopy` for the local copy mechanism on Windows.

Format:

$usecp <host name>:<drive name>:<directory> <drive name>:<directory>

When a network location is mapped to a local drive, you can cover all host names and case-sensitivity using entries similar to these:

```
$usecp *:Q: Q:
$usecp *:q: q:
```

Using this mapping, when MoM sees files with this format:

<hostname>:Q:<file path>

or

<hostname>:q:<file path>

she passes them to the copy command with this format:

Q:<file path>

or

q:<file path>

Example 15-5: Mapping locations with different directory names:

```
$usecp HostB:C:/xxxxx C:/yyyyy
```

15.6.3 Configuring MoM for Remote Copy

15.6.3.1 Configuring MoM to use `scp` or PBS_SCP Entry

By default MoM uses `scp` for remote copying, if the `scp` command is in the system PATH when PBS is installed. If you want MoM to use `scp` for remote copying on Windows or if PBS_SCP was not set in `pbs.conf` by default on Linux, follow the steps below.

1. Make sure that `scp` and `ssh` are installed on each host involved in the file transfer.
2. If you use plain `scp` without a wrapper script, MoM calls it with the `-B` option, which requires passwordless authentication. If you have not done so, set up passwordless authentication on all machines involved in file transfer. See section 15.6.7.1, "Enabling Passwordless Authentication", on page 567.
3. To use `scp` on Windows, set up passwordless authentication on all machines involved in file transfer. See section 15.6.7.1, "Enabling Passwordless Authentication", on page 567.
4. Set PBS_SCP to the absolute path to `scp`.
5. If the MoM is already running, restart the MoM.

The PBS_SCP `pbs.conf` entry is the absolute path to a command or script used for remote transfer. When PBS_SCP is defined, this entry overrides PBS_RCP, and MoM tries PBS_SCP first for remote transfers.

MoM calls the command this way:

```
$PBS_SCP -Brvp <path to source> <username>@<destination>.<host>:<path to destination>
```

You cannot specify options inside the PBS_SCP entry.

15.6.3.2 Configuring MoM to use `rcp`, `pbs_rcp` or PBS_RCP Entry

If you want MoM to use `rcp`, you will need to remove PBS_SCP from the `pbs.conf` file and restart MoM.

If you want MoM to use a different `rcp`, or another mechanism such as a script:

1. Make sure that `rcp` and `rsh` are installed on each host involved in the file transfer.
2. Specify the absolute path to the command or script in the PBS_RCP entry in `pbs.conf`.
3. If MoM is running, restart MoM.

The PBS_RCP `pbs.conf` entry is the absolute path to a command or script used for remote transfer. If MoM is unable to copy using the PBS_SCP entry, she uses the entry in PBS_RCP as an alternate method.

MoM calls the command this way:

```
$PBS_RCP -rp <path to source> <username>@<destination>.<host>:<path to destination>
```

You cannot specify options inside the PBS_RCP entry.

15.6.3.3 Configuring MoM to Use Different Flags, a Script, or a Different Command

If you want MoM to use different flags to `rcp` or `scp`, or a different command, or your own script, for remote file transfer:

1. If needed, write a script that does what you need
2. Specify the path to the command or script in PBS_SCP in `pbs.conf`
3. If the MoM is already running, restart the MoM.

When MoM calls PBS_SCP, she calls it with the `-Brvp` (Linux) or `-Brv` (Windows) flags. This means that when you are writing a script, the arguments being passed to the script are:

$1	`-Brvp` or `-Brv`
$2	path to source
$3	path to destination

You choose which arguments the script passes to the command inside the script. If you are using a different command, make sure that you pass the correct flags to it.

Example 15-6: Pass desired options to `scp` by writing a wrapper script for `scp` that contains the desired options, and pointing PBS_SCP to the wrapper script. In this case, we don't use the default `-Brvp`, which is passed to the script as $1. The script does not pass $1 to `scp`; instead, it specifies `-Br`. We do pass in the source and destination as $2 and $3.

In `pbs.conf`:

```
PBS_SCP=/usr/bin/scp_pbs
```

In `/usr/bin/scp_pbs`:

```
#!/bin/sh
/usr/bin/scp -Br $2 $3
```

Example 15-7: Use `rsync` by writing a wrapper script that passes all arguments except for the first (`-Brvp`) to `rsync`, and pointing PBS_SCP to the wrapper script. In this case, the script passes all but the first argument to `rsync` as $*. We get rid of the first argument using the `shift` command.

In `pbs.conf`:

```
PBS_SCP=/usr/bin/rsync_pbs
```

In `/usr/bin/rsync_pbs`:

```
#!/bin/sh
shift
/usr/bin/rsync -avz -e ssh $*
```

For remote copying, MoM tries the PBS_SCP entry in `pbs.conf` first. If you configure both PBS_RCP and PBS_SCP with scripts or commands, put the script or command that you want MoM to try first in PBS_SCP.

15.6.4 Allowing Direct Write of Standard Output and Error to /dev/null

Standard output and standard error are normally written to a location such as `/var/spool`, then copied to their final location. To avoid creating these files at all, and to avoid copying them, you need two things:

In MoM's version 1 configuration file, add this:

```
$usecp $<MoM hostname>:/dev/null /dev/null
```

Job submitters can use direct write to send them to /dev/null:

```
qsub -koed -o /dev/null -e /dev/null
```

15.6.5 Troubleshooting File Transfer

15.6.5.1 Problems with rcp

When using `rcp`, the copy of output or staged files can fail for the following reasons:

- The user lacks authorization to access the specified system
- Under Linux, if the user's `.cshrc` prints any characters to standard output, e.g. contains an `echo` command, the copy will fail

You may encounter a strange hang in stageout, with jobs stuck in the *E* state for a long time. This can happen because `rcp` may be trying to connect to a port that's already in use. If your standard copy mechanism is `scp`, and you don't want to let PBS fall back on `pbs_rcp`, do one of the following:

- You can move `pbs_rcp`
- If you specify PBS_SCP, set PBS_RCP to /bin/false in pbs.conf
- If you are using CM/PAS and specify PBS_SCP in /etc/conf, put the PBS_SCP line after the PBS_RCP line

15.6.5.2 Problems with Directory Access

Local and remote delivery of output may fail for the following additional reasons:

- A directory in the specified destination path does not exist
- A directory in the specified destination path is not searchable by the user
- The target directory is not writable by the user

15.6.6 Advice on Improving File Transfer Performance

15.6.6.1 Avoiding Server Host Overload

Avoid staging files from the server host, unless you can isolate the daemons from the effects of CPU and memory usage by `scp`/`ssh`, by using a mechanism such as cpusets. Consider the impact from a large job array that causes many files to be staged from the server host. Instead, use a shared filesystem. See section 15.6.6.2, “Avoiding Remote Transfers in Large Complexes”, on page 566.

15.6.6.2 Avoiding Remote Transfers in Large Complexes

If you are running a very large HPC complex, consider using MoM's $usecp directive to avoid `rcp` and `scp` transfers. Instead, have your users place input files on a shared filesystem before submitting jobs, write their output to the shared filesystem, and keep as much as possible out of `stdout` and `stderr`.

15.6.6.3 Improving Performance for `ssh`

If network bandwidth is a limiting factor, you can use compression to improve performance. However, if CPU usage and/or memory are limiting factors, do not use compression, because compression also requires CPU and memory.

You can use compression ciphers that minimize the CPU and memory load required, for example `arcfour` or `blowfish-cbc`:

```
ciphers         arcfour,blowfish-cbc
```

15.6.6.4 Improving Performance when Staging Similar Files

If you are staging in many similar files, for example, for job arrays, you can use `rsync` in a wrapper script. Follow the instructions in section 15.6.3.3, "Configuring MoM to Use Different Flags, a Script, or a Different Command", on page 565.

15.6.6.5 Avoiding Limits on `ssh` Connections

To prevent `scp` requests being denied when using `ssh`, you can set higher limits on incoming `ssh` connections. By default `ssh` is configured to treat more than 10 incoming connections (plus 10 in the authentication phase) as a denial-of-service attack, even on machines that could service many more requests.

Set higher limits in `/etc/ssh/sshd_config` for servers that are meant to service a lot of incoming openSSH sessions, but only on machines that have enough CPU and memory to service all of the requests.

See the MaxSessions and MaxStartups parameters in the man page for `sshd_config`. You can make these at least as large as the number of hosts in the cluster plus 10, assuming that any MoM only has one `scp` session open at any one time.

15.6.6.6 Alternatives to Changing `ssh` Limits

To avoid having to change limits on incoming `ssh` connections, you can do the following:

- Use a mounted directory and employ $usecp MoM parameters. See section 15.6.6.2, "Avoiding Remote Transfers in Large Complexes", on page 566.
- Use compression to service more requests with the same amount of hardware resources. See section 15.6.6.3, "Improving Performance for ssh", on page 566.

15.6.6.7 Getting Around Bandwidth Limits

If you have bandwidth limits, you can use a command such as `gsiftp`, which allows you to specify the bandwidth you want to use for file transfer. Follow the instructions in section 15.6.3.3, "Configuring MoM to Use Different Flags, a Script, or a Different Command", on page 565.

15.6.7 General Advice on File Transfer

15.6.7.1 Enabling Passwordless Authentication

You must enable passwordless authentication so that job files can be staged in and out. You must also choose and set a file transfer mechanism such as `rcp` or `scp` for remote file copying. Before you set up the remote file copy mechanism, enable passwordless authentication for it.

Enable passwordless authentication for each machine in the complex, and for any machine from which or to which files will be transferred.

You can use any authentication method you want, such as a `shosts.equiv` file, an authorized keys file, or `.rhosts` authentication. You can choose a cipher and use encryption; balance the CPU time required by encryption with the CPU time required by MoMs and job tasks.

PBS requires that `rsh`/`rcp` and/or `ssh`/`scp` works between each pair of hosts where files will be transferred. Test whether you have succeeded by logging in as root, and using your chosen file transfer mechanism to copy a file between machines.

15.6.7.2 Using scp for Security

Unless your complex is a closed system, we recommend using scp instead of rcp, because scp is more secure.

15.6.7.3 Avoiding Asynchronous Writes to NFS

Asynchronous writes to an NFS server can cause reliability problems. If using an NFS file system, mount the NFS file system synchronously (without caching.)

15.6.7.4 Returning Output on Cray

If your site has disabled the use of remote operation functions ("r" commands) and output cannot be returned for jobs running on compute nodes, enable the use of the cp command by adding $usecp to the $PBS_HOME/mom_priv/config file on each login node. See section 15.6.2, “Configuring MoM for Local Copy”, on page 563.

15.6.7.5 Editing the pbs.conf File Under Windows

You can edit the pbs.conf file by calling the PBS program named "pbs-config-add". For example, on Windows systems:

```
\Program Files (x86)\PBS\exec\bin\pbs-config-add "PBS_SCP=\winnt\scp.exe"
```

Do not edit pbs.conf directly; this could reset the permission on the file, which could prevent other users from running PBS.

15.6.7.6 The pbs_rcp Command

15.6.7.6.i Exit Values for pbs_rcp

The pbs_rcp command exits with a non-zero exit status for any error. This tells MoM whether or not the file was delivered.

15.6.7.7 Caveats

- Output is not delivered if the path specified by PBS_SCP or PBS_RCP in pbs.conf is incorrect.
- When a job is rerun, its stdout and stderr files are sent to the server and stored in PBS_HOME/spool. When the job is sent out for execution again, its stdout and stderr are sent with it. The copy mechanism used for these file transfers is internal to PBS; you cannot alter it or manage it in any way.

15.7 Some Performance Tips

15.7.1 Improving Scheduling Performance

- The scheduler can run asynchronously, so it doesn't wait for each job to be accepted by MoM, which means it also doesn't wait for an execjob_begin hook to finish. For short jobs, this can give you better scheduling performance. The scheduler runs asynchronously by default when the complex is using TPP mode, and can run asynchronously only when the complex is using TPP mode. To run the scheduler asynchronously, set the throughput_mode scheduler attribute to *True*. For details on TPP mode, see “Communication” on page 45 in the PBS Professional Installation & Upgrade Guide; for job throughput, see section 4.5.7.1, “Improving Throughput of Jobs”, on page 99.
- If you limit the number of jobs queued in execution queues, you can speed up the scheduling cycle. See section 4.5.7.2, “Limiting Number of Jobs Queued in Execution Queues”, on page 100.
- Avoid using dynamic resources where possible; see section 5.4.4, “Static vs. Dynamic Resources”, on page 236
- We give advice on minimizing the impact hooks can have on scheduling in "Scheduling Impact of Hooks" on page 72 in the PBS Professional Hooks Guide.

15.7.2 Improving Communication Performance

- We give recommendations for improving communication daemon performance in “Recommendations for Maximizing Communication Performance” on page 51 in the PBS Professional Installation & Upgrade Guide.
- You can use placement sets to keep job processes topologically close to one another; see section 4.9.32, “Placement Sets”, on page 170.
- See our recommendations on file transfer performance improvement in section 15.6.6, “Advice on Improving File Transfer Performance”, on page 566.

15.7.3 Improving Hook Speed

- See our hook performance recommendations in "Performance Considerations" on page 73 in the PBS Professional Hooks Guide.

15.8 Temporary File Location for PBS Components

You can configure where all PBS components put their temporary files and directories on each system. You may want to avoid using the usual temporary file locations of `/tmp` and `/var/tmp`, because users tend to fill these up.

15.8.1 Default Location for Temporary Files

By default, on Linux platforms, PBS components put their temporary files and directories in `/var/tmp`. PBS uses this location because it is persistent across restarts or crashes, allowing diagnosis of a problem, whereas the contents of `/tmp` may be lost.

On Windows, the default location is `C:\WINNT\TEMP` if it is present, or `C:\WINDOWS\TEMP`.

15.8.2 Configuring Temporary File Location for PBS Components

You configure the location of temporary files and directories for PBS components by setting the value of the PBS_TMPDIR configuration parameter in the `/etc/pbs.conf` file on each system. Set this parameter to the directory to be used for storing temporary files and directories by all PBS components on that system.

After you set the location of temporary files and directories, restart all PBS components:

```
<path to init.d>/init.d/pbs restart
```

The location for temporary files and directories for PBS components is determined by the following settings, in order of decreasing precedence:

1. $tmpdir in `mom_priv/config` (affects `pbs_mom` only, not other components)
2. PBS_TMPDIR (for Linux) or TMP (for Windows) environment variable
3. PBS_TMPDIR in PBS configuration file
4. If none of the preceding settings are present, PBS uses default values:
   - `/var/tmp` (for Linux)
   - `C:\WINNT\TEMP` or `C:\WINDOWS\TEMP` (for Windows)

15.8.3 Requirements

- The specified directory must exist.

  If the configured temporary file location does not exist, PBS prints the following error message:

  ```
  <command>: No such file or directory (2) in chk_file_sec, Security violation "<directory>"
      resolves to "<directory>"
  <command>: Unable to configure temporary directory.
  ```
- The directory must be globally readable and writable.
- On Linux systems, the directory must have the sticky bit set in the file permissions.
- The directory must not present a security risk:
  - All parent directories of the configured temporary directory must be owned by a UID less than 11 and a GID less than 10.
    - If the assigned owner has write permission, the UID must be 10 or less.
    - If the assigned group has write permission, the GID must be 9 or less.
  - Each parent directory must not be writable by "other".

  If a PBS component detects a security risk for a file or directory, it prints the following messages and exits:

  ```
  <command>: Not owner (1) in chk_file_sec, Security violation "<directory>" resolves to
      "<directory>"
  <command>: Unable to configure temporary directory.
  ```

15.8.4 Advice and Recommendations for Temporary File Location

- Make sure that the location you choose for temporary files is cleaned periodically.
- In the past, some PBS components defaulted to `/tmp` for storing temporary files. All components now default to `/var/tmp`, which is most likely a persistent storage location. You should take this into account and adjust the cleaning of `/var/tmp` accordingly.
- If a PBS component prints a security error message and exits, fix the security problem and restart the component.

15.9 Administration Caveats

15.9.1 General Caveats

Do not manually delete files in PBS private directories.

15.9.2 Windows Caveats

When you edit any PBS configuration file, make sure that you put a newline at the end of the file. The Notepad application does not automatically add a newline at the end of a file; you must explicitly add the newline.

15.10 Support for Globus

Globus can still send jobs to PBS, but PBS no longer supports sending jobs to Globus.

15.11 Support for Hyperthreading

On Linux machines that have Hyper-Threading Technology, PBS can end up reporting and using the number of logical processors, instead of the number of physical CPUs, as the value for resources_available.ncpus.

PBS does not control how CPUs are allocated to processes within a job. That is handled by the OS kernel.

15.11.1 Linux Machines with HTT

On Linux, PBS uses the number of CPUs shown in `/proc/cpuinfo`. If the CPUs are hyper-threaded and hyper-threading is enabled, the number of virtual and physical CPUs is different.

15.11.2 Windows Machines with HTT

On Windows, PBS calls the `CPUCount` Windows function, which reports whether hyper-threading is enabled. If hyper-threading is enabled, MoM uses the number of physical CPUs. If hyper-threading is not enabled, MoM uses the number of CPUs reported by the OS. MoM logs whether or not hyper-threading is enabled.

15.11.3 Using Number of Physical CPUs

If you do not wish to use hyper-threading, you can configure PBS to use the number of physical CPUs. Do this by setting resources_available.ncpus to the number of physical cpus:

```
Qmgr: set node <vnode name> resources_available.ncpus=<number of physical CPUs>
```

15.11.4 Hyperthreading Caveats

On a cpusetted system, NEVER change the value for resources_available.ncpus, resources_available.vmem, or resources_available.mem.

15.12 How To...

15.12.1 How to Drain Jobs

You can drain jobs from the entire complex by setting up dedicated time. Do not allow jobs in the dedicated time queue. See section 4.9.10, "Dedicated Time", on page 127.

You can drain jobs from a specific set of vnodes by creating a reservation that blocks out those vnodes for the desired amount of time. See section 4.9.37, "Reservations", on page 199.

15.12.2 How to Find Out Which Daemons Should Be Running

On the host in question, look in `/etc/pbs.conf`, or the location pointed to in the PBS_CONF_FILE environment variable. Check the settings that specify whether each daemon should run. 1 means the daemon should run.

```
PBS_START_MOM
PBS_START_COMM
PBS_START_SERVER
PBS_START_SCHED
```

16 Configuring and Using PBS with Cgroups

16.1 Chapter Contents

16.2 Introduction to Cgroups

The term cgroup (pronounced see-group, short for control groups) refers to a Linux kernel feature that was introduced in version 2.6.24.

A cgroup may be used to manage access to system resources and to account for resource usage. The root cgroup is the ancestor of all cgroups and provides access to all system resources. When a cgroup is created, it inherits the configuration of its parent. When a process assigned to a cgroup creates a child process, the child is automatically assigned to its parent's cgroup.

Once created, a cgroup may be configured to restrict access to a subset of its parent's resources. These restrictions may include such things as memory, NUMA nodes, and devices. These different resource classes are grouped into categories referred to as *cgroup subsystems*. When processes are assigned to a cgroup, the kernel enforces all configured restrictions.

In Cgroups v1, supported by this cgroups hook, the kernel supports a number of cgroup subsystems. A cgroup subsystem is a kernel component that modifies the behavior of the processes in a cgroup. Subsystems are sometimes also known as *cgroup resource controllers* or *cgroup controllers*. We describe PBS support for cgroup subsystems in this chapter.

PBS provides a hook that allows you to take advantage of cgroups. When the cgroups hook is enabled, it runs on every node assigned to the job. When a job is started, the hook creates a set of directories for the configured subsystems based on the resource requirements of the job and then places the job process within the cgroup.

While the job is running, the kernel, not PBS, enforces resource restrictions, based on the cgroup settings written by the hook earlier. The cgroups hook can be configured to periodically poll the job's cgroup and update resource usage. When the job finishes, the hook writes final resource usage to the job's resources_used attribute, and removes the cgroup directories it created to house the job.

16.3 Why Use Cgroups?

Without cgroups, Linux can define sets of processes as related, but cannot define a set of loosely coupled processes as a single entity. Without cgroups, PBS uses Linux sessions to track job processes, but less accurately than with cgroups. Linux sessions impose the following limitations:

- Restrictions on how processes have to be related: sessions must encompass a parent process and nothing else but its progeny; it is impossible to merge a job session and another session created by for example `sshd`. However, PBS can manage more than one session per host.
- Inability to set resource usage restrictions for the entire set of processes belonging to a job; while you can set per-process limits on memory or CPU time, you cannot limit a session or a group of sessions belonging to a job.
- Inability to make job sessions be inescapable containers: the `setsid` call or command will make processes leave the current session and create their own unrelated session; users and applications can use it without restriction.

With cgroups, all of these issues can be avoided:

- Since cgroups offer a well-established and general way of grouping processes together, cgroup controllers can implement precise resource usage accounting, resource usage limits, and process control for the entire cgroup. The cgroup also persists until it is explicitly destroyed, allowing some resource usage counters in a cgroup to outlive the processes that were members of the cgroup.
- Root can add processes to a cgroup regardless of the relationship between the processes, so a daemon can force processes spawned by OS services to join an existing cgroup. A process or thread spawned by a process appears at first in the cgroup of the parent process, and a non-root process cannot use any library call to escape the cgroup unless another cgroup grants that process permission to change cgroups.

16.3.1 What PBS Can Do With Cgroups

- More correctly identify which processes are part of a PBS job, even when libraries mislead PBS by creating processes that move into their own sessions that are not registered with PBS
- Make processes spawned through external `systemd` daemons, including `ssh`, fully join a job
- Prevent job processes from using more resources than specified; for example disallow bursting above limits set according to the resources requested by the job when it was submitted
- Keep job processes within defined memory and CPU boundaries, ensuring there is minimal interference between jobs sharing a host, in order to provide consistent job run times
- More accurately track and account for resource usage, even at the end of the job, when the job processes have exited and can no longer be investigated
- Enable or disable access to devices
- Ensure jobs leave enough resources for OS processes, to avoid disrupting OS services and turning nodes into "black hole nodes" that will no longer correctly run jobs

In addition to leveraging the kernel's cgroups support, the cgroups hook can also optionally discover the hardware configuration of a host and create child vnodes that reflect the hardware configuration, for example a number of CPU sockets with locally attached memory and GPU device.

This allows configuring the server and scheduler for optimal job performance. This functionality is an extension of the functionality formerly supported by the cpuset MoM (since the cpuset controller is now just one of the cgroup controllers in the kernel).

16.3.2 Examples of Using Cgroups

- Limit all of a job's processes to 6 CPUs and 6GB of RAM on vnode A
- Ensure that if two MPI jobs share a host, they do not pin processes to the same CPUs
- Limit access to GPU devices to only those assigned to the job by the cgroups hook
- Partition a host into a number of socket-aligned vnodes for optimal placement of jobs
- Pair processor, memory, and coprocessors like Xeon Phi and GPUs for optimal job placement

16.4 How PBS Uses Cgroups

16.4.1 Vnode Creation via Cgroups Hook

The hook creates a child vnode for each NUMA node on a host when all of the following conditions are true:

- The hook is enabled on the host
- At least one subsystem is enabled on the host
- The vnode_per_numa_node parameter is set to *true*
- The hook finds a NUMA node on the host

For example, if the host named "myhost" has one NUMA node, you end up with two vnodes to represent the host: the parent vnode, named "myhost", and a vnode to represent the NUMA node, named "myhost[0]".

16.4.1.1 Caveats for Vnode Creation

- Make sure that you run the cgroups hook only after you have created the parent vnode.
- If the cgroups hook creates vnodes for a host, do not use any other method to create child vnodes for that host. For example, do not create special vnodes for GPUs.

16.4.2 Job Life Cycle with Cgroups

16.4.2.1 Running Single-host Jobs with Cgroups

When PBS runs a single-host job, the following happens:

1. On the host assigned to the job, PBS creates a cgroup for each enabled subsystem. PBS assigns resources (CPUs, memory, and optionally co-processors such as GPUs or Xeon Phis) to the job on the host. It sets the required limits on resource usage in the cgroups created.
2. PBS places the top job process in each created cgroup. Cgroup semantics then automatically ensure that the progeny of the top job process are also confined to the correct cgroups.
3. The cgroup periodic hook collects resource usage information about the cgroups and hands it over to MoM; MoM uses these values when it reports job resource usage to the server to set the resources_used attribute.
4. When the job has finished, the cgroups hook reports CPU and memory usage to MoM and cleans up the cgroups.

16.4.2.2 Running Multi-host Jobs with Cgroups

When PBS runs a multi-host job, the following happens:

1. PBS creates a cgroup on each host assigned to the job. PBS assigns resources to the job and sets the required cgroup limits.
2. PBS places the top job process in the cgroup on the first node (the primary execution host). Any child processes that the job spawns on the primary execution host remain in the cgroup, even if they use calls to change Linux session.
3. The job creates processes on the remote hosts. If PBS integration of multihost applications has been done correctly, those processes will either:
   - Be created as children of MoM through a call to the TM API `tm_spawn` call (possibly indirectly through the use of `pbs_tmrsh`)
   - Be spawned by an external service and then registered as part of the job through a call to `tm_attach` (possibly indirectly through the use of `pbs_attach`)

   In both cases, the cgroups hook migrates the processes into the correct cgroups; the kernel then ensures their progeny remain in the cgroups.
4. On each host, the cgroup periodic hook collects usage information about the cgroups and hands it over to MoM; the primary execution host MoM periodically queries the resource usage on sister nodes, sums the contributions of all the nodes, and reports it to the server, which publishes it in the resources_used attribute.
5. When the job has finished, on each host, the cgroups hook reports final CPU and memory usage to the local MoM and cleans up the job cgroups. The primary execution host MoM collects resource usage information from all nodes, sums it across nodes, and sends it to the server, which makes a final update to the resources_used attribute.

16.4.3 Cgroup Subsystems

The cgroups hook can manage the subsystems listed in "Subsystems Managed by the Cgroups Hook" on page 577.

For other subsystems, listed in "Subsystems Used by Other Software" on page 577, the hook can only create and destroy per-job cgroups and move job processes into those cgroups; apart from that, it does not manage any values in those cgroups. Some of these subsystems are used by other software.

16.4.3.1 Cgroup Subsystems Managed by the Cgroups Hook

The cgroups hook can manage the following subsystems:

Table 16-1: Subsystems Managed by the Cgroups Hook

Subsystem	Functionality Used by Cgroups Hook
cpu	Set quota for CPU usage and/or set CPU usage shares for each job, to allow the Linux CFS scheduler to implement fair sharing See section 16.5.3.7, "cpu Subsystem", on page 590.
cpuacct	Monitor CPU resource usage See section 16.5.3.5, "cpuacct Subsystem", on page 587.
cpuset	Allocate and restrict jobs to specific CPU and optionally NUMA memory domains See section 16.5.3.6, "cpuset Subsystem", on page 587.
devices	Restrict job access to only specific character and block devices See section 16.5.3.8, "devices Subsystem", on page 592.
memory	Set kernel-enforced per-job limits for memory usage; monitor memory usage See section 16.5.3.9, "memory Subsystem", on page 594.
memsw	Set kernel-enforced per-job limits for swap usage; monitor swap usage See section 16.5.3.10, "memsw Subsystem", on page 598.
hugetlb	Set kernel-enforced per-job limits for huge pages usage; monitor huge pages usage See section 16.5.3.11, "hugetlb Subsystem", on page 601.

16.4.3.2 Cgroup Subsystems Not Managed by Cgroups Hook

When subsystems not managed by the cgroups hook are enabled, the cgroups hook only creates per-job cgroup directories, ensures job processes are moved into them, and deletes the per-job cgroup when the job ends. Managing any parameters is left to other hooks or software.

If you run another hook, for example the container hook, that expects per-job cgroups to have been created by the cgroups hook for a set of subsystems, make sure you enable these subsystems on the host.

The cgroups hook can create and destroy cgroups for, and move processes into, the following subsystems:

Table 16-2: Subsystems Used by Other Software

Subsystem	Functionality Used by Other Software
freezer	Can be used to suspend entire job
blkio	Can track and limit usage and bandwidth to specific disk block devices
pids	Can be used to track and limit number of processes in a job

Table 16-2: Subsystems Used by Other Software

Subsystem	Functionality Used by Other Software
net_cls	Can be used to tag network packets sent by the job with a job-specific class identifier that can be used in e.g. firewall configuration
net_prio	Can be used to dynamically set the priority of network traffic generated by each job
perf_events	Allow the `perf` tool to monitor a PBS Professional job as a group

16.5 Configuring Cgroups

You manage the behavior of the cgroups hook across your complex by setting parameters in the cgroups hook configuration file.

16.5.1 Prerequisites for Cgroups Hook

16.5.1.1 Ensure that Cgroups v1 are Available

Many Linux distributions have cgroups v1 available by default; for others you may need to install and enable cgroups. We provide some tips here for making sure that cgroups are available on your system:

- Verify that you have cgroups configured on your system:

  ```
  cat/proc/mounts|grep cgroup
  ```

  You should see cpuset, cpuacct, memory, etc. enabled.

  Each subsystem that will be enabled on the host by the configuration file should be listed (except memsw; see below).

  If you do not have cgroups available, install them.

  You may need to set your kernel flags so that they enable cgroup support.
- A cgroup subsystem may be disabled at boot time. To check for this, look for "cgroup_disable" entries in `/proc/cmdline` and take appropriate actions to remove it from the kernel command line parameters.
- The memsw subsystem is not a separate controller but an option of the memory controller that is present or absent depending on the kernel options at boot time.

  If you plan to enable the memsw subsystem, to verify whether swap accounting and limits are available:

  ```
  cat /proc/mounts | grep cgroup | grep memory | awk 'BEGIN {FS=" "} {print $2}' | head -n 1 | xargs
      --replace=dir ls dir/memory.memsw.usage_in_bytes
  ```

  If this lists a file, then memory plus swap accounting is turned on. If instead, `ls` reports it cannot access the file, then kernel support for it is disabled; in some kernels it is disabled by default.

  If memsw support is disabled, either add "`swapaccount=1`" to the kernel command line parameters to enable it and reboot the node, or ensure that the memsw section of the configuration file is disabled for the host.
- Make sure that cgroups will survive a reboot. Test whether cgroups survive by rebooting the host, then look to see whether cgroups are available. If they are not available, refer to the documentation for your Linux distribution.

16.5.1.2 Ensure that PBS Is Already Installed and Started

Make sure that PBS is installed and started.

16.5.2 Enabling and Tuning Hook According to Host and/or Vnode Type

You can use just one configuration file across a complex containing hosts with different configurations. You can enable the hook for a specific subset of the hosts in your complex. You can also tune the hook by enabling each subsystem independently according to host. For example if you have some hosts with swap, and some without, and some hosts with GPUs and some without, you can enable the memsw subsystem only for the hosts that have swap, and enable the devices subsystem only for the hosts that have GPUs.

You can similarly tune the hook for any parameter that takes *true* and *false*. So for example you can tune the soft_limit parameter in the memory subsystem so that soft_limit evaluates to *true* for certain hosts.

16.5.2.1 Vnode Types for Cgroups Hook

You can label each host to reflect its characteristics, then use the label when specifying which hosts are included in a subset. The labeling mechanism is a single string, in a file on MoM's host in `PBS_HOME/vntype`. We refer to this string as a "*vnode type*", and the hook stores the value of the string in the variable "vntype". You can define any vnode type you need. Write your vntypes using only alphanumerical characters and the delimiters ".", "-" and "_".

16.5.2.1.i Vnode Type File and vntype Resource

The resources_available.vntype vnode resource and the `vntype` file contents are related but different tools. Do not try to set the `vntype` file contents by changing resources_available.vntype for the vnode (this will not work). If you want the value of resources_available.vntype for the vnode to reflect the contents of the `vntype` file on the execution host, you can propagate the file string to the resource by setting the propagate_vntype_to_server parameter in the hook's configuration file to *True*.

16.5.2.2 Tuning Where Hook, Subsystems, and Parameters are Enabled

For each of the *true*/*false* parameters, and for the swappiness parameter, you can specify whether a host or vnode type is in, or not in, the list for which the parameter evaluates to *true*. A list is one or more comma-separated host or vnode names, specified using one of these:

"vntype in:"

"vntype not in:"

"host in:"

"host not in:"

Whitespace around the entries is ignored. You can use hostnames or vntypes, or Python `fnmatch` sequences, which allows "*" or "?" wildcards. Do not use commas inside an entry.

Example 16-1: If you have four vntypes "compute_swap", "compute_noswap", "gpu_swap", "gpu_noswap", you can set the swappiness parameter for the memory subsystem using

```
"swappiness" : "vntype in: *_swap"
```

and set the vnode_per_numa_node parameter in the main section using:

```
 "vnode_per_numa_node" : "vntype in: gpu_*"
```

16.5.2.2.i Enabling the Hook and Subsystems

For the hook and each subsystem, the enabled parameter can be modified using the exclude_vntypes, exclude_hosts, include_hosts, and run_only_on_hosts parameters. In the following hierarchy, each parameter modifies the previous parameters. Always specify these parameters in this order in the configuration file:

1. enabled
2. exclude_hosts
3. exclude_vntypes
4. include_hosts
5. run_only_on_hosts

16.5.2.2.ii exclude_vntypes

Modifies the enabled parameter. JSON list of patterns for vntypes to exclude from enabled group. For example, to include all hosts except those without cgroups (marked with "no_cgroup" in their vntype):

```
"enabled" : true,
"exclude_vntypes": [ "*no_cgroup*"]
```

This is equivalent to:

```
"enabled" : "vntype not in: *no_cgroup*"
```

16.5.2.2.iii exclude_hosts

Modifies the enabled parameter. List of hosts to exclude from membership group. For example, to enable all hosts with GPUs (marked with "gpu" in their vntype), except for the hosts marked for testing:

```
"enabled" : "vntype in: gpu"
"exclude_hosts" : [ "gpu_test*" ]
```

16.5.2.2.iv include_hosts

Modifies and overrides the enabled, exclude_vntypes, and exclude_hosts parameters. List of hosts to include in membership group, despite having been among those excluded. For example, to include two "thin" hosts in the cpuset subsystem list, despite the fact that they did not qualify to be enabled in the "fat" group:

```
"cpuset"  : {
    "enabled" : "vntype in: fat"
    "include_hosts" : [ "test_cpuset_thin01", "test_cpuset_thin02" ]
```

This is equivalent to:

```
"cpuset"  : {
    "enabled" : "vntype not in: thin"
    "include_hosts" : [ "test_cpuset_thin01", "test_cpuset_thin02" ]
```

16.5.2.2.v run_only_on_hosts

Modifies the enabled, exclude_vntypes, exclude_hosts, and include_hosts parameters. Provides additional restriction on hosts otherwise qualified for inclusion in membership list. Any host included must pass all membership tests. For example, to include only hosts that are both "willing" and among the list of "able01", "able02", and "able03":

```
"enabled" : "vntype in: willing"
"run_only_on_hosts" : [ "able01", "able02", "able03" ]
```

16.5.2.2.vi Hook and Subsystem Enablement Tuning Parameters

The following parameters let you tune whether the hook and each subsystem is enabled on any host and/or vntype. You can set each parameter in this table for the entire hook and for each subsystem individually. Here we show the defaults in the configuration file, and in the code, as they apply to whether the hook itself is enabled. We do not list the defaults for each subsystem; they may be different.

Table 16-3: Cgroups Hook Global and Subsystem Membership Configuration Parameters

Parameter Name	Default Value: Configuration File	Default Value: Hook	Description
enabled	*true*	*True*	When *true*, the cgroups hook is enabled on the host. Can be modified using the exclude_vntypes, exclude_hosts, include_hosts, and run_only_on_hosts parameters. See section 16.5.2, “Enabling and Tuning Hook According to Host and/or Vnode Type”, on page 579.
exclude_hosts	*[]*	*[]*	Modifies the enabled parameter. If not empty, specifies a list of hosts where the hook should be disabled. See section 16.5.2.2.iii, “exclude_hosts”, on page 580
exclude_vntypes	*["no_cgroups"]*	*[]*	Modifies the enabled parameter. Specifies a list of vnode types for which the cgroups hook should be disabled. See section 16.5.2.2.ii, “exclude_vntypes”, on page 580
include_hosts			Modifies the enabled and exclude_hosts parameters. If not empty, specifies a list of hosts where the hook should be enabled despite earlier exclusion. See section 16.5.2.2.iv, “include_hosts”, on page 580
run_only_on_hosts	*[]*	*[]*	Overrides the enabled, exclude_hosts, exclude_vntypes, and include_hosts parameters. If not empty, specifies a list of hosts limiting the hosts for which the cgroups hook should be enabled to the matching hosts. See section 16.5.2.2.v, “run_only_on_hosts”, on page 580

16.5.3 Cgroups Hook Configuration Parameters

The cgroups hook configuration file contains parameters that the hook uses as guides for its behavior, and parameters that the hook uses when it sets values in the cgroups directories. For any parameter that is unset in the configuration file, the cgroups hook uses defaults built into the hook. This file must conform to JSON syntax.

The cgroups hook configuration file is named *pbs_cgroups.json* before it is imported as the hook configuration file. After the file is imported as the hook configuration file, PBS names it *pbs_cgroups.CF*.

16.5.3.1 Global Parameters for Cgroups Hook

Here are the cgroups hook configuration parameters, except for the membership tuning parameters described above. Please note that some parameters may be different from those shown here:

Table 16-4: Cgroups Hook Configuration File Global Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled	*true*	*True*	When *true*, the cgroups hook is enabled on the host. Can be modified using the exclude_vntypes, exclude_hosts, include_hosts, and run_only_on_hosts parameters. See section 16.5.2, "Enabling and Tuning Hook According to Host and/or Vnode Type", on page 579.
cgroup_lock_file		*"/var/spool/pbs/mom_priv/cgroups.lock"*	This file ensures that only one hook event can manipulate the cgroups at any one time. The filesystem on which this file resides must support file locking.
cgroup_prefix	*"pbs_jobs"*	*"pbs_jobs"*	The parent directory under each cgroup subsystem where job cgroups are created. If the memory subsystem is located at `/sys/fs/cgroup/memory`, the memory cgroup for job 1.foo is found in the `/sys/fs/cgroup/memory/pbs_jobs.service/<job ID>/1.foo` directory.
kill_timeout	*10*	*10*	Maximum number of seconds the cgroups hook spends attempting to kill job processes before destroying cgroups
server_timeout	*15*	*15*	Maximum number of seconds the cgroups hook spends attempting to fetch node comments from the server
nvidia-smi		*"/usr/bin/nvidia-smi"*	The location of the `nvidia-smi` command on nodes supporting NVIDIA GPU devices. See section 16.5.5, "Managing GPUs or Xeon Phi via Cgroups", on page 605.
online_offlined_nodes	*true*	*false*	When enabled, if the periodic hook manages to confirm there are no orphan groups, it will online vnodes again if it can confirm they were earlier offlined by the cgroups hook. See section 16.5.3.4, "Automatic Onlining of Fixed Vnodes", on page 586.
periodic_resc_update	*true*	*false*	When set to *true*, the hook periodically posts updates of the job's resource usage on this host to MoM. When set to *false*, the usage is sent to MoM only when the job ends
use_hyperthreads	*false*	*false*	When set to *true*, all CPU threads are made available to jobs. When *false*, only the first hyperthread of each core is made visible to jobs. See section 16.5.3.3, "Configuring Hyperthreading Support", on page 584.

Table 16-4: Cgroups Hook Configuration File Global Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
ncpus_are_cores	*false*	*"false"*	When *true*, resources_available.ncpus of a vnode is the number of cores, and the hook assigns all threads of each core to a job. When *false*, resources_available.ncpus is the number of CPU threads available to jobs, and the hook assigns individual CPU threads to jobs. See section 16.5.3.3, "Configuring Hyperthreading Support", on page 584.
vnode_per_numa_node	*false*	*"false"*	When set to *true*, each NUMA node is represented by a separate vnode, and the host is managed by a resourceless parent vnode. When set to *false*, the entire host is represented by a single vnode. See section 16.5.3.2, "Setting vnode_per_numa_node", on page 584.
propagate_vntype_to_server		*"true"*	When set to *true*, the contents of the vntype file on the local host are propagated to the resources_available.vntype vnode resource. When set to *false*, the vntype file contents are not propagated to the vnode resources_available.vntype resource. See section 16.5.2.1.i, "Vnode Type File and vntype Resource", on page 579.
manage_rlimit_as	*true*	*"true"*	When set to *true*, the cgroups hook resets the RLIMIT_AS process limit for task processes to the value of pvmem requested for the job, or to unlimited if pvmem is not requested. Requires a kernel that supports the `prlimit` system call. When set to *false*, limits set by MoM are not changed. Set this to *true* when you enable the memsw subsystem. Otherwise you can set it to *false*. When it is *false*, MoM sets RLIMIT_AS to Resource_List.pvmem if specified, otherwise Resource_List.vmem.
discover_gpus	*true*	*"true"*	Enables or disables call to `nvidia-smi`. When set to true, `nvidia-smi` is called. When set to *false*, speeds the process of device discovery when the devices subsystem is enabled on a GPU-less host.

We show a sample file in section 16.5.3.12, "Sample Cgroups Hook Configuration File", on page 603. You can also export and look at the installed PBS cgroups hook configuration file:

```
qmgr -c "export hook pbs_cgroups application/x-config default" >pbs_cgroups.json
```

You can edit this file and change its parameters, then read it back in:

```
qmgr -c "import hook pbs_cgroups application/x-config default pbs_cgroups.json"
```

Note that if your configuration file is incomplete or not present, hook behavior may differ from what is expected.

16.5.3.2 Setting vnode_per_numa_node

When this is *false*, all resources of the host are presented to the server as a single vnode (the parent vnode). In a large complex, minimizing the number of vnodes makes it faster for the scheduler to select nodes for jobs, and if large parallel jobs span a set of small hosts used exclusively by one job at a time, there is little advantage in making subdivisions of the host visible to the server and scheduler.

However, on clusters where execution hosts run more than one job at a time, you can take advantage of hosts made up of a number of separate NUMA nodes. (A NUMA node is a set of CPUs with uniform access speed and latency to a set of local memory and PCIe resources. Usually a NUMA node maps to a socket in a multi-socket computer, but some processors integrate more than one NUMA node on a single socket. On both AMD and Intel processors, the number of NUMA nodes per socket also depends on BIOS configuration, which allows tuning the size of a NUMA node to the workload. The cgroups hook does not decide how many NUMA nodes there are; it relies on the Linux kernel's view of the NUMA nodes on a host.)

When this parameter is *true*, the scheduler is able to improve application performance in these ways:

- Run small jobs only on single-NUMA-node vnodes
- Give parallel applications smaller than a host exclusive use of their NUMA nodes
- Run jobs that request GPUs on vnodes where the CPUs are on the socket directly connected to the GPU's PCIe bus

When vnode_per_numa_node is *true*, the host is presented to the server as a parent vnode that has no resources, plus a number of child vnodes that are aligned to NUMA nodes and hold specific CPU, memory, and coprocessor resources such as GPUs or Intel Xeon Phi processors.

The scheduler can still spread a single chunk across several vnodes on the same host. To ensure that a job is placed on only one NUMA node, use `-lplace=group=vnode`. You can also group using custom resources that identify larger sets of well-connected vnodes.

The main drawback to enabling vnode_per_numa_node is the increase in the number of vnodes in a cluster, which may slow down the scheduler, and make the output of pbsnodes larger and more difficult to interpret. A second drawback is that certain classes of jobs will no longer fit in one vnode, making it more complex to ensure they are still placed in a well-connected set of vnodes.

16.5.3.3 Configuring Hyperthreading Support

Hyperthreading can increase the throughput for some applications; it can also allow the operating system to retain access to some idle CPU threads even when PBS jobs use every core. If you disable hyperthreading in the BIOS, the kernel must share the only visible thread in each core with PBS jobs. On the other hand,

- Hyperthreading makes it more complicated to run applications that get no performance benefits from it, especially on clusters where some nodes are hyperthread-enabled and others are not
- On a host that runs more than one job, for parallel applications, hyperthreading that is not tightly managed can have severe negative impacts on performance if the threads of a single core are running processes from unrelated applications

This is why the cgroups hook supports three different models of hyperthreading support:

"No hyperthreads" behavior

use_hyperthreads disabled

In this model PBS makes only the first thread of each core visible to PBS jobs, so if your workload cannot leverage hyperthreading well, you don't need to disable hyperthreading in the BIOS. The other CPU threads are still usable by the operating system, which means throughput is better than if hyperthreading support is disabled in the BIOS.

The value of resources_available.ncpus reflects the number of cores associated with a vnode, minus the cores whose threads have been marked as reserved by using exclude_cpus in the cpuset section of the configuration file.

This model is different from "Assign whole cores to jobs" behavior only when the cpuset subsystem is enabled.

"Default behavior"

use_hyperthreads enabled and ncpus_are_cores disabled

This mode mimics the behavior you would get without the cgroups hook, as well as the behavior of the former cpuset MoM.

The value of resources_available.ncpus reflects the number of CPU threads available on a vnode. For applications to request all threads of N cores, they must request 2*N ncpus on 2-way hyperthreaded hosts, or N ncpus on hosts where hyperthreading is disabled. The cgroups hook tries to allocate those threads from the minimum number of cores.

The main use case of this mode is a workload consisting of many single-threaded jobs for which running one job per thread rather than one job per core improves throughput. For example, on a host with a total of 24 2-way hyperthreaded cores, you can run 48 unrelated jobs instead of 24. The 48 jobs will run slower than if you ran only 24, but the total throughput might still be greater than if you had run 24 jobs.

"Assign whole cores to jobs" behavior

use_hyperthreads enabled and ncpus_are_cores enabled

In this model, hyperthreads are exposed to applications within a job, but one CPU of ncpus maps to all the threads of a single core. The cgroups hook assigns each CPU core exclusively to one job, but within a job the processes see all CPU threads of the assigned cores and can either choose to ignore hyperthreading or leverage it.

This is the easiest model to use when you do not need to map more than one job on a single core to increase throughput.

The value of resources_available.ncpus reflects the number of cores associated with a vnode, minus the cores whose threads have been marked as reserved by using exclude_cpus in the cpuset section of the configuration file.

This model is often preferred.

This model is different from "No hyperthreads" behavior only when the cpuset subsystem is enabled.

16.5.3.3.i Mixing Hyperthreading Models in a Complex

If you have a mixed workload or complex where you want to run some high-throughput single-threaded jobs, and some that take advantage of hyperthreading:

- You can tune your hook configuration file in order to partition your complex, where:
    - Some hosts are configured with ncpus_are_cores disabled, to run high-throughput single-threaded workloads
    - Other hosts are configured with ncpus_are_cores enabled
- You can allow jobs to request hyperthreaded hosts based on whether or not ncpus_are_cores is enabled

You can include hyperthreading information in each host's vnode type string in its vntype file, so that the cgroups hook parameters use_hyperthreads and ncpus_are_cores evaluate correctly to *true* or *false* for each host. You can set a resource on each host to indicate how hyperthreads are handled on that host, so that jobs can request the hyperthreading they want. You can also use this resource to associate hosts with queues, so that job submitters can specify a queue instead of requesting a resource. The string in the vntype file is probably going to be used for multiple characteristics such as GPUs, swap, etc., so you probably don't want to propagate it to resources_available.vntype.

Example 16-2: You use the custom resource ht to indicate whether and what kind of hyperthreads are available, and you use "ht" or "nohyper" in the vntype file to indicate whether hyperthreads exist. You can associate queues with hosts according to host configuration. If you have some hosts with hyperthreading and some without, some hosts with all threads of a core assigned to one job and some hosts without, and some hosts with GPUs and some without, you might end up with the following:

Table 16-5: Example of Mixing Hyperthreading Models

Host	use_hyperthreads	ncpus_are_cores	vntype file	resources_available.ht	queue name
hosta	*true*	*true*	gpu_ht	ht_by_core	ht_core_q
hostb	*true*	*true*	compute_ht	ht_by_core	ht_core_q
hoste	*true*	*false*	gpu_ht	ht_by_thread	ht_thread_q
hostf	*true*	*false*	compute_ht	ht_by_thread	ht_thread_q
hostc	*false*	*true*	gpu_nohyper	core	core_q
hostd	*false*	*true*	compute_nohyper	core	core_q
hostg	*false*	*false*	gpu_nohyper	core	core_q
hosth	*false*	*false*	compute_nohyper	core	core_q

In our example, none of the job submitters care about whether their jobs run on hosts with GPUs; the GPU machines are here just to illustrate how you might use the vntype file string for more than one aspect of a host.

Jobs that want hyperthreads and want all of the threads for each core can request "ht=ht_by_core" in the select statement, or they can request or be routed to the queue named "ht_core_q".

Single-threaded jobs that are I/O bound and don't mind sharing a core can request "ht=ht_by_thread", or they can request or be routed to the queue named "ht_thread_q".

Single-threaded jobs that want non-hyperthreaded cores can request "ht=core", or they can request or be routed to the queue named "core_q".

16.5.3.4 Automatic Onlining of Fixed Vnodes

When cleaning up a job, if the cgroups hook fails to kill all processes within a cgroup, it cannot destroy the job's cgroups. If that happens, it offlines the vnodes on the host to prevent the scheduler from sending new jobs to the vnodes; since resources_assigned is no longer accurate for the vnodes, the cgroups hook might reject the jobs. The cgroups hook then periodically attempts to clean up these orphaned cgroups.

When the online_offlined_nodes parameter is enabled, the hook automatically onlines the vnodes once no more orphaned cgroups exist, if the node comment confirms that the cgroups hook offlined the vnodes. When this parameter is disabled, it leaves the node offline; you can manually online vnodes again later after confirming the host is healthy.

16.5.3.5 cpuacct Subsystem

The cpuacct subsystem enables per-job CPU time accounting, through per-cgroup usage counters provided by the kernel. Advantages:

- The kernel maintains per-cgroup usage counters, so MoM doesn't have to sum the usage of each job process
- MPI libraries or applications that use `setsid` to detach processes from existing sessions do not cause inaccurate resource usage accounting, since the processes are still seen as part of the job
- A session spawning a child session that registers itself to PBS (not necessary with cgroups) does not cause some CPU time to be counted twice incorrectly at the end of the job
- Usage accounting does not rely on MoM polling, and usage accumulated after the last poll cycle is still counted. (When the cpuacct subsystem is not used, CPU time for `tm_attach`ed processes is counted only until the last MoM poll cycle)
- Short MoM polling cycles are not required for accurate accounting at the end of the job

By default this subsystem is enabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, "Hook and Subsystem Enablement Tuning Parameters", on page 581.

16.5.3.6 cpuset Subsystem

The cpuset subsystem restricts jobs to specific CPUs and optionally memory sockets allocated to them by the hook.

Advantages:

- Libraries know which set of CPUs are available for process pinning, so when a vnode is shared between multiple jobs, libraries don't try to pin more than one job to the same CPUs. For example, if you have two 4-CPU jobs and an 8-CPU vnode, they won't both try to pin themselves on CPUs 0, 1, 2, and 3.
- Strict job isolation is enforced; it is impossible for a job to steal CPU resources from another job on the same host, since the Linux scheduler will only run processes on the designated CPUs. If a job requests N CPUs and then creates N*2 processes, the job's processes will compete with each other for CPU resources, instead of disturbing other jobs.
- Since job processes are restricted to specific CPUs and not left to wander over the entire host, the default "first touch node local" memory allocation policy can minimize memory latency; for jobs that do not span NUMA nodes, pinning processes to CPUs to avoid non-local memory accesses is no longer even necessary.

Disadvantages: if you want to overcommit CPU resources, for example by setting resources_available.ncpus to 128 on a host that has 64 CPU threads, you cannot use the cpuset subsystem.

Note that there can be a problem when using the cpuset subsystem and preemption via suspend and resume. See section 16.8.1, "Interactions Between Suspend/resume and the cpuset Subsystem", on page 614.

By default this subsystem is enabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, "Hook and Subsystem Enablement Tuning Parameters", on page 581.

16.5.3.6.i Using Memory Fences for Job Memory Requests

You can set memory fences around jobs by setting the mem_fences parameter to *true*. When *true*, the cgroups hook sets the cpuset.mems to only the NUMA nodes assigned to the job, preventing jobs from using memory from other NUMA nodes. When *false*, cpuset.mems encompasses all NUMA nodes present on the host. This parameter is *false* by default.

Using job memory fences maximizes application performance, and mimics the behavior of the former cpuset MoM most closely.

Problems can arise when mem_fences is set to *true* but some jobs can still straddle nodes and grab memory on a node where a fenced job runs. In this case the straddling job can cause the fenced job not to have enough memory available, and the fenced job can die.

Recommendations when using memory fences for job requests:

- Precisely match job chunk specifications to vnodes, and/or run only a combination of jobs that use `-lplace=group=vnode` for small jobs and `-lplace=excl` for larger jobs. Do not allow the scheduler to split chunks across several vnodes. If a job requests -lncpus=1:mem=2GB and the ncpus are allocated on vnode node[0] but the memory is partially allocated on vnode node[1], memory fences are not going to enforce node local memory allocations. Memory fences can cause jobs to fail if some jobs straddle vnodes and share vnodes with jobs entirely confined to one vnode. For example, if job B is allocated 1GB of memory on node node[0] and 63GB of memory on node[1], the kernel may let the job allocate 64GB on node[0] instead, causing memory allocations for jobs confined to node[0] to fail through no fault of their own.
- When erecting memory fences and using huge pages, install utilities to ensure the correct amount of huge pages are present on NUMA nodes allocated to jobs; if the huge pages still available are on the wrong nodes, jobs may fail.

Without memory fences, processes in a cpuset still have a strong preference to allocate memory on the NUMA node of the first process to access the memory, unless memory on that NUMA node is depleted, when the kernel will satisfy requests using memory on other NUMA nodes.

Disabling memory fences is the safest option to ensure that jobs do not fail because they cannot request enough memory. This can happen when another job, possibly one using more than one vnode, grabs the memory first.

The drawback of not having memory fences is that when unanticipated off-node allocations do happen, a job will not fail but will silently use remote memory and run slower; you may prefer these jobs to fail, so that you can address the root cause rather than just run jobs too slowly, especially for large parallel jobs that should never cause such off-node allocations.

If you wish to rely on first touch local node memory placement to work most of the time and would rather see jobs still run rather than fail when remote memory allocations become inevitable, disable memory fences.

Recommendations when not using memory fences for job requests:

- If you disable memory fences, you must appropriately set kernel tunables governing how the OS uses memory for caching files; see section 16.5.3.6.iii, "Memory Spreading for OS File Caching", on page 588.
- When using large memory pages (see section 16.5.3.11, "hugetlb Subsystem", on page 601) you must ensure that enough large pages are always available on the NUMA nodes where they are needed to ensure best performance.

16.5.3.6.ii Using Memory Fences for OS File Caching

Pages allocated by the kernel to cache files accessed by processes have their own fences, controlled by the mem_hardwall parameter. In theory, placing these on remote NUMA nodes has less deleterious effects, both because memory latency to these pages is less important, and also because a job on foreign NUMA nodes can in theory reuse these pages fairly easily, since the kernel can discard the cached contents of the file to mark the memory free again (but possibly only after writing out dirty cache to disk, which may take a while).

By default mem_hardwall is set to *false*, which allows the operating system the freedom to use memory on all nodes to cache files for any process. If you want to isolate jobs to get more repeatable performance, you can enable the mem_hardwall parameter, so that a cgroup can cache files using pages on only the NUMA nodes assigned to it.

16.5.3.6.iii Memory Spreading for OS File Caching

By default memory_spread_page is disabled for a cpuset, which means that file cache allocated for a process in the cgroup will preferentially be allocated on the NUMA node where the process that causes the file to be cached is currently running. This minimizes I/O latency to the buffer cache, but may create hotspots on certain NUMA nodes where file cache is concentrated, reducing the free memory immediately available for application memory allocations. If the kernel cannot reuse the file cache rapidly enough, the concentration of file cache may cause memory to be allocated off-node, which can slow application performance.

You can enable the memory_spread_page parameter to reduce file cache hotspots by spreading file cache allocation across the NUMA nodes that can be used by the cgroup. This may cause a slight increase in latency for accessing cached files.

To control whether pages are spread only on the NUMA nodes assigned to the job, or on the entire host, use the mem_hardwall parameter. Set this to *true* to spread pages only on the NUMA nodes assigned to the job.

16.5.3.6.iv Allowing Zero CPU Jobs

Some job submitters may want to run "weightless" jobs that consume few CPU resources; these jobs are assigned zero CPUs. The cpuset subsystem allows these jobs to run in the parent cpuset that has access to all CPUs and memories. However, these processes break down the barriers that otherwise ensure jobs are isolated from other jobs, so you may want to disable support for these by setting the allow_zero_cpus parameter in the cpuset subsystem to *false*.

If you want to allow zero-CPU jobs while ensuring that they don't take up too much of your resources, enable the cpu subsystem.

16.5.3.6.v Excluding CPUs

You can exclude CPUs so that they are not used by jobs by listing them in the exclude_cpus parameter. If the cpuset subsystem is enabled, the CPUs you specify in exclude_cpus are not assigned to jobs. Note, however, that if the cpuset subsystem is disabled, CPUs are still excluded from jobs, but only by reducing the count of CPUs available; you cannot control which CPUs are excluded.

16.5.3.6.vi cpuset Subsystem Configuration Parameters

Table 16-6: cpuset Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled	*true*	*false*	When set to *true*, the hook creates a cpuset for each job, taking into account the number of ncpus and mem resources assigned by the scheduler to this host's vnodes. When set to *false*, the kernel is free to schedule processes and allocate memory based on the system configured policies. See section 16.5.2, “Enabling and Tuning Hook According to Host and/or Vnode Type”, on page 579.
exclude_cpus	*[]*	*[]*	Specifies CPU thread IDs not to be assigned to jobs Format: JSON list Default: Empty list, no CPU thread IDs excluded See section 16.5.3.6.v, “Excluding CPUs”, on page 589
mem_fences	*false*	*false*	When *true*, the cgroups hook sets the cpuset.mems to only the NUMA nodes assigned to the job, preventing other NUMA nodes from satisfying memory requests from the job. When *false*, cpuset.mems encompasses all NUMA nodes present on the host. See section 16.5.3.6.i, “Using Memory Fences for Job Memory Requests”, on page 587
mem_hardwall	*false*	*false*	Specifies whether kernel allocations for file caching should be restricted to the memory nodes in the cpuset. By default, all NUMA nodes can be used for caching files accessed by job processes. When set to *true*, the buffer cache for this job will be constrained to the NUMA nodes listed in cpuset.mems for the job. See section 16.5.3.6.ii, “Using Memory Fences for OS File Caching”, on page 588
memory_spread_page	*false*	*false*	Specifies whether file system buffers should be spread evenly across the memory nodes allocated to the cpuset. By default, no attempt is made to spread memory pages for these buffers evenly, and buffers are placed on the same node on which the process that created them is running. See section 16.5.3.6.iii, “Memory Spreading for OS File Caching”, on page 588
allow_zero_cpus		*true*	Specifies whether zero CPU jobs should be allowed to run or refused when the cpuset subsystem is enabled. See section 16.5.3.6.iv, “Allowing Zero CPU Jobs”, on page 589

16.5.3.7 cpu Subsystem

The cpu subsystem is an alternative way to control which processes get access to CPU resources. It cannot isolate jobs with the precision of the cpuset subsystem, but you can use it in some specific circumstances:

- When you use the cpuset subsystem while allowing zero CPU jobs, but want to ensure that the Linux scheduler favors the jobs requesting one or more CPUs.
- When one of the features you use in PBS does not interoperate well with cpusets, for example when using suspend/resume when both the high-priority workload and the low-priority workload might have jobs that share vnodes. See section 16.8.1, “Interactions Between Suspend/resume and the cpuset Subsystem”, on page 614.
- When you want to overcommit CPU resources (impossible if the CPUs are assigned to jobs via the cpuset subsystem) but still want jobs to get access to CPU resources according to the ncpus requested.

The cpu subsystem implements two different mechanisms:

- Linux scheduler fair sharing, where different shares are assigned to cgroups, according to requested ncpus. If there are CPU resource conflicts, the Linux scheduler favors cgroups that have used less than their allotted share
- Hard quotas that can be enforced if too much CPU usage is detected.

By default this subsystem is disabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, “Hook and Subsystem Enablement Tuning Parameters”, on page 581.

16.5.3.7.i cpu Subsystem Caveats

- The cpu subsystem controls are often imprecise when hyperthreading is enabled, since the Linux kernel CFS scheduler sees each CPU thread as 100% of a CPU, regardless of how slow or fast it runs (which depends on usage of the other threads of the core). When ncpus_are_cores is enabled, quotas are multiplied by the number of threads per core, which can be misleading.
- There is no strict isolation between jobs; the Linux scheduler enforces a quota only on the set of processes, not individual processes. Linux fair sharing is not as efficient as cpusets in isolating jobs from rogue jobs. The cpu subsystem will slow down the rogue job, but since throttling may be uneven, a rogue process may still interfere with other jobs; if the hapless victims belong to a parallel application, that whole application may be affected, including its processes on CPUs where there is no conflict, since these will be forced to wait for the application process that was slowed down.

16.5.3.7.ii cpu Subsystem Configuration Parameters

Table 16-7: cpu Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled		*false*	When set to *true*, the hook creates a cpu subsystem directory for each job, and assigns a number of shares and optionally a quota based on ncpus. When set to *false*, no per-job cgroup is created for this subsystem. See section 16.5.2, "Enabling and Tuning Hook According to Host and/or Vnode Type", on page 579.
cfs_period_us		*100000*	Time in microseconds between periodic checks by the Linux scheduler to compute usage and check quotas. Lowering this makes computation more precise and throttles rogues faster, but uses more OS scheduler overhead, with less CPU resources left for jobs.
cfs_quota_fudge_factor		*1.03*	Sets quota slightly above theoretically valid value. Setting a CPU usage quota to 100% of a CPU still throttles applications, due to rounding errors. The default is appropriate for the default cfs_period_us, but should be raised if cfs_period_us is lowered.
enforce_per_period_quotas		*false*	Specifies whether hard quotas are set. When *false*, only shares are set, and a job can use more CPU resources than it requested provided other jobs leave CPU resources idle. When *true*, hard CPU usage quotas are set
zero_cpus_shares_fraction		*0.002*	Specifies fraction of shares allotted for a CPU to a "zero-CPU" job. The default, *0.002*, is the minimum allowed by the kernel, and ensures that such a job gets CPU resources only if they are left idle by other jobs.
zero_cpus_quota_fraction		*0.2*	Specifies fraction of a CPU allotted to a "zero-CPU" job before it is throttled by its hard quota. Default fraction: *one-fifth of a CPU*

16.5.3.8 devices Subsystem

The devices subsystem is used to grant or restrict access to devices on the system, restricting the job to use specific devices, including GPU and Intel Xeon Phi ("MIC") devices assigned to the job. If MICs and/or GPUs are available in the complex and the devices subsystem is enabled, the PBS cgroups hook creates the nmics and/or ngpus resources if they are not already present.

Since detecting the GPU and/or MIC resources assigned to existing jobs relies on the devices cgroups for these jobs, enable this subsystem if you want the cgroups hook to manage GPU and/or MIC assignments.

For examples of how to use this subsystem, see section 16.5.5, “Managing GPUs or Xeon Phi via Cgroups”, on page 605.

By default this subsystem is disabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, “Hook and Subsystem Enablement Tuning Parameters”, on page 581.

You may want to discover and manage devices on hosts that do not have GPUs. You can speed that process, avoiding a call to `nvidia-smi`, by having the discover_gpus parameter evaluate to *false* for GPU-less hosts in the main section.

Devices such as GPUs are discovered only when the devices subsystem is enabled.

16.5.3.8.i Allowing Access to Devices

The allow parameter specifies how access to devices will be controlled. The list consists of entries in one of the following formats:

- A single string entry, used verbatim. For example:
  - "b *:* rwm" allows full access (read, write, and `mknod`) to all block devices
  - "c *:* rwm" allows full access to all character devices
- A list containing two strings. For example:
  - ["mic/scif","rwm"] looks for the major and minor number of the mic/scif device and allows full access.
  - If `ls /dev/mic` reported

    ```
    "crw-rw-rw- 1 root root 244, 1 Mar 30 14:50 scif"
    ```
    then the line added to the allow file looks like

    ```
    "c 244:1rwm"
    ```
- A list containing three strings. For example:
  - ["nvidiactl","rwm", "*"] looks for the major number of the nvidiactl device and allows full access to all devices with that major number.
  - If `ls /dev/nvidiactl` reported

    ```
    "crw-rw-rw- 1 root root 284, 1 Mar 30 14:50 nvidiactl"
    ```
    then the line added to the allow file looks like

    ```
    "c 284:* rwm"
    ```

16.5.3.8.ii devices Subsystem Configuration Parameters

Table 16-8: devices Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled	*false*	*false*	When set to *true*, the hook configures the devices subsystem based on the number of nmics and ngpus requested by the job. Refer to the allow parameter for additional information. When set to *false*, no cgroup is created for the devices subsystem.
allow	*[* "*b *:* rwm*", "*c *:* rwm*" *]*	*[]*	Specifies how access to devices will be controlled. The list consists of entries in one of the following formats: • A single string entry, used verbatim. Example: "b *:* rwm" • A list containing two strings. Example: ["mic/scif","rwm"] • A list containing three strings. Example: ["nvidiactl","rwm", "*"] See section 16.5.3.8.i, "Allowing Access to Devices", on page 593

16.5.3.9 memory Subsystem

The memory subsystem allows you to monitor and limit the amount of physical memory used by all of the processes of a job on a host.

By default this subsystem is enabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, "Hook and Subsystem Enablement Tuning Parameters", on page 581.

Advantages to enabling the memory subsystem:

- With cgroups, jobs and operating systems are protected from any attempt by a job to use too much memory. Without cgroups, enforcing memory limits relies on monitoring and after-the-fact interventions to kill processes; MoM may not be able to act in time to protect the health of the host from being compromised through excessive memory usage.
- Accurate monitoring and records of memory usage. Without cgroups, memory usage such as resources_used.mem, which is supposed to capture peak usage, relies instead on periodic polling, which can miss the high-water mark.
- The accuracy of memory usage monitoring is unaffected by processes that leave the Linux sessions registered as part of the job; without cgroups, this behavior breaks memory usage accounting when using some precompiled MPI libraries.
- Because memory usage reporting does not depend on polling, MoM can be configured to poll less often, which reduces the load on the PBS datastore.
- Jobs are prevented from rampantly filling host memory with kernel-allocated file cache. Instead, because kernel-allocated file cache for job file access is considered job memory, when the job hits its memory limit, job memory requests are fulfilled by reclaiming file cache allocated by the job earlier, or even by temporarily moving some of the job to swap until this can be done. If necessary, job processes will hang until memory can be allocated without crossing the memory usage limit.
- Recommended: you can reserve enough memory for the operating system and the file cache required for OS services to run well. If you do this, jobs are prevented from starving operating system services of memory resources.

16.5.3.9.i Reserving Memory

If you want to reserve memory so that it is not assigned to jobs, you can set a percent of physical memory using reserve_percent, and add a fixed amount to that using reserve_amount. The reserve_amount parameter sets a specific amount of available physical memory that is not to be assigned to jobs.

Reserving memory decreases the amount of resources_available.mem that MoM advertises to the server as being available for each vnode, as well as the amount of memory the cgroups hook is willing to assign to jobs.

For most HPC compute nodes with a minimum of 32GB, we recommend at least 2GB of memory for the operating system. Since there is no minimum amount of memory specified for a MoM host, the defaults are conservative.

16.5.3.9.ii Effect of Cgroups Hook on the mem Resource

The cgroups hook changes how much memory must be requested for job I/O and accounted in resources_used.mem.

Without the cgroups hook, file content cached in memory need not be included in a job's memory request, and is not accounted for in resources_used.mem. With the cgroups hook, reported memory usage reported includes memory for cached files accessed by the job.

Jobs requesting memory can use that amount both for physical memory and for caching. For example, when using the cgroups hook, a job that requests 20GB and uses 16GB but reads a 50GB file can hold only 4GB of the file in cache at a time. So if a job requires 32GB of application memory but also requires 5GB of private file cache to perform adequately, then it needs to request 37GB.

Memory is accounted accurately with cgroups. For jobs with multiple processes all accessing the same memory, without the cgroups hook the amount of memory reported as used is multiplied by the number of processes, but with the cgroups hook, the memory is only counted once. However, memory usage includes file cache placed into memory by job I/O, but not file cache merely accessed by the job but placed into memory earlier by unrelated processes.

It may be necessary to use other tools to determine application usage not involving file cache instead of resources_used.mem.

Applications using direct I/O to filesystems, meaning they bypass the buffer cache, are unaffected; these jobs do not see a change in resources_used.mem with and without cgroups.

16.5.3.9.iii Assigning a Default Amount of Memory to Jobs

The default parameter is the amount of memory assigned to the job if it doesn't request any memory. Because the scheduler does not know about this allocation, do not make this overly large, otherwise the cgroups hook may reject jobs because there isn't enough available memory. Instead, set large defaults for job memory resource requests (Resource_List.mem, default_chunk.mem, etc.) via a queuejob hook or defaults at the server or queue.

This value is not communicated to the server or scheduler; setting this value has no effect on the job's resource request.

16.5.3.9.iv Managing Use of Swap by Jobs

If your execution nodes have no swap or if you do not want your jobs to be able to swap to disk, set the swappiness parameter to *0* or *false*. In this case you should disable the memsw subsystem.

When this is zero or false, if a job cannot have its memory requests satisfied by claiming free physical memory or reclaiming memory from the page cache, then the Out of Memory killer will step in and kill job processes instead of allowing swap usage.

If you want your jobs to swap only when it is necessary to avoid job failure, and not to proactively move infrequently-used job pages to swap, set the swappiness parameter to *1* or *true*.

You can use the membership tuning tools described in section 16.5.2, “Enabling and Tuning Hook According to Host and/or Vnode Type”, on page 579 to specify swappiness for hosts or vnodes.

Not recommended for HPC workloads: if you set this parameter to larger values such as *60*, the kernel will move infrequently-accessed user pages in order to free memory for file caching. We recommend using larger values only if you have at least as much swap as there is physical memory not assigned to jobs in the memsw subsystem. You can either not enable the memsw subsystem, or enable it but ensure there is enough swap and set reserve_amount in the memsw section to at least the physical memory of the host.

If swappiness is set to 1, make sure you enable the memsw subsystem unless you have an enormous amount of swap. Unless you explicitly set resources_available.swap on a node, the scheduler is unaware of the swap on that node if memsw is disabled. If swappiness is set to 1 and the memsw subsystem is disabled, jobs will swap but without any controls; you can run out of swap, performance can suffer, the OOM killer may kill the wrong process, and you can end up with black hole nodes.

16.5.3.9.v Setting Memory Soft Limits

You can limit whether PBS imposes hard memory limits on job processes.

If you set the soft_limit parameter to *false*, PBS uses hard memory limits which prevent the processes from ever exceeding their requested memory usage. If a job accesses more memory than it has requested, some of the job's memory is moved to swap or the job is killed.

If you set this parameter to *true*, PBS uses soft memory limits; the memory requested by the job is set as a hint to the kernel as to what usage is expected, but no hard limit is enforced; when the kernel experiences memory shortage it uses the limits to select the cgroups from which memory is moved to swap.

16.5.3.9.vi Setting Aside Memory for Kernel Drivers

Some kernel drivers (notably, GPFS or Lustre filesystem) may lower the memory available on the host or NUMA nodes by a small number of MB, typically 32MB or 64MB, after MoM has started.

This may reduce the amount of memory actually available at a vnode to less than the amount the scheduler thinks is available, and if jobs requiring the full amount are scheduled on that vnode, the hook will reject those jobs.

To compensate, you can hide some memory from the server. You set vnode_hidden_mb to for example "32" or "64".

The amount listed in the vnode_hidden_mb parameter lowers the memory advertised to the server when the exechost_startup hook is run, but not the memory that the cgroups hook itself is willing to assign to jobs.

16.5.3.9.vii Using Configuration File Defaults for Memory

If you set the enforce_default parameter to *true*, jobs that don't explicitly request memory are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all memory available to cgroups. By default, this parameter is set to *true*.

16.5.3.9.viii Allowing Whole-host Jobs to Use Available Memory

If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request memory are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the memory available to cgroups. If enforce_default is *false*, exclhost_ignore_default has no meaning. By default, this exclhost_ignore_default is set to *false*.

16.5.3.9.ix memory Subsystem Configuration Parameters

Table 16-9: memory Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled	*true*	*false*	Boolean. When *True*, enables the memory subsystem. See section 16.5.2, "Enabling and Tuning Hook According to Host and/or Vnode Type", on page 579.
default	*"256MB"*	*"0MB"*	Amount of memory assigned to the job if it doesn't request any memory. Recommendation: keep this small. See section 16.5.3.9.iii, "Assigning a Default Amount of Memory to Jobs", on page 595.
swappiness		*1*	Sets the memory.swappiness value for the cgroup. When set to *false* or *0*, jobs are not allowed to use swap. When set to *true* or *1*, kernel is allowed to only swap if absolutely required. When set to larger values, kernel is allowed to proactively swap. Not recommended for HPC workloads. See section 16.5.3.9.iv, "Managing Use of Swap by Jobs", on page 595.
reserve_amount	*"1GB"*	*"0MB"*	A specific amount of available physical memory that is not to be assigned to jobs. The actual amount of memory reserved is reserve_amount plus the amount specified by reserve_percent. See section 16.5.3.9.i, "Reserving Memory", on page 595.
reserve_percent	*"0"*	*"0"*	The percentage of available physical memory that is not to be assigned to jobs. The actual amount of memory reserved is reserve_amount plus the amount specified by reserve_percent. See section 16.5.3.9.i, "Reserving Memory", on page 595.
soft_limit	*false*	*false*	When set to *false*, PBS uses hard memory limits which prevent the processes from ever exceeding their requested memory usage. When set to *true*, PBS uses soft memory limits; the memory requested by the job is set as a hint to the kernel as to what usage is expected, but no hard limit is enforced. See section 16.5.3.9.v, "Setting Memory Soft Limits", on page 596.

Table 16-9: memory Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
vnode_hidden_mb	*"1"*	*"1"*	Amount of memory per vnode to hide from the server but keep available to the hook, to compensate for memory reduction by kernel drivers. See section 16.5.3.9.vi, "Setting Aside Memory for Kernel Drivers", on page 596.
enforce_default	*true*	*"true"*	If you set the enforce_default parameter to *true*, jobs that don't explicitly request memory are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all memory available to cgroups. By default, this parameter is set to *true*.
exclhost_ignore_default	*false*	*"false"*	If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request memory are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the memory available to cgroups. By default, this parameter is set to *false*.

16.5.3.10 memsw Subsystem

The memsw subsystem is part of the memory subsystem. The memsw subsystem lets you specify how you want swap handled within the memory subsystem. The memsw subsystem allows you to monitor and limit swap used by all of the job processes on a host. If a job exceeds the limit, processes associated with that job are killed.

By default this subsystem is disabled. If you want to enable it, check the prerequisites in section 16.5.1.1, "Ensure that Cgroups v1 are Available", on page 578.

You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, "Hook and Subsystem Enablement Tuning Parameters", on page 581.

16.5.3.10.i Effect of memsw Subsystem on the vmem Resource

Enabling the memsw subsystem changes the meaning of vmem to be memory + swap usage instead of the address space of the job processes. Enabling the memsw subsystem also changes how much vmem must be requested and how vmem is accounted in resources_used.vmem. The value of resources_available.vmem at a host or vnode reflects the disk swap that can be assigned to jobs. If there is more than one vnode per NUMA node, swap resources are split equally over the number of NUMA nodes reported.

If this subsystem is enabled, requesting the vmem resource sets a limit for the job's memory plus swap usage. For example, a job requesting -lselect=1:ncpus=16:mem=8GB:vmem=64GB is allowed to use 8GB in physical memory plus 56GB of memory resident in swap.

The value of resources_used.vmem reflects the job's memory plus swap usage across all nodes.

The way physical memory is accounted changes with the cgroups hook; see section 16.5.3.9.ii, "Effect of Cgroups Hook on the mem Resource", on page 595.

16.5.3.10.ii Reserving Swap

If you want to reserve swap so that it is not assigned to jobs, you can set a percent of swap using reserve_percent, and add a fixed amount to that using reserve_amount. The reserve_amount parameter sets a specific amount of swap that is not to be assigned to jobs.

Reserving swap decreases the amount of resources_available.vmem that MoM advertises to the server as being available for each vnode, as well as the amount of vmem the cgroups hook is willing to assign to jobs.

16.5.3.10.iii Computing Requested Swap

When the manage_cgswap parameter is *true*, the cgroups hook can compute the amount of swap a job requests. The hook computes the available swap for each vnode where it runs, and sets this value for the vnode in resources_available.cgswap. The value of resources_available.cgswap is resources_available.vmem - resources_available.mem.

The hook creates the cgswap resource.

To enable cgswap management:

1. Enable the cgroup hook
2. In the memsw section of the hook configuration file, set manage_cgswap to *true* or to a value that evaluates to *true* on the relevant hosts (e.g. by setting it to "vntype in: ignore_default_mem")
3. On the relevant hosts, HUP or restart the MoM (so that the hook computes resources_available.cgswap):
   ```
   killall -HUP pbs_mom
   ```
4. Set the flags for cgswap to "nhm", to make the server manage resources_available.cgswap:
   ```
   qmgr -c "set resource cgswap flag = 'nhm'"
   ```
5. Add "cgswap" to the "resources:" line in `$PBS_HOME/sched_priv/sched_config`
6. HUP the scheduler. On the host where the server runs:
   ```
   killall -HUP pbs_sched
   ```
7. Enable the cgroup hook's queuejob and modifyjob events:
   ```
   qmgr -c "set hook pbs_cgroups event +=queuejob"
   qmgr -c "set hook pbs_cgroups event +=modifyjob"
   ```
8. Examine hook order. If there are other queuejob or modifyjob hooks that set or modify mem or vmem, you might want the cgroups hook queuejob and modifyjob events to run after them.

16.5.3.10.iv Using Configuration File Defaults for Swap

If you set the enforce_default parameter to *true*, jobs that don't explicitly request swap are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all swap available to cgroups. By default, this parameter is set to *true*.

16.5.3.10.v Allowing Whole-host Jobs to Use Available Swap

If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request swap are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the swap available to cgroups. If enforce_default is *false*, exclhost_ignore_default has no meaning. By default, this parameter is set to *false*.

16.5.3.10.vi memsw Subsystem Configuration Parameters

Table 16-10: memsw Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
enabled	*false*		Boolean. When *true*, enables the memsw subsystem. When *false*, the subsystem is disabled, and jobs reaching their memory limit are allowed to use swap in an unrestrained fashion (unless memory.swappiness was set to *0*) until resources are depleted. See section 16.5.2, “Enabling and Tuning Hook According to Host and/or Vnode Type”, on page 579.
default	*"0B"*	*"0"*	Specifies the amount of swap assigned to the job if it doesn't request any vmem or cgswap resource. This value is not communicated to the server or scheduler; setting this value has no effect on the job's resource request.
reserve_amount	*"64MB"*	*"0MB"*	An amount of available swap that is not to be assigned to jobs. The amount reserved is the amount determined by reserve_percent plus reserve_amount. See section 16.5.3.10.ii, “Reserving Swap”, on page 599.
reserve_percent	*"0"*	*"0"*	Percentage of available swap that is not to be assigned to jobs. The amount reserved is the amount determined by reserve_percent plus reserve_amount. See section 16.5.3.10.ii, “Reserving Swap”, on page 599.
manage_cgswap	*false*	*"false"*	Boolean. When set to *true*, the memsw computes how much swap is available and advertises it to the scheduler via resources_available.cgswap.
enforce_default	*true*	*"true"*	If you set the enforce_default parameter to *true*, jobs that don’t explicitly request swap are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all swap available to cgroups. By default, this parameter is set to *true*.
exclhost_ignore_default	*false*	*"false"*	If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request swap are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the swap available to cgroups. By default, this parameter is set to *false*.

16.5.3.10.vii Scheduling on the vmem Resource

To allow the scheduler to take resources_available.vmem and resources_assigned.vmem on nodes and vmem requested by jobs into account when deciding where and when to schedule jobs, list "vmem" on the "resources:" line in `$PBS_HOME/sched_priv/sched_config`.

16.5.3.10.viii Caveat for Swap Limits

When enabling the memsw subsystem in the cgroup hook, manage_rlimit_as should be set to *true*. This way RLIMIT_AS is unlimited unless the job requests pvmem, in which case RLIMIT_AS is set to the value of pvmem.

Without the manage_rlimit_as parameter set to *true*, memory limits are imposed as described in section 5.15.2.4.i, “Job Memory Limit Enforcement on Linux”, on page 309. This address space limit is usually too low.

16.5.3.10.ix Caveat for Jobs that Use Swap

If jobs will use swap, we recommend enabling the memsw subsystem and setting manage_cgswap to *true*.

If you set manage_cgswap to *true*, but disable the queuejob event, make sure that the jobs correctly request mem, vmem, and cgswap.

If manage_cgswap is false, jobs can be submitted requesting only mem and possibly vmem, but you run the risk of running out of swap unless you use the second or third recommendation below.

The cgroups hook prevents a job from using more physical memory than it has requested, which means that a swap shortage cannot always be made up with physical memory.

If the memory and memsw subsystems are enabled, a job can fall into a trap where the scheduler thinks there is enough swap at a host or vnode, but there is not. The reason is that there is no separate resource for swap; resources_available.vmem is the sum of physical memory plus swap.

For example, suppose a node has 64GB of physical memory and 2GB of swap. With no memory reservations in the cgroups hook configuration file, resources_available.mem is approximately 64GB and resources_available.vmem is approximately 66GB.

If you submit a job with -lselect=1:mem=2GB:vmem=10GB, the scheduler sees enough available vmem and enough available mem on the node. But when the job runs, if it does indeed use 10GB of memory, it will fail. The memory cgroup will limit the job memory resident in physical memory to 2GB, but there is only 2GB of swap, so even though there is enough memory plus swap, the job will not be able to use 8GB of swap to make up the remainder of the 10GB.

The hook will try to catch one common case: if the explicitly requested vmem is larger than the requested mem, then nodes without any swap will refuse to run the job; the cgroups hook will reject the request to run the job. Administrators and job submitters must ensure that such jobs do not land on nodes without swap, for example by using resources to tag nodes accordingly and setting the proper requests based on those tags.

To avoid the problem of running out of swap when enabling both memory and memsw:

- Set manage_cgswap to *true*, so that the cgroups hook can manage swap as a separate resource. See section 16.5.3.10.iii, “Computing Requested Swap”, on page 599.
- Set reserve_amount in the memsw section to a value that is equal to resources_available.mem for the host; this makes any job specification safe, but requires that swap resources are larger than the physical memory on the host.
- Do not use jobs that leave a lot of physical memory on the host unrequested if Resource_List.vmem > Resource_List.mem: only use jobs like that when the physical memory cannot fit the job, to use swap as extra memory. This will drastically reduce the amount of swap you need to reserve as not visible to jobs in the configuration file.

16.5.3.11 hugetlb Subsystem

The hugetlb subsystem lets you manage the amount of huge page memory used in a cgroup.

While this subsystem imposes limits on the huge pages that can be used by a job, it does not create huge pages on the different NUMA nodes. That must be done separately, so that the cgroups hook exechost_startup portion can report huge pages available on the different nodes.

You can control how many huge pages you want on a set of nodes dynamically:

```
numactl -m <node list> echo X >/proc/sys/vm/nr_hugepages_mempolicy.
```

You can see the number of huge pages currently available here:

```
/sys/devices/system/node/node[0-9]*/hugepages/
```

The `free_hugepages` and `surplus_hugepages` pseudofiles are read-only.

Writing to `nr_hugepages` tells the system to adjust the number of persistent huge pages on the NUMA node, but if existing memory that is free is too fragmented, it may have to repurpose buffer cache pages for it (which may take time if the pages are dirty and need to be pushed to the filesystem) or even move existing used memory to swap.

By default this subsystem is disabled. You can tune the parameters that modify whether this subsystem is enabled; the parameters, but not their defaults, are listed in section 16.5.2.2.vi, "Hook and Subsystem Enablement Tuning Parameters", on page 581.

16.5.3.11.i Reserving Huge Page Memory

If you want to reserve huge page memory (hpmem) so that it is not assigned to jobs, you can set a percent of huge page memory using reserve_percent, and add a fixed amount to that using reserve_amount. The reserve_amount parameter sets a specific amount of huge page memory that is not to be assigned to jobs.

Reserving huge page memory decreases the amount that MoM advertises to the server as being available for each node, as well as the amount that the cgroups hook is willing to assign to jobs.

16.5.3.11.ii Caveat for hugetlb Subsystem

When a job spans more than one vnode, it may split its allocation of huge page memory across NUMA nodes differently from how PBS assigned the memory. This can lead to other jobs on those NUMA nodes not having enough huge page memory.

You can:

- Use utilities to check whether huge pages are available on the correct NUMA nodes just before you launch applications
- Use a memory-fences-safe workload
- Disable memory fences to allow huge pages to be allocated off-node

16.5.3.11.iii Using Configuration File Defaults for Huge Pages

If you set the enforce_default parameter to *true*, jobs that don't explicitly request huge pages are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all huge pages available to cgroups. By default, this parameter is set to *true*.

16.5.3.11.iv Allowing Whole-host Jobs to Use Available Huge Pages

If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request huge pages are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the huge pages available to cgroups. If enforce_default is *false*, exclhost_ignore_default has no meaning. By default, this parameter is set to *false*.

16.5.3.11.v hugetlb Subsystem Configuration Parameters

Table 16-11: hugetlb Subsystem Configuration Parameters

Parameter Name	Default Value: Config File	Default Value: Hook	Description
default	*0MB*		The amount of huge page memory assigned to the cgroup when the job does not request hpmem.
enabled	*false*		When set to *true*, the hook registers a limit that restricts the amount of hugepage memory processes may access. When set to *false*, no limit is registered. See section 16.5.2, “Enabling and Tuning Hook According to Host and/or Vnode Type”, on page 579.
reserve_amount	*0MB*		An amount of available huge page memory (hpmem) that is not to be assigned to jobs. The amount reserved is the amount determined by reserve_percent plus reserve_amount. See section 16.5.3.11.i, “Reserving Huge Page Memory”, on page 602.
reserve_percent	*0*		The percentage of available huge page memory (hpmem) that is not to be assigned to jobs. The amount reserved is the amount determined by reserve_percent plus reserve_amount. See section 16.5.3.11.i, “Reserving Huge Page Memory”, on page 602
enforce_default	*true*	*"true"*	If you set the enforce_default parameter to *true*, jobs that don’t explicitly request huge pages are bound by the defaults in the cgroups hook configuration file. If you set this to *false*, these jobs have access to all huge pages available to cgroups. By default, this parameter is set to *true*.
exclhost_ignore_default	*false*	*"false"*	If you set the exclhost_ignore_default parameter to *true*, jobs that request the whole host via `-lplace=exclhost` and do not explicitly request huge pages are treated as if enforce_default is false, and not bound by the defaults in the cgroup hook configuration file, so they have access to all of the huge pages available to cgroups. By default, this parameter is set to *false*.

16.5.3.12 Sample Cgroups Hook Configuration File

Here we show a sample cgroups hook configuration file similar to the default configuration file:

```
{
    "enabled"                : "vntype not in: no_cgroups",
    "cgroup_prefix"          : "pbs_jobs",
    "periodic_resc_update"   : true,
    "vnode_per_numa_node":   : false,
    "online_offlined_nodes"  : true,
    "use_hyperthreads"       : true,
"ncpus_are_cores"         : true,
"manage_rlimit_as"        : true,
"discover_gpus"           : true
"cgroup":{
    "cpuacct":{
        "enabled"         : true
    },
    "cpuset":{
        "enabled"         : true,
        "exclude_cpus"    : [0,8],
        "mem_fences"      : false,
        "mem_hardwall"    : false,
        "memory_spread_page"   : true
    },
    "devices":{
        "enabled"         : false,
        "allow":[
            "b*:*rwm",
            "c*:*rwm"
        ]
    }
    "memory":{
        "enabled"         : true,
        "soft_limit"      : false,
        "default"         : "256MB",
        "reserve_percent"  : "0",
        "reserve_amount"   : "1GB",
        "soft_limit"      : "false",
        "vnode_hidden_mb"  : "1",
        "enforce_default"  : "true",
        "exclhost_ignore_default" : "false"
    },
    "memsw":{
        "enabled"         : false,
        "default"         : "256MB",
        "reserve_percent"  : "0",
        "reserve_amount"   : "1GB",
        "manage_cgswap"    : "false",
        "enforce_default"  : "true",
        "exclhost_ignore_default" : "false"
    },
    "hugetlb":{
        "enabled"         : false,
        "default"         : "0MB",
        "reserve_percent"  : "0",
        "reserve_amount"   : "0MB",
            "enforce_default"  : "true",
            "exclhost_ignore_default" : "false"
        }
    }
}
```

16.5.4 Finish Up

16.5.4.1 Enable cgroups hook

The cgroups hook and its default configuration file are already imported. You must enable the cgroups hook as root:

1. Log in as root
2. Enable the cgroups hook on the server host:

```
Qmgr: set hook pbs_cgroups enabled = true
```

16.5.4.2 HUP or Restart MoM

HUP or restart each MoM:

```
kill -HUP <MoM PID>
```

or

```
<path to PBS start/stop script>/pbs restart
```

or

```
systemctl restart pbs
```

16.5.4.3 Enable Use of Resources by the Scheduler

Modify the resources: line in `<sched_priv directory>/sched_config`:

- The nmics and ngpus resources are automatically created, but you have to add them to the `resources`: line in `<sched_priv directory>/sched_config`.
- If you have configured huge page memory, and it is enabled in the cgroups hook, PBS creates the hpmem resource, but you need to add it to the `resources`: line in `<sched_priv directory>/sched_config`.
- If you have configured the memsw subsystem, add "vmem" to the `resources`: line in `<sched_priv directory>/sched_config`.

Set resource flags:

- If the cgroups hook creates the nmics and ngpus resources, you may need to set their flags.You also need to set the flags for the vmem and hpmem resources. Set the flags for the nmics, ngpus, vmem, and hpmem resources to "*nh*":

```
Qmgr: set resource nmics,ngpus,vmem,hpmem flag=nh
```

16.5.5 Managing GPUs or Xeon Phi via Cgroups

Integration with Linux cgroups allows PBS to automatically detect and configure GPUs and Xeon Phi processors. Since some of the details are different, we will proceed by describing the case with GPUs.

16.5.5.1 Managing GPUs via Cgroups

PBS can restrict jobs to specific allocated GPUs. If you set vnode_per_numa_node to *true* in the cgroups hook configuration file, PBS takes advantage of topology and associates GPUs with the closest memory and CPUs in the system.

If GPUs are available in the complex and the devices subsystem is enabled, the PBS cgroups hook creates the ngpus resource if it is not already present, and discovers and sets values for it.

16.5.5.2 Using NVIDIA Multi-Instance GPUs (MIGs)

The NVIDIA Multi-Instance GPU (MIG) feature partitions the GPU into multiple separate GPU instances. PBS recognizes each GPU instance and treats it as a normal GPU. To use the MIG feature, follow the steps in the NVIDIA documentation at https://docs.nvidia.com/datacenter/tesla/mig-user-guide/:

- Enable the MIG feature
- Enable the nv_cap_enable_devfs NVIDIA kernel module parameter
- Create GPU Instances (GIs)
- Create Compute Instances (CIs)

16.5.5.3 Configuration Steps

Here we summarize the configuration steps that allow the cgroups hook to manage your GPUs:

- Modify the `resources`: line in `<sched_priv directory>/sched_config`.

The ngpus resource is automatically created, but you have to add it to the `resources:` line in `<sched_priv directory>/sched_config`.

- Set the flags for the ngpus resource to "*nh*":

  `Qmgr: set resource ngpus flag=nh`

- Export the installed PBS cgroups hook configuration file:

  `qmgr -c "export hook pbs_cgroups application/x-config default" >pbs_cgroups.json`

- Edit this file and change its parameters:
  - If `nvidia-smi` is someplace other than `/usr/bin/nvidia-smi`, add the nvidia-smi global parameter with the absolute path to `nvidia-smi`. Be sure to add the comma to the end of the line. For example:

    ```
    "nvidia-smi"    : "/usr/bin/nvidia/nvidia-smi",
    ```
  - Add the "nvidiactl" value to the allow parameter of the devices subsystem section. Be sure to add the comma to the end of the previous line:

    ```
    "c : rwm",
    ["nvidiactl", "rwm", "*"]
    ```
  - Make sure that the vnode_per_numa_node global parameter is set to *true*
  - Enable the devices subsystem (it is disabled by default); see section 16.5.3.8, "devices Subsystem", on page 592

    ```
    "enabled" : true,
    ```
  - Enable the cpuset subsystem (it is enabled by default); see section 16.5.3.6, "cpuset Subsystem", on page 587

    ```
    "enabled" : true,
    ```
- Read the configuration file back in:

  `qmgr -c "import hook pbs_cgroups application/x-config default pbs_cgroups.json"`

- Enable the cgroups hook:

  `qmgr -c "set hook pbs_cgroups enabled=True"`

- HUP or restart each MoM:

  `kill -HUP <MoM PID>`

  or

  `<path to PBS start/stop script>/pbs restart`

  or

  `systemctl restart pbs`

If device isolation is not enabled for GPUs, the hook assigns devices to jobs, and sets the CUDA_VISIBLE_DEVICES environment variable for processes created as children of MoM according to the devices assigned to the job on the host on which the process runs.

16.5.5.4 Isolating NVIDIA GPUs

For NVIDIA GPU isolation to work, you need to restrict access to only those devices assigned to the job. In the "allow" subsection of the devices section of the configuration file, do not use the broad "c *:* rwm".

Make sure that the "allow" section excludes read and write access for the 195 major number ("c 195:* m"), which is what all NVIDIA devices use. Preserve `mknod` ("m") access, since other software such as the container hook may need "m" access.

You also need to include ["nvidia-uvm", "rwm"], since it is part of how the driver determines isolation, and possibly other global NVIDIA devices used by NVIDIA tools. You may also have to add other devices, such as those required for MPI library access to Infiniband devices.

The cgroups hook assigns the correct NVIDIA GPUs when a job requests ngpus.

Here is an example of the devices section of the cgroups hook configuration file, configured to allow NVIDIA GPU isolation:

```
"devices":{
    "enabled"      : true,
        "allow"    :
        [
            "b *:* m",
            "b 7:* rwm",
            "c *:* m",
            "c 136:* rwm",
            "c 195:* m",
            ["infiniband/rdma_cm", "rwm"],
            ["fuse", "rwm"],
            ["net/tun", "rwm"],
            ["tty", "rwm"],
            ["ptmx", "rwm"],
            ["console", "rwm"],
            ["null", "rwm"],
            ["zero", "rwm"],
            ["full", "rwm"],
            ["random", "rwm"],
            ["urandom", "rwm"],
            ["cpu/0/cpuid", "rwm", "*"],
            ["nvidia-modeset", "rwm"],
            ["nvidia-uvm", "rwm"],
            ["nvidia-uvm-tools", "rwm"],
            ["nvidiactl", "rwm"]
        ]
},
```

Here we detail the block devices with major number 7. On this host, block device 7 are the loop devices. See the manual page for `losetup`:

```
root@mhost:~# ls -l loop*
brw-rw----. 1 root disk 7, 0 May 18 08:22 loop0
brw-r-----. 1 root disk 7, 1 May 18 07:43 loop1
brw-r-----. 1 root disk 7, 10 May 18 07:43 loop10
brw-r-----. 1 root disk 7, 100 May 18 07:43 loop100
brw-r-----. 1 root disk 7, 101 May 18 07:43 loop101
brw-r-----. 1 root disk 7, 102 May 18 07:43 loop102
brw-r-----. 1 root disk 7, 103 May 18 07:43 loop103
brw-r-----. 1 root disk 7, 104 May 18 07:43 loop104
brw-r-----. 1 root disk 7, 105 May 18 07:43 loop105
brw-r-----. 1 root disk 7, 106 May 18 07:43 loop106
brw-r-----. 1 root disk 7, 107 May 18 07:43 loop107
```

Here we detail the 136 device:

```
root@myhost:~# ls -l /dev/pts
crw------- 1 altair tty  136, 0 Jul 22 20:38 0
c--------- 1 root   root   5, 2 Jul 22 19:18 ptmx
```

Here we detail the 195 devices:

```
root@myhost:~# ls -l /dev/nvidia*
crw-rw-rw- 1 root root 195,   0 Jul 22 19:18 /dev/nvidia0
crw-rw-rw- 1 root root 195,   1 Jul 22 19:18 /dev/nvidia1
crw-rw-rw- 1 root root 195,   2 Jul 22 19:18 /dev/nvidia2
crw-rw-rw- 1 root root 195,   3 Jul 22 19:18 /dev/nvidia3
crw-rw-rw- 1 root root 195, 255 Jul 22 19:18 /dev/nvidiactl
crw-rw-rw- 1 root root 195, 254 Jul 22 19:35 /dev/nvidia-modeset
crw-rw-rw- 1 root root 238,   0 Jul 22 19:35 /dev/nvidia-uvm
crw-rw-rw- 1 root root 238,   1 Jul 22 19:35 /dev/nvidia-uvm-tools
```

16.5.5.5 Environment Variables for CUDA and Xeon Phi

When you use Xeon Phi co-processors, PBS sets the OFFLOAD_DEVICES environment variable during job initialization, for each process that is a child of MoM.

When you use CUDA devices, PBS sets the CUDA_VISIBLE_DEVICES environment variable for each process that is a child of MoM.

16.5.5.5.i Using CUDA_VISIBLE_DEVICES with Multihost Jobs

On each host, the correct value for CUDA_VISIBLE_DEVICES references unique identifiers for the GPUs on that host, which means that the value of CUDA_VISIBLE_DEVICES is different on each host of a multihost job. As a result, you cannot just propagate the value of CUDA_VISIBLE_DEVICES visible in the job script to all processes of a multihost job; you need to get the correct value for each host.

PBS sets the correct value for the CUDA_VISIBLE_DEVICES environment variable for the job script on the primary execution host of the job.

For job processes on remote hosts, the CUDA_VISIBLE_DEVICES environment variable is also correctly set if the processes are spawned as children of MoM through the Task Management API (the TM API). To spawn processes through the TM API, you can use `pbs_tmrsh`, or an MPI library that was compiled with TM API support, or an MPI library that was configured to use `pbs_tmrsh` as the remote process launcher; see Chapter 10, "Using MPI with PBS", on page 453.

For other jobs that use an MPI library that does not spawn processes through the TM API (for example HPE MPI, for which remote processes are spawned by array services) or that use other mechanisms such as `ssh`, processes on sister hosts are not children of MoM, and MoM is unable to set the CUDA_VISIBLE_DEVICES environment variable directly for these processes. Processes can use `pbs_attach` to join the job, but `pbs_attach` cannot set environment variables for existing processes.

For these non-MoM-child processes on sister hosts it is necessary to fetch the correct value for the CUDA_VISIBLE_DEVICES environment variable from a file PBS wrote for the job. The location of that file depends on PBS_HOME (or PBS_MOM_HOME if it is set) and the job ID. In the rest of this section we describe how to find the value for CUDA_VISIBLE_DEVICES using PBS_HOME. See examples $PBS_HOME is different and PBS_MOM_HOME is not defined and $PBS_HOME is different and PBS_MOM_HOME is defined.

If PBS_HOME/PBS_MOM_HOME is the same on all hosts for the job, the file that contains the CUDA_VISIBLE_DEVICES is in the same location on each host, and you can pass the location of the file to processes on sister hosts via an environment variable. The PBS_NODEFILE environment variable is set to the path to the file containing the GPU identifiers for CUDA_VISIBLE_DEVICES; see the example `$PBS_HOME` is the same everywhere.

If PBS_HOME may be different on the different hosts:

- Pass the job ID to the sister host(s):
  - Transmit the job ID from the primary execution host to the sister(s):

    On the primary execution host, make sure that `/etc/ssh/ssh_config` contains "SendEnv PBS_JOBID".

    On the sister host(s):
    - Make sure that `/etc/ssh/sshd_config` contains "AcceptEnv PBS_JOBID".
    - Restart `sshd` if necessary.
- On the sister host, look up PBS_HOME in `/etc/pbs.conf` (in a shell process, you can source `/etc/pbs.conf` directly).

Once you know PBS_HOME and PBS_JOBID, you know the name of the file that contains the CUDA_VISIBLE_DEVICES assignment. The file is located at `$PBS_HOME/aux/$PBS_JOBID.env` .

Example 16-3: `$PBS_HOME` is different and PBS_MOM_HOME is not defined

Look in or source `/etc/pbs.conf`. `$PBS_HOME/aux/$PBS_JOBID.env` is the file to read.

If `$PBS_HOME` is `/var/spool/node2`, and $PBS_JOBID is 332.tc72:

```
echo $PBS_HOME/aux/$PBS_JOBID.env
/var/spool/node2/aux/332.tc72.env
cat $PBS_HOME/aux/$PBS_JOBID.env
CUDA_VISIBLE_DEVICES=GPU-232cc436-c5b4-6bd9-c5bc-6820334123d7
CUDA_DEVICE_ORDER=PCI_BUS_ID
```

Example 16-4: `$PBS_HOME` is different and PBS_MOM_HOME is defined

`$PBS_MOM_HOME/aux/$PBS_JOBID.env` is the file to read.

If `$PBS_MOM_HOME` is `/var/spool/node2`, and $PBS_JOBID is 332.tc72:

```
echo $PBS_MOM_HOME/aux/$PBS_JOBID.env
/var/spool/node2/aux/332.tc72.env
cat $PBS_MOM_HOME/aux/$PBS_JOBID.env
CUDA_VISIBLE_DEVICES=GPU-232cc436-c5b4-6bd9-c5bc-6820334123d7
CUDA_DEVICE_ORDER=PCI_BUS_ID
```

Example 16-5: `$PBS_HOME` is the same everywhere

`$PBS_NODEFILE.env` is the file to read.

If `$PBS_HOME` is `/var/spool/node2`, and $PBS_JOBID is 332.tc72:

```
echo $PBS_NODEFILE.env
/var/spool/node2/aux/332.tc72.env
cat $PBS_NODEFILE.env
CUDA_VISIBLE_DEVICES=GPU-232cc436-c5b4-6bd9-c5bc-6820334123d7
CUDA_DEVICE_ORDER=PCI_BUS_ID
```

16.6 Configuring MPI for Cgroups

In order to capture job processes and put their PIDs in cgroups, PBS needs the MPI to tell it about those processes. An MPI that is integrated with PBS does this. You need to make sure that your MPI is integrated with PBS. If you are already using an MPI that is integrated with PBS, you do not need to perform this step. OpenMPI, MVAPICH2, and MPICH behave well if they have been compiled with support for the TM API and linked with the PBS libraries. Intel MPI also behaves well if it has been integrated with PBS.

However, if your MPI uses `ssh` and is not integrated with PBS, you can use `pbs_attach` to capture processes started with `ssh`. In section 10.1, “Integration with MPI”, on page 453, we describe integrating MPIs with PBS. If your MPI is not integrated with PBS, cgroups cannot help you manage spawned processes.

If your MPI is not integrated with PBS, you might notice that jobs are running significantly slower, or jobs are crashing with errors such as "Unable to set CPU", or "Unable to join process"; the MPI may be trying to pin all processes to CPU 0 or crashing.

Wrapping `ssh` is sufficient for all precompiled MPIs to work.

16.6.1 Steps to Integrate MPI with PBS via ssh

The following is a helpful example of integrating MPI with PBS via `ssh`:

- On each host in the PBS complex, edit `/etc/ssh/ssh_config`:
  - Add the following as the last `SendEnv` line, after the other `SendEnv` lines:

    ```
    SendEnv PBS_JOBID
    ```
- On each execution host in the PBS complex, edit `/etc/ssh/sshd_config`:
  - Add the following as the last `AcceptEnv` line, after the other `AcceptEnv` lines:

    ```
    AcceptEnv PBS_JOBID
    ```
- On each host in the PBS complex, restart `sshd`:

  `/etc/init.d/sshd restart`
- On each host in the PBS complex, edit `/etc/ssh/sshrc` to include the following lines:

```
#!/bin/sh
if read proto cookie && [ -n "$DISPLAY" ]; then
        if [ `echo $DISPLAY | cut -c1-10` = 'localhost:' ]; then
                # X11UseLocalhost=yes
                echo add unix:`echo $DISPLAY |
                    cut -c11-` $proto $cookie
        else
                # X11UseLocalhost=no
                echo add $DISPLAY $proto $cookie
        fi | xauth -q -
fi
string=$*
# Make sure the following points to your $PBS_EXEC/bin
pbs_bin="/opt/pbs/bin"
attach_cmd="pbs_attach"
#echo "PBS_JOBID: $PBS_JOBID"
#echo "$*"
if [ -n "$PBS_JOBID" ]; then
    # Check to see whether the command is already calling pbs_attach
    if [ "${string/$attach_cmd}" = "$string" ] ; then
        echo "Attaching $PPID to $PBS_JOBID"
        $pbs_bin/$attach_cmd -j $PBS_JOBID -p $PPID 2> /dev/null
        exit 0
    fi
fi
```

- Test to ensure that it works as expected and PBS can capture PIDs:

  a. Make sure cgroups are enabled

  b. Submit an interactive PBS job

  c. `ssh` into a host belonging to the job and verify that the job process PID was added to the tasks file for the desired subsystem, e.g. `cpuacct/pbspro/<job ID>/tasks`

16.7 Managing Jobs with Cgroups

16.7.1 Requesting Memory

The default amount of memory assigned by cgroups to jobs that do not request it is 256MB. If this value does not work for your site, either change the default value if you need to only slightly more, or assign a default value using a queuejob hook or a server default. See section 16.5.3.9.iii, “Assigning a Default Amount of Memory to Jobs”, on page 595.

16.7.2 Limit Enforcement

When a job is killed due to hitting a cgroup limit, you will see something like the following in the job's `stdout`:

```
mpirun noticed that process rank 0 with PID 115249 on node node0042 exited on signal 9 (Killed).
```

The hook will also attempt to find OOM killer messages in the kernel `dmesg` buffer. If it finds them it prints more specific errors in the MoM log, and in the job's `stderr`, if the cgroup limit violation occurs on the first node.

The messages will contain either "Cgroup memory limit exceeded" or "Cgroup memsw limit exceeded" and will attempt to print the corresponding kernel `dmesg` buffer messages (if found), which usually identify the process that was killed.

16.7.3 Examples of Requesting Cores and Hyperthreads

Assume we have 2-way hyperthreaded processors.

When hyperthreading is enabled on a system and ncpus_are_cores is disabled, each core is associated with two threads. In this case, if a job submitter wants all threads of a hyperthreaded core, they should request ncpus in multiples of *2*.

When hyperthreading is not enabled, or if it is and ncpus_are_cores is enabled, a job submitter should request just the number of cores

For example, a job submitter requests the following on a cluster with 2-way hyperthreaded CPUs on all nodes:

```
-lselect=1:ncpus=2
```

Result:

- If hyperthreading is not enabled, this nets two cores. If the cpuset subsystem is enabled, only the first thread of each core is visible in the job cpuset.
- If hyperthreading is enabled and ncpus_are_cores is enabled, this also nets two cores, with a total of four threads visible in the job's cpuset.
- If hyperthreading is enabled and ncpus_are_cores is disabled, this nets two threads, with an attempt to assign the two threads from a single core; this may not succeed if other jobs on the vnode have requested odd numbers of ncpus.

16.7.4 Spawning Job Processes

When a job process is spawned using `tm_spawn`, the execjob_launch cgroups hook runs. The execjob_launch hook can set environment variables correctly and set per-process limits for the processes.

When a job process is spawned outside of PBS and `pbs_attach` is used to make the process join the job, the execjob_attach cgroups hook runs, but it is unable to set the environment for the job or set per-process limits for the process.

16.8 Caveats and Errors

16.8.1 Interactions Between Suspend/resume and the cpuset Subsystem

The cgroups hook is in general compatible with suspend/resume. But when using preemption via suspend and resume, unless vnodes are allocated exclusively to jobs in the class of preempting jobs, the class of preempted jobs, or both, since the scheduler is unaware of the CPU assignments made by MoM, it is possible for the scheduler to resume a low-priority job even though the job's cpuset still overlaps with that of a running high priority job.

To avoid this, use any of these methods:

- Disable the cpuset subsystem, and use only the cpu controller to limit excessive CPU resource usage by jobs. The lack of CPU isolation may still cause the jobs to interfere on some workloads.

  Also, not using the cpuset subsystem may require you to disable process pinning in your applications to share a vnode between more than one job, to allow the Linux CFS scheduler to move processes to CPU threads that are free.
- Ensure that each job in either the preempting workload or the preempted workload has exclusive access to all vnodes it uses.
- Use one of the recent hook events triggered on job resumption to either reject resumption of a job when a conflict is detected, or to migrate the cpusets to CPUs no longer assigned to active jobs. If migrating the cpuset, take a lock on the cgroups lock file.

16.8.2 Caveats for Shrinking a Job on a Host

If the cpuset subsystem is enabled, ensure that if the cgroups hook helps to shrink a job, no processes are running on the host.

16.8.3 Caveats for Using CUDA

To use CUDA version earlier than 7.0, you must allow access to all devices. Otherwise, the NVIDIA commands will fail. With CUDA 7.0 or greater, you do not need to allow access to all devices.

16.8.4 Do Not Change ncpus When cpuset Subsystem is Enabled

Do not change the value of the ncpus resource from that reported by MoM if the cpuset subsystem is enabled. Otherwise the cgroups hook will attempt to use CPUs that don't exist, and jobs will fail.

16.8.5 Cgroups Hook Prevents Epilogue from Running

If you are running the cgroups hook, any epilogue script will not run. The cgroups hook has an execjob_epilogue event which takes precedence over an epilogue script, so if you are running the cgroups hook, make your epilogue script into an execjob_epilogue hook instead. See section 14.5.2, “Using Hooks for Prologue and Epilogue”, on page 514.

16.8.6 Errors

When a job is trying to access a Xeon Phi device on a vnode, but the device is not accessible by the job cgroup, you will see the following error in the job error output:

```
Error getting SCIF driver version
```

17 Configuring PBS for SELinux

17.1 Overview of PBS Support for MLS-compliant SELinux

With this version of PBS Professional, we offer a separate package named PBSPro_2021.1.0-RHEL7_x86_64_selinux.tar.gz that supports SELinux enforcement mode used with one or more MLS policies on RHEL 7. In this chapter, we describe how to use SELinux PBS only.

17.2 Terminology

In this section, we use the following terms:

DCID	Director of Central Intelligence
MLS	Multi-level Security
PL4	Protection Level 4

17.3 How Support for SELinux Works

17.3.1 Security Context

SELinux PBS collects the security context at the time a request is made, records it in the server, and associates it with a user's job when the job is passed to the MoM. MoMs then use the information to create user processes with the correct context.

17.3.2 Authorization

Job submitters can alter, delete, and hold only those jobs with a security context which matches that of the requester.

PBS managers and operators are expected to have sufficient SELinux privilege to operate on all users' jobs.

17.3.3 Authentication

When authenticating a user, this version of PBS captures the user's SELinux security context, collecting the SELinux user identity, role, type, and MLS levels.

The only supported authentication method when using PBS with SELinux is the default of *resvport*.

17.3.4 Instantiation

When a MoM creates a user process, she creates it with the security context of the user who submitted the job. For each job, PBS records the security context of the job submitter in the security_context job attribute.

17.4 Enforcement of Permissions

PBS does not make the permission decisions required by MLS or DCID PL4. These decisions are made by the SELinux mechanisms delivered with the OS.

17.4.1 Policy Files

Altair supplies policy files describing the permissions for PBS. These files are in SELinux format.

The SELinux policy framework includes the permissions PBS needs to impersonate users. The policy framework is encapsulated in a set of policy files for this product.

SELinux policy files for PBS are located in `$PBS_EXEC/selinux/`. These policy files are the following:

`pbs.fc`

`pbs.if`

`pbs.te`

`pbs_dontaudit.te`

PBS policy files must be inspected and vetted by site security personnel before installation. See section 17.8.3, “Installation Steps”, on page 620.

17.4.2 Location of pbs_mom.pamd File

The `pbs_mom.pamd` file is shipped in `$PBS_EXEC/selinux`.

For polyinstantiation to work properly, copy `$PBS_EXEC/selinux/pbs_mom.pamd` to the `/etc/pam.d/` directory.

17.5 Special Attributes and Directories

`$PBS_EXEC/selinux`

Directory that contains SELinux policy files and miscellaneous data.

security_context

Job attribute. Contains security context of job submitter. Set by PBS to the security context of the job submitter at the time of job submission. Visible to all. If not present when a request is submitted, an error occurs, a server message is logged, and the request is rejected.

Format: String in SELinux format

Default: Unset

17.6 Prerequisites

Because PBS managers and operators may need access to information requiring elevated privilege such as job names or security contexts, PBS requires that PBS managers and operators have sufficient SELinux privilege to operate on all users' jobs.

You can enable SELinux only on RHEL 7 hosts.

17.7 Caveats and Restrictions

- You cannot upgrade from a non-SELinux compliant PBS version to this version; you must do a fresh install.
- This version of PBS cannot interoperate with non-SELinux compliant clients (`qsub`, `qstat`, etc.).
- This version of PBS cannot interoperate with non-SELinux compliant complexes; you cannot do peer scheduling, route jobs, etc.
- You cannot mix compliant and non-compliant daemons
- In order to use SELinux with containers, you will probably need to adjust your site policy.
- The X forwarding that is enabled by PBS does not work with this version of PBS. You may be able to set up X forwarding via normal methods, without the help of PBS. Omit the "-X" `qsub` argument, and forward the DISPLAY information into the job itself.
- If a user runs `qstat` on a non-server host, all jobs are reported regardless of the value of query_other_jobs. To protect against this, set the server's acl_hosts attribute to exclude all non-server hosts:

  set server acl_hosts="-*<non-server host>*,-*<non-server host>*"

  For example:

  ```
  set server acl_hosts ="-submithost1,-submithost2,-submithost3"
  ```

  Set the server's acl_host_enable attribute to *True* to enable restricting host access:

  ```
  set server acl_host_enable=true
  ```
- An SELinux-enabled PBS complex cannot interoperate with non-SELinux-enabled PBS complexes.

17.8 Installing PBS For Use With SELinux

17.8.1 Pre-installation Requirements

- An SELinux run-time environment must be present.
- The SELinux run-time environment must be able to compile and install new policies.
- The site must configure polyinstantiation as needed.
- You must install, start, and stop PBS using an account that is not subject to polyinstantiation.
- If PBS will run on more than one host, you must ensure that the MLS label is passed through and trusted among the PBS peer services. Add the following line to each PBS node's `/etc/netlabels.rules`:

  ```
  map add default address:<site-specific address/mask> protocol:cipsov4,32
  ```

17.8.2 Installing in Non-default Location

The policy files, for example pbs.fc, contain full paths that assume default locations for PBS_HOME, PBS_EXEC, and PBS_CONF_FILE. If you will install PBS in a non-default location, make sure that you set these correctly. We recommend that you review these anyway.

17.8.3 Installation Steps

1. Make sure you are using an account that is not subject to polyinstantiation.
2. Make sure you have sufficient privilege to install a policy.
3. Extract the policy files:
   ```
   # rpm2cpio pbs-<version>.x86_64.rpm | cpio -id './opt/pbs/selinux/pbs*.[fit][cfe]'
   ```
4. Site security personnel inspect the policy files and PBS package.
5. Install the PBS policy module. We provide the following instruction for convenience:
   ```
   # make -f /usr/share/selinux/devel/Makefile && /usr/sbin/semodule -i pbs-mine.pp pbs_dontaudit.pp
   ```
6. Install the PBS package, but do not start PBS:
   ```
   # rpm -i pbspro-server-<version>.el7.x86_64.rpm
   ```
7. Put the PBS PAM module in place. Polyinstantiation is controlled by the PAM session module. You need a PBS PAM module in order to allow pbs_mom to polyinstantiate user jobs.
8. Copy pbs_mom.pamd from $PBS_EXEC/selinux/ on the PBS server installation host to /etc/pam.d/pbs_mom on all execution hosts.
9. Make sure that /etc/pam.d/pbs_mom is readable by all.

17.8.4 Starting SELinux PBS

Use the following instructions to start PBS. Do **not** use the standard instructions for starting PBS. Use the exact instructions below:

```
# systemctl start pbs.service
```

17.8.5 Post-installation Steps

17.8.5.1 Configure Job Privacy

Once PBS has been started, set the query_other_jobs server attribute to *False*.

17.8.5.2 Set Privacy for PBS Logs

Protect the PBS service logs from being read or written by anyone except root. The logs are found here:

```
$PBS_HOME/mom_logs
$PBS_HOME/sched_logs
$PBS_HOME/server_logs
$PBS_HOME/comm_logs
```

Change permissions on the logs:

```
chmod 700 $PBS_HOME/mom_logs $PBS_HOME/sched_logs $PBS_HOME/server_logs $PBS_HOME/comm_logs
```

17.8.6 Configuring Ports Used by PBS

If client commands such as `qstat`, `qsub`, etc., frequently fail with error code 15007, the likely problem is that the port in the 512-1023 range that PBS is trying to use to communicate has other SELinux policy rules set up which prohibit use by PBS.

For example, in this illustration PBS tried to use port 548, which is listed like this in `semanage`:

```
dhcpd_port_t                tcp      547, 548, 647, 847, 7911
dhcpd_port_t                udp      67, 547, 548, 647, 847
```

In our illustration, the audit log shows something like this:

```
type=AVC msg=audit(1437660325.774:5672072): avc:  denied  { name_bind } for  pid=40996
    comm="pbs_iff" src=548 scontext=staff_u:sysadm_r:sysadm_t:s1
    tcontext=system_u:object_r:dhcpd_port_t:s0 tclass=tcp_socket
```

When this happens, you need to let PBS know which ports in the 512 to 1023 range may be used by PBS. Specify at least 128 ports for use by PBS. Use the `semanage` command to appropriately label the ports that are usable by PBS:

```
semanage port -a -t pbsd_iff_port_t -p tcp <port range>
```

See `semanage-port(8)`.

17.9 Configuring PBS for SELinux

17.9.1 Configure File Staging Utilities

PBS needs to use file staging utilities that can preserve security labels when staging files in and out. Files to be used for a job must have the user's context. Copying files without preserving the context results in a file that cannot be used by the job. When copying a local file, MoM automatically preserves the context. You must configure MoM to preserve context when copying remote files. You can use the following option for authenticated file transfer between Linux systems. The `-xattrs` option preserves context:

```
rsync -e ssh -xattrs
```

The following is another option for preserving context:

```
cp --preserve=context
```

MoM performs remote staging using the file transfer methods that you specify, or the default if none is specified. You specify the method you want by putting the path in the PBS_SCP and PBS_RCP variables in `pbs.conf`. First MoM tries the path in PBS_SCP, then the path in PBS_RCP, so put the same path in both. The following is a summary of how to tell MoM to use `rsync`:

- Write a script that passes the desired options and arguments to `rsync`
- Edit `pbs.conf`, and specify the path to the script in PBS_RCP and PBS_SCP
- If the MoM is running, HUP the MoM

17.9.1.1 Steps to Configure Utility

1. Write a wrapper script named `rsync_pbs` that passes all arguments except for the first (`-Brvp` or `-rp`) to `rsync`.

   MoM uses the `-Brvp` flags when calling PBS_SCP, and the `-rp` flags when calling PBS_RCP. The arguments that were being passed, and that you can borrow, are the following:

   $1 `-Brvp` or `-rp`

   $2 path to source

   $3 path to destination

   For example, our script passes all but the first argument to `rsync` as $*. We get rid of the first argument using the `shift` command.

   In `pbs.conf`:

   ```
   PBS_SCP=/usr/bin/rsync_pbs
   ```

   In `/usr/bin/rsync_pbs`:

   ```
   #!/bin/sh
   shift
   /usr/bin/rsync -e ssh -xattrs $*
   ```

2. Configure both PBS_RCP and PBS_SCP with the path to `rsync_pbs`.
3. If the MoM is already running, HUP the MoM.

17.10 Managing an SELinux System

17.10.1 Checking Security Context

PBS writes the security context for a job in its security_context attribute. For example, if you need to compare the security context of jobs and users:

Find job security context:

```
bash-4.2$ qstat -f | grep security
security_context = user_u:user_r:user_t:s3:c1,c2
```

Find user security context:

```
bash-4.2$ id -Z
user_u:user_r:user_t:s3:c1,c2
```

18 Configuring PBS for Containers

18.1 Introduction

PBS supplies a built-in hook that runs jobs and applications inside containers. The hook launches separate container(s) for each job, and runs the job with the same submission or job script commands and environment as it would have outside the container(s). The same job environment variables are exported inside the container(s), and file staging and job output and error files are handled the same way as outside a container.

Users can run multi-vnode, multi-host, and interactive jobs in containers, and PBS tracks resource usage for these jobs. The PBS container(s) use cgroups to constrain the resources that the job can use, track resource usage, and pin and isolate resources. The PBS container(s) use the cgroups hook to assign GPUs correctly; see Chapter 16, "Configuring and Using PBS with Cgroups", on page 573.

When the job finishes, PBS removes the container(s).

Jobs are matched to hosts running container daemons via a custom string array resource, which indicates which container engines are available on each host. You create this resource, and tell the container hook which engines are available on each host by setting the container_resource_name parameter in the hook's configuration file to the name of the custom string array resource. The default for the container_resource_name parameter is "container_engine", so we recommend using that name when you create the resource.

Job submitters can specify the job container image by requesting it or setting the CONTAINER_IMAGE environment variable to the name of the container in which the job should run. A container request in the container_image resource overrides the CONTAINER_IMAGE environment variable. The PBS container hook looks for a container request and monitors job submissions for this environment variable, launches the appropriate container, and starts the job in the container.

You can configure a list of allowed registries, and set a default registry.

PBS can perform a registry login in order to pull from registries that require a login.

You can whitelist specific additional arguments to the container engine by listing them in the container_args_allowed container hook parameter. Job submitters can then specify any of these whitelisted arguments in the PBS_CONTAINER_ARGS environment variable.

You can configure the container hook so that it automatically adds job owners to additional groups inside Docker containers. The hook finds the groups on the execution host where the job owner is already a member, and adds the job owner to these groups inside the container. To do this, set the enable_group_add_arg container hook parameter to *True*. This feature applies only to Docker; Singularity users are automatically added to all groups inside containers. Note that for security, we recommend that you never whitelist the `--group-add` container argument in the container_args_allowed hook configuration parameter.

You can set permissions on files mounted inside containers, for example setting files in a container to be read-only.

18.1.1 Container Engines Used by PBS

A PBS server can create Docker and Singularity containers. Each job can specify which container engine to use, but can use only one container engine. You specify the default container engine by setting the container_resource_default_value parameter in the container hook's configuration file to either "docker" or "singularity". In addition, a user can always run a single-node job in a single Singularity container by prepending their scripts, executables, or commands with the Singularity binary.

18.1.1.1 Using nvidia-docker

PBS can invoke `nvidia-docker` if the `nvidia-docker-cmd` line in the hook's configuration file points to the location of the `nvidia-docker` command, and the job requests ngpus inside its select statement.

18.1.1.2 Caching Singularity Images

When an image is downloaded from the container hub, it is saved on the execution host in the cache path. You can set the cache path in the container_cache_path hook configuration parameter. The default value for this parameter is empty, in which case it is treated as if it is `<user home>/.singularity/cache`.

PBS sets the value of the SINGULARITY_CACHEDIR Singularity environment variable to the value of container_cache_path. See the Singularity documentation for more information on this environment variable.

18.1.2 Container Ports

For single-vnode jobs in Docker containers, job submitters can request ports for applications. The container hook maps requested ports to available ports on the host and returns the mapping. You can define which port ranges are available for containers. The job submitter requests ports by listing comma-separated port numbers in the container_ports job resource. Lists of port numbers must be enclosed in single quotes. The hook sets the job's resources_used.container_ports value to comma-separated *<container port>:<host port>* pairs. For example, a job can request `-l container_ports="'2324,8989'"`, and the hook sets the job's resources_used.container_ports to 2324:8080,8989:32771.

18.1.3 Managing How Files and Directories are Mounted in Containers

18.1.3.1 Setting Permissions on Mounted Files

You can set permissions on the files and directories mounted in both Docker and Singularity containers using the mount_paths container hook configuration parameter. The default value for the mount_paths parameter is *["/etc/passwd", "/etc/group"]*.

You can set multiple mounting paths in the mount_paths parameter. Syntax:

"mount_paths": [<first path spec>, <second path spec>, ... <nth path spec>]

where *<path spec>* can be any of:

- A single filename, indicating that source and target have the same name
- ["<source name>", "<target name>"], indicating no restriction
- ["<source name>", "<target name>", "<restriction>"], specifying restriction on file inside container

When you put more than one element in a path spec, for example both a source and a target, enclose the path spec in square brackets.

Example 18-1: Setting `/etc/passwd` to read-only for a Singularity container:

In the hook configuration file:

```
"mount_paths": [["/etc/passwd","/etc/passwd","ro"]]
```

PBS mounts `/etc/passwd` in the container with the destination `/etc/passwd`, and sets the permissions to *ro* (read-only) on the file inside container.

Example 18-2: Docker: setting multiple mount paths, with restriction

In the hook configuration file, we have two path specifications:

```
"mount_paths": [["/etc/passwd","/etc/passwd","readonly", "bind-propagation=rslave"],
    "/etc/group"]
```

The first path spec is ["/etc/passwd","/etc/passwd","readonly"], and PBS passes the following to Docker:

```
docker --mount type=bind,source=/etc/passwd,target=/etc/passwd,readonly,bind-propaga-
    tion=rslave
```

The second path spec is ["/etc/group"], and PBS passes the following to Docker:

```
docker --mount type=bind,source=/etc/group,target=/etc/group
```

18.1.3.2 Allowing or Disallowing Job Work Directory Inside Container

It may be possible to submit a job from a place that is not sensitive on the submission host, but is sensitive on the compute hosts. You can allow or disallow mounting the job's work directory inside Docker or Singularity containers by setting the value of the mount_jobdir hook configuration parameter. Setting this to *True* enables mounting the job's work directory in containers. The default value of this parameter is *True*.

18.1.4 How PBS Uses Container Registries

You can configure a list of allowed (whitelisted) registries by listing them in the allowed_registries hook configuration parameter. PBS checks each job's registry specification against the whitelist. PBS uses only whitelisted registries. If the specified registry is not whitelisted, PBS rejects the job. If the job submitter does not specify a registry, PBS uses the default registry. You specify the default registry by making it the first entry in the allowed_registries parameter. Set the default registry according to the default container engine you are using (*docker* or *singularity*). For Singularity, set the default based on the value of container_image_source (*docker://* or *library://*).

You can whitelist all registries by including *PBS_ALL* in the list.

The default value for allowed_registries is ["docker.io", "SylabsCloud", "PBS_ALL"].

18.1.5 Registry Credential File

PBS can pull images using job owner registry login credentials; this allows job owners to use images from registries where a login is required. If a registry allows you to pull without logging in, PBS allows this.

PBS stores login credentials in a JSON file, in a directory you specify. Make sure that the hook, which runs as root, can read the file.

Example 18-3: PBS uses the job owner's credentials to pull a container image:

```
qsub -v CONTAINER_IMAGE= myregistry.local/MyImage
```

PBS checks whether "myregistry.local" is included in the allowed_registries parameter.

If "myregistry.local" is included, PBS logs in using the credentials that are listed in `<job owner>/.container/tokens.json` for `myregistry.local`.

If "myregistry.local" is not included, the job is rejected.

18.1.5.1 Registry Credential Filename

The credential filename has this format:

<job owner>/.container/tokens.json

18.1.5.2 Registry Credential File Format

The file contents have this format:

```
{
  "registry1 <URL>/<endpoint>": {
    "user_id" : "<user ID>" , "passwd" : "<generated OAUTH token/password>"
  },

  "registry2 <URL>/<endpoint>": {
    "user_id" : "<user ID>" , "passwd" : "<generated OAUTH token/password>"
  }
}
```

18.1.5.3 Registry Credential File Default Values

registry: default registry (first element in the allowed_registries parameter)

user_id: job owner; if this is empty, PBS tries instead with the job owner ID

passwd: no password

18.1.5.4 Registry Credential File Location

The registry credential file *base path* is the path to where registry credential files are stored, up to but not including `<job owner>/.container/tokens.json`. The default base path to registry credential files is `/home`. You can configure the base path to where registry credential files are stored, by setting the value of the cred_base_path parameter in the hook configuration file.

Example 18-4: You set cred_base_path to "/container/creds/", and your job owner is User1. The full path to the JSON file is:

```
/container/creds/User1/.container/tokens.json
```

18.1.5.5 Docker Examples

Example 18-5: Job submission with image specification:

```
qsub -v CONTAINER_IMAGE=pbsprohub.local/pbsuser/test-image
```

PBS looks for "pbsprohub.local" in the allowed_registries hook configuration parameter. If the registry is whitelisted, PBS looks for login credentials for the pbsprohub.local registry in the `<job owner>/.container/tokens.json` file. PBS logs into the registry and pulls the requested container image.

If the login credentials for the pbsprohub.local registry are not listed in `<job owner>/.container/tokens.json` and the registry does not require a login, PBS skips logging in and pulls the requested container image.

If "pbsprohub.local" is not listed in the allowed_registries configuration parameter, PBS rejects the job.

Example 18-6: Job submission without image specification:

```
qsub -v CONTAINER_IMAGE=pbsprohub.local/centos:7
```

PBS looks for "pbsprohub.local" in the allowed_registries hook configuration parameter. If the registry is whitelisted, PBS looks for login credentials for the pbsprohub.local registry in the `<job owner>/.container/tokens.json file`. PBS logs into the registry and pulls the requested container image.

If "pbsprohub.local" is not listed in allowed_registries, PBS uses the default registry. This can lead to possible failure at runtime.

Example 18-7: Job submission without registry specification:

```
qsub -v CONTAINER_IMAGE=pbsuser/test-image
```

Since no registry is specified, PBS uses the default registry. PBS uses the login credentials if they are listed in `<job owner>/.container/tokens.json`, and pulls `<default registry>/pbsuser/test-image`.

18.1.5.6 Singularity Examples

Example 18-8: Job submission without registry specification:

```
qsub -v CONTAINER_IMAGE=pbsuser/test-image
```

In the hook configuration file:

```
container_image_source = "docker://"
```

Since no registry is specified in the job request, PBS uses the default registry.

PBS uses the container image found at `docker://<default registry>/pbsuser/test-image`, and PBS uses login credentials if they are listed in `<job owner>/.container/tokens.json`.

Example 18-9: Job submission without defined endpoint:

```
qsub -v CONTAINER_IMAGE=pbspro/default/test-image
```

In the hook configuration file:

```
container_image_source = "library://"
```

If "pbspro" is not a defined endpoint, and is not listed in allowed_registries, PBS uses the default registry. Singularity remote endpoints enable secure container sharing. See the Singularity documentation about remote endpoints.

If "pbspro" is a defined endpoint, PBS checks the allowed_registries list, then uses the credentials in `<job owner>/.container/tokens.json`. PBS uses the "pbspro" endpoint, authenticating via the credentials in `<job owner>/.container/tokens.json`, by calling the command "`singularity remote login`".

Example 18-10: Path to image is "shub":

In the hook configuration file:

```
container_image_source = "shub://"
```

Because the Singularity hub is a public repository, PBS does not perform any authorization.

18.2 The PBS Container Hook

PBS has a built-in container hook named "PBS_hpc_container" which does several useful things:

- The `PBS_hpc_container` hook can create Docker and Singularity containers, and it can invoke `nvidia-docker` if it is configured and the job requests ngpus inside the select statement.
- The hook runs for the following events, with these actions:
  - At a queuejob event, the hook adds the name and desired value of the string array resource listing container engines to the job's select statement, if the job does not already specify it. This allows the scheduler to match the job to a host running the selected container daemon.
  - At a queuejob event, the hook checks the allowed_registries parameter. If there are whitelisted registries, it then looks for registry login credentials for the job owner.
  - At an execjob_launch event, the hook launches the job inside the selected container
- The hook starts a container instance from the requested image, and sets up the job's environment. The image is specified via `-lcontainer_image=<container image>` or in the job's CONTAINER_IMAGE environment variable. The hook uses the requested container engine, or if the job does not request a container engine, the hook uses the default set in the container_resource_default_value parameter in the hook's configuration file.
  - The name of the container is the job ID.
  - If the job is interactive, the hook runs the job in the container in interactive mode.
  - If the job has multiple chunks that are scheduled to run on a single host:

    With Docker, the hook runs all of the job's child processes in one container on that host.

    With Singularity, the hook runs each child process in its own container.
  - If the job runs on multiple hosts, the hook ensures that containers created on sister MoMs are network linked to the container running on the primary execution host.
- The hook updates the resources used by the job, and removes the job's container.
- The hook cleans up any orphaned containers left behind by previous jobs on the host.
- The hook can automatically add the job owner to groups in the container; these are the groups on the execution host to which the job owner already belongs.

18.3 Prerequisites

The required container daemon(s) must be running on all hosts where users will run jobs in containers.

18.4 Configuring PBS for Containers

18.4.1 Create Container Resources

1. For the container image name, create a custom string resource named "container_image":
   ```
   Qmgr: create resource container_image type=string,flag=m
   ```
2. For the container port number, create a custom string array resource named "container_ports":
   ```
   Qmgr: create resource container_ports type=string_array,flag=m
   ```
3. Create the custom string array resource that will list the container engines available on each host. We recommend naming it "container_engine":
   ```
   qmgr -c "create resource container_engine type=string_array,flag=mh"
   ```
4. Set the value of the container_engine resource on each host to the list of available container engines:

   qmgr -c "s n node1 resources_available.container_engine=<list of container engines>"

   For example, if you have Docker on node1, and you have both Docker and Singularity on node2:
   ```
   qmgr -c "s n node1 resources_available.container_engine=docker"
   qmgr -c "s n node2 resources_available.container_engine=docker"
   qmgr -c "s n node2 resources_available.container_engine += singularity"
   ```
5. Add the container_engine resource to the `resources:` line in `PBS_HOME/<sched_priv directory>/sched_config`.
6. HUP the scheduler:
   ```
   kill -HUP <scheduler PID>
   ```

18.4.2 Configure PBS Container Hook

The container hook's configuration file allows parameters that are specific to each container engine.

18.4.2.1 Default Configuration File

```
{
    "container_resource_name": "container_engine",
    "container_resource_default_value": "docker",
    "mount_paths": ["/etc/passwd", "/etc/group"],
    "mount_jobdir": true,
    "cred_base_path": "",
    "allowed_registries": ["docker.io", "SylabsCloud", "PBS_ALL"],
    "docker":{
        "container_cmd": "/usr/bin/docker",
        "remove_env_keys": [],
        "port_ranges": [],
        "container_args_allowed": [],
        "enable_group_add_arg": false
    },
    "singularity":{
        "container_cmd": "/usr/local/bin/singularity",
        "container_image_source": "",
        "container_cache_path": "",
        "container_args_allowed": []
    }
}
```

The following table shows the parameters:

Table 18-1: PBS Container Hook Configuration File Parameters

Parameter Name	Default Value	Description
allowed_registries	*[]*	Whitelist of registries PBS is allowed to pull from. Put default registry first; PBS uses this when it cannot find the specified registry. Set this to *PBS_ALL* to allow all registries.
container_args_allowed	*[]*	Whitelist of arguments that job submitters are allowed to pass to container engine via the PBS_CONTAINER_ARGS environment variable. Do not whitelist `--env`, `--entrypoint`, `--group-add`
container_cache_path	*[]*	For Singularity. Path to cache directory on execution host where singularity images are cached.
container_cmd	*/usr/bin/docker*	Path to container command. Can be "/usr/bin/docker" or "/usr/local/bin/singularity"

Table 18-1: PBS Container Hook Configuration File Parameters

Parameter Name	Default Value	Description
container_image_source	*[]*	Singularity only. Can be path to existing container image, or URI of container hub. Optional; job submitters can specify path to image. Example: For an image with the path `/home/user1/singularity_images/centos_latest.sif`, set container_image_source to *["/home/user1/singularity_images/"]* Example Singularity hub: ["shub://"] Example Docker hub where Singularity can fetch an image and convert it to SIF: ["docker://"]
container_resource_default_value	*docker*	Default container engine
container_resource_name	*container_engine*	Name of resource that lists available container engines on each host.
cred_base_path	*[]*	Base path to user login credential file, where credential file is `<user ID>/.container/tokens.json`. Default is empty, in which case PBS uses `/home`.
enable_group_add_arg	*false*	The hook automatically adds the job owner to groups in the container; these are the groups on the execution host to which the job owner already belongs. Applies to Docker only; Singularity automatically adds job owners to all groups.
mount_jobdir	*true*	Boolean for enabling or disabling mounting the job's working directory inside the container
mount_paths	*["/etc/passwd", "/etc/group"]*	Additional paths to mount into container at creation time, with additional options for security. For example ["/opt/mpich"], or [["/etc/passwd","/etc/passwd","ro"]]
nvidia_docker_cmd	None	Path to `nvidia-docker` command
port_ranges	*[]*	Docker only. Comma-separated ranges of ports, for example ["2001-9999","3500-4500","7600-9500"]
remove_env_keys	*[]*	Docker only. List of environment variables not to export to job container

To configure your PBS container hook, export the configuration file, edit it, and re-import it.

1. Export the PBS container hook's configuration file:

   ```
   #qmgr -c "export pbshook PBS_hpc_container application/x-config default" > container_config.json
   ```

2. Set global parameters in the PBS container hook configuration file to match your site. The configuration file must conform to JSON syntax.
   - Set the alllowed_registries parameter to the list of allowed registries. See section 18.1.4, “How PBS Uses Container Registries”, on page 625
   - Set the container_cmd parameter to the path of the container command
   - Set the container_resource_name parameter to the name of the resource that lists available container engines, if you used a name other than "container_engine"
   - Set the container_resource_default_value parameter to the default container engine, if you want it to be different from "docker"
   - Optionally create the credential file(s) `<job owner>/.container/tokens.json` (job submitters may want to do this step)
   - Optionally set the cred_base_path parameter to the credential file path; see section 18.1.5.4, “Registry Credential File Location”, on page 626
   - If using Singularity, optionally set the container_cache_path parameter to the path where Singularity images will be stored. See section 18.1.1.2, “Caching Singularity Images”, on page 624
   - Optionally set the container_image_source parameter
   - Optionally set mount_paths; see section 18.1.3.1, “Setting Permissions on Mounted Files”, on page 624
   - Optionally disallow mounting the job's work directory in containers; see section 18.1.3.2, “Allowing or Disallowing Job Work Directory Inside Container”, on page 625
   - If using `nvidia-docker`, set nvidia_docker_cmd
   - If using Docker, set port_ranges to ranges of allowed ports on hosts
   - Optionally set remove_env_keys
   - Optionally set container_args_allowed to a whitelist of arguments that job submitters can pass to the container engine via the PBS_CONTAINER_ARGS environment variable.
     - Do not include "--entrypoint"; entry points are not supported
     - Do not include "--env"; this is not supported
     - Do not include "--group-add"; this poses security risks
   - Optionally set enable_group_add_arg to *True* so that the hook automatically adds the job owner to groups in the container; these are the groups on the execution host to which the job owner already belongs.

3. For local users and local groups, include `/etc/passwd` and `/etc/group` in mount paths so the image has the host operating system users and groups defined.

4. To configure PBS to use `nvidia-docker`, make sure it is available in the path specified in the `nvidia-docker-cmd` line in the hook configuration file.

We show a sample configuration file here:

```
{
    "container_resource_name": "container_engine",
    "container_resource_default_value": "docker",
    "mount_paths": ["/etc/passwd", "/etc/group"],
    "mount_jobdir": true,
    "cred_base_path": "",
    "allowed_registries": ["docker.io", "SylabsCloud", "PBS_ALL"],
    "docker":{
        "container_cmd": "/usr/bin/docker",
        "remove_env_keys": [],
        "port_ranges": [],
        "container_args_allowed": [],
        "enable_group_add_arg": false
    },
    "singularity":{
        "container_cmd": "/usr/local/bin/singularity",
        "container_image_source": "",
        "container_cache_path": "",
        "container_args_allowed": []
    }
}
```

5. Re-import the PBS container hook's configuration file:

```
#qmgr -c "import pbshook PBS_hpc_container application/x-config default container_config.json"
```

6. Enable the PBS container hook:

```
#qmgr -c "set pbshook PBS_hpc_container enabled=True"
```

18.4.3 Install and Start Container Engines

Install and start Docker and/or Singularity on all hosts where you want to use them. Make sure that users are not part of any Docker groups. Consult documentation for your OS, Docker, and Singularity.

18.4.4 Configure Security Enhancement for Docker

We see a security shortcoming in Docker in the case where multiple users are on the same host, where users can see into each others' containers. We have implemented a security enhancement for this. We allow the job to run inside the container, but we don't add job submitters to the Docker group, and we don't allow job submitters to connect to the Docker container.

Our security enhancement for Docker integration allows jobs to run inside the container, but prevents job submitters from connecting to the Docker container. We use `pbs_container` to accomplish this.

Make `PBS_EXEC/sbin/pbs_container` a part of the Docker group. Set its SGID permissions:

```
chgrp docker PBS_EXEC/sbin/pbs_container
chmod 2755 PBS_EXEC/sbin/pbs_container
```

18.5 Caveats and Restrictions

- To run a shell in a container using anything besides the user's default, the job submitter must specify the shell using the `-S` option to `qsub`.
- Job submitters cannot use old-style resource requests such as `-lncpus` with containers.
- Any entry point in a container is disabled. If job submitters want to run an entry point command, they must include the complete command with its arguments on the command line.
- Make sure that when you are configuring the container hook, if you whitelist any container arguments in the container_args_allowed hook configuration parameter, do not whitelist "--group-add". This would allow job submitters to add themselves to any groups inside the container. Instead, set the enable_group_add_arg hook parameter to *True* so the hook automatically adds the job owner to groups in the container; these are the groups on the execution host to which the job owner already belongs.

18.6 Errors and Logging

Container creation errors are logged in the MoM log files. You can use `tracejob` to display these errors.

19 Accounting

19.1 The Accounting Log File

The PBS server automatically maintains an accounting log file on the server host only.

19.1.1 Name and Location of Accounting Log File

Accounting log files are written on the server host only.

The accounting log filename defaults to `PBS_HOME/server_priv/accounting/ccyymmdd` where *`ccyymmdd`* is the date.

You can place the accounting log files elsewhere by specifying the `-A` option on the `pbs_server` command line.

The argument to the `-A` option is the absolute path to the file to be written. If you specify a null string, the accounting log is not opened and no accounting records are recorded. For example, the following produces no accounting log:

```
pbs_server -A ""
```

19.1.2 Managing the Accounting Log File

If you use the default filename including the date, the server closes the file and opens a new file every day on the first write to the file after midnight.

If you use either the default file or a file named with the `-A` option, the server closes the accounting log upon daemon/service shutdown .and reopens it upon daemon/service startup.

The server closes and reopens the account log file when it receives a SIGHUP signal. This allows you to rename the old log and start recording again on an empty file. For example, if the current date is February 9, 2015 the server will be writing in the file `20150209`. The following actions cause the current accounting file to be renamed `feb9` and the server to close the file and start writing a new `20150209`.

```
cd $PBS_HOME/server_priv/accounting
mv 20150209 feb9
kill -HUP <server PID>
```

19.1.3 Permissions for Accounting Log

The `PBS_HOME/server_priv/accounting` directory is owned by root, and has the following permissions:

```
drwxr-xr-x
```

19.2 Viewing Accounting Information

To see accounting information, you can do any of the following:

- Use the `tracejob` command to print out all accounting information for a job
- Use the `pbs-report` command to generate reports of accounting statistics from accounting files
- Use the PBS Works front-end tool called PBS Analytics
- Look at the accounting files using your favorite editor or viewer

19.2.1 Using the `tracejob` Command

You can use the `tracejob` command to extract the accounting log messages for a specific job and print the messages in chronological order. The `tracejob` command looks at all log files, so if you want to see accounting information only, use the `-l`, `-m`, and `-s` options to filter out scheduler, MoM, and server log messages. You can use `tracejob` to see information about a job that is running or has finished. For accounting information, use the `tracejob` command at the server host.

```
tracejob <job ID>
```

See "tracejob" on page 236 of the PBS Professional Reference Guide for details about using the `tracejob` command.

19.2.1.1 Permissions for the `tracejob` Command

Root privilege is required when using `tracejob` to see accounting information.

19.3 Format of Accounting Log Messages

The PBS accounting log is a text file with each entry terminated by a newline. There is no limit to the size of an entry.

19.3.1 Log Entry Format

The format of a message is:

<logfile date and time>;<record type>;<ID string>;<message text>

where

logfile date and time

Date and time stamp in the format:

mm/dd/yyyy hh:mm:ss

record type

A single character indicating the type of record

ID string

The job or reservation identifier

message text

Message text format is blank-separated *keyword=value* fields.

Message text is ASCII text.

Content depends on the record type.

There is no dependable ordering of the content of each message.

There is no limit to the size of an entry.

19.3.2 Space Characters in String Entries

String entries in the accounting log may contain spaces. Under Linux, you must enclose any strings containing spaces with quotes.

Example 19-1: If the value of the Account_Name attribute is "*Power Users*", the accounting entry should look like this, either because you added the quotes or PBS did:

```
user=pbstest group=None account="Power Users"
```

19.3.2.1 Replacing Space Characters in String Entries

You can specify a replacement for the space character in any accounting string via the `-s` option to the `pbs_server` command by doing the following:

1. Bring up the *Services* dialog box
2. Select *PBS_SERVER*
3. Stop the server
4. In the start parameters, use the `-s` option to specify the replacement
5. Start the server

Example 19-2: To replace space characters with "*%20*", bring up the server with "`-s %20`".

In this example, PBS replaces space characters in string entries with "*%20*":

```
user=pbstest group=None account=Power%20Users
```

If the first character of the replacement string argument to the `-s` option appears in the data string itself, PBS replaces that character with its hex representation prefixed by *%*.

Example 19-3: Given a percent sign in one of our string entries:

```
account=Po%wer Users
```

Since % appears in the data string and our replacement string is "%20", PBS replaces % with its hex representation (%25):

```
account="Po%25wer%20Users"
```

19.4 Types of Accounting Log Records

Accounting records for job arrays and subjobs are the same as for jobs, except that subjobs do not have Q (job entered queue) records. PBS writes different types of accounting records for different events. We list the record types, and describe the triggering event and the contents for each record type.

A

Job was aborted by the server. The *message text* contains the explanation for why the job was aborted.

a

Job was altered via `qalter` or a server hook. The message text is a list of <job attrribute>=<new value> pairs, separated by spaces. This record shows only changes to a job attribute made via `qalter` or a server hook. This record does not show changes made by the server, a scheduler, or when MoM changes resources_used.

B

Reservation record, written at the beginning of a reservation period, for all types of reservations. This record is written when the start time of a confirmed reservation is reached. Possible information includes the following:

Table 19-1: B Record: Reservation Information

Entry	Explanation
Authorized_Groups= *<groups>*	Groups who are and are not authorized to submit jobs to the reservation.
Authorized_Hosts= *<hosts>*	Hosts from which jobs may and may not be submitted to the reservation.
Authorized_Users = *<users>*	Users who are and are not authorized to submit jobs to the reservation.
ctime= *<creation time>*	Timestamp; time at which the reservation was created, in seconds since the epoch.
duration = *<reservation duration>*	The duration specified or computed for the reservation, in seconds.
end= *<end of period>*	Time at which the reservation period is to end, in seconds since the epoch.
name= *<reservation name>*	Reservation name, if reservation creator supplied a name string for the reservation.
nodes= *<vnodes>*	Contents of resv_nodes reservation attribute
owner= *<reservation owner>*	Name of party who submitted the reservation request.
queue= *<queue name>*	Name of the reservation queue.
Resource_List= *<requested resources>*	List of resources requested by the reservation. Resources are listed individually , for example: `Resource_List.ncpus = 16 Resource_List.mem = 1048676kb`
start= *<start of period>*	Time at which the reservation period is to start, in seconds since the epoch.

C

Job was checkpointed and requeued. Not written for a snapshot checkpoint, where the job continues to run.

When a job is checkpointed and requeued, PBS writes a C record in the accounting log. The C record contains the job's exit status. If a job is checkpointed and requeued, the exit status recorded in the accounting record is *-12*.

The C record is written for the following:

- Using the `qhold` command
- Checkpointing and aborting a job

c

After vnode release, the c record shows job information for the upcoming phase. See also the u record, which shows the phase that just finished, and the e record, which shows the final phase. The c record's *message text* field contains the following:

Table 19-2: c Record: Upcoming Phase, After Vnode Release

Entry	Explanation
ctime=*<creation time>*	Timestamp; time at which the job was created, in seconds since the epoch.
etime=*<time when job became eligible to run>*	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "Q" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
exec_host=*<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
exec_vnode=*<vnode_list>*	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode. Parentheses may be missing if the exec_vnode string was entered without them while executing `qrun -H`.
group= *<group name>*	Group name under which the job will execute.
jobname= *<job name>*	Name of the job.
project= *<project name>*	Job's project name at the start of the job.
qtime=*<time>*	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue=*<queue name>*	The name of the queue in which the job resides.
resources_used.<resource name> = <resource value>	List of resources used by the job. Written only when the server can contact the primary execution host MoM, as in when the job is `qrerun`, and only in the case where the job did start running.

Resource_List.<resource name>= *<resource value>*	List of resources requested by the job. Resources are listed individually, for example:
	
	`Resource_List.ncpus =16`
	
	`Resource_List.mem =1048676kb`

run_count=*<count>*	The number of times the job has been executed.
session=<`job` *session ID*>	Session number of job.
start=*<start time>*	Time when job execution started, in seconds since epoch.
user=*<username>*	The user name under which the job will execute.

D

Job or subjob was deleted by request. If a running job is discarded by PBS, PBS writes a D record, but not an E record. The *message text* contains `requestor=<username>@<hostname>` to identify who deleted the job. The D record is written for the following actions:

Table 19-3: D Record Triggers

Action	Result
`qdel` a non-running job	Write record immediately
`qdel -W force` a job	Kill job, then write record after job is deleted
`qdel -W force` a provisioning job	Kill job, then write record after job is deleted
`qdel` a running job	Kill job, then write record when MoM gets back to us
`qrerun` a job	Kill job, then write record after job is requeued
`qdel` a subjob	Kill subjob, then write record after subjob is deleted
PBS discards a running job, for example due to hardware failure, and node_fail_requeue is triggered	Write record and requeue job

E

Job or subjob ended (terminated execution). If a running job is discarded by PBS, PBS writes a D record, but not an E record. The end-of-job accounting record is not written until all of the job's resources are freed. The E record is written for the following actions:

- When a job array finishes (all subjobs are in the X state). For example, [1] and [2] finish, but we delete [3] while it's running, so the job array [] gets an E record.
- After a multi-node job is discarded (deleted) after nodes go down and node_fail_requeue is triggered
- When MoM sends an obit to the server

The E record can include the following:

Table 19-4: E Record: Job End

Entry	Explanation
account= <*account name*>	Written if job has a value for its Account_Name attribute
accounting_id= <*JID value*>	CSA JID, job container ID; value of job's accounting_id attribute
alt_id= <*alternate job ID*>	Optional alternate job identifier.
array_indices=<*array indices*>	Array indices job array was submitted with, if this is a job array. Not reported for subjobs.
ctime= <*creation time*>	Timestamp; time at which the job was created, in seconds since the epoch.
eligible_time= <*eligible time*>	Amount of time job has waited while blocked on resources, in seconds.
end= <*job end time*>	Time in seconds since epoch when this accounting record was written. Includes time to stage out files, delete files, and free job resources. The time for these actions is not included in the walltime recorded for the job.

Table 19-4: E Record: Job End

Entry	Explanation
etime= *<time when job became eligible to run>*	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "*Q*" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
exec_host= *<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
exec_vnode= *<vnodes>*	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode. Parentheses may be missing if the exec_vnode string was entered without them while executing `qrun -H`.
Exit_status= *<exit status>*	The exit status of the job or subjob. See "Job Exit Status Codes" on page 521 in the PBS Professional Administrator's Guide and "Job Array Exit Status", on page 156 of the PBS Professional User's Guide. The exit status of an interactive job is always recorded as 0 (zero), regardless of the actual exit status.
group= *<group name>*	Group name under which the job executed. This is the job's egroup attribute.
jobname= *<job name>*	Name of the job
pcap_accelerator	Power cap for an accelerator. Corresponds to Cray capmc set_power_cap --accel setting.
pcap_node	Power cap for a node. Corresponds to Cray capmc set_power_cap --node setting.
pgov	Cray ALPS reservation setting for CPU throttling corresponding to p-governor.
project= *<project name>*	Job's project name when this record is written
qtime=*<time>*	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue= *<queue name>*	Name of the queue from which the job executed
resources_used.<resource name>= *<resource value>*	Resources used by the job as reported by MoM. Typically includes ncpus, mem, vmem, cput, walltime, cpupercent. walltime does not include suspended time. Some resources get special reporting; see section 19.6.2.2, "Reporting Resources Used by Job", on page 660.
Resource_List.<resource name>= *<resource value>*	List of resources requested by the job. Resources are listed individually, for example: `Resource_List.ncpus =16 Resource_List.mem =1048676kb`
resvID=*<reservation ID>*	ID of reservation job is in, if any
resvname=*<reservation name>*	Name of reservation job is in, if any
run_count=*<count>*	The number of times the job has been executed.

Table 19-4: E Record: Job End

Entry	Explanation
session=*<session ID>*	Session number of job.
start=*<start time>*	Time when job execution started, in seconds since epoch.
user=*<user name>*	The user name under which the job executed. This is the job's euser attribute.

e

For a job whose vnodes were released, the e record shows information for the final phase of the job, after vnodes were released. See also the c record, which shows info for an upcoming phase, and the u record, which shows info for the just-finished phase. The e record's *message text* field contains the following:

Table 19-5: e Record: Final Phase After Vnode Release

Entry	Explanation
ctime=*<creation time>*	Timestamp; time at which the job was created, in seconds since the epoch.
etime=*<time when job became eligible to run>*	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "Q" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
exec_host=*<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
exec_vnode=*<vnode_list>*	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode. Parentheses may be missing if the exec_vnode string was entered without them while executing `qrun -H`.
group= *<group name>*	Group name under which the job will execute.
jobname= *<job name>*	Name of the job.
project= *<project name>*	Job's project name at the start of the job.
qtime=*<time>*	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue=*<queue name>*	The name of the queue in which the job resides.
resources_used.<resource name> = <resource value>	List of resources used by the job. Written only when the server can contact the primary execution host MoM, as in when the job is `qrerun`, and only in the case where the job did start running.

Resource_List.<resource name>= *<resource value>*	List of resources requested by the job. Resources are listed individually, for example:
	`Resource_List.ncpus =16`
	`Resource_List.mem =1048676kb`

run_count=*<count>*	The number of times the job has been executed.

Table 19-5: e Record: Final Phase After Vnode Release

Entry	Explanation
session=<`job` *session ID*>	Session number of job.
start=<*start time*>	Time when job execution started, in seconds since epoch.
user=<*username*>	The user name under which the job will execute.

K

Reservation deleted at request of scheduler or server. The *message text* field contains `requestor=Server@<hostname>` or `requestor=Scheduler@<hostname>` to identify who deleted the resource reservation.

k

Reservation terminated by owner issuing a `pbs_rdel` command. Written for all types of reservations. The *message text* field contains `requestor=<username>@<hostname>` to identify who deleted the reservation.

L

Information about node or socket licenses. Written when the server periodically reports license information from the license server. This line in the log has the following fields:

<Log date>; <record type>; <keyword>; <specification for license>; <hour>; <day>; <month>; <max>

The following table describes each field:

Table 19-6: Licensing Information in Accounting Log

Field	Description
Log date	Date of event
record type	Indicates license info
keyword	license
specification for license	Indicates that this is license info
hour	Number of licenses used in the last hour
day	Number of licenses used in the last day
month	Number of licenses used in the last month
max	Maximum number of licenses ever used. Not dependent on server restarts.

M

Job move record. When a job or job array is moved to another server, PBS writes an M record containing the date, time, record type, job ID, and destination.

Example of an accounting log entry:

```
7/08/2008 16:17:38; M; 97.serverhost1.domain.com; destination=workq@serverhost2
```

When a job array has been moved from one server to another, the subjob accounting records are split between the two servers.

Jobs can be moved to another server for one of the following reasons:

- Moved for peer scheduling
- Moved via the `qmove` command
- Job was submitted to a routing queue, then routed to a destination queue at another server

P

Provisioning starts for job or reservation.

Format: *<Date and time>;<record type>;<job or reservation ID>; <message text>,* where *message text* contains:

- User name
- Group name
- Job or reservation name
- Queue
- List of vnodes that were provisioned, with the AOE that was provisioned
- Provision event (START)
- Start time in seconds since epoch

Example:

```
"01/15/2009 12:34:15;P;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=START start_time=1231928746"
```

p

Provisioning ends for job or reservation. Provisioning can end due to either a successful finish or failure to provision. Format: *<Date and time>;<record type>;<job or reservation ID>; <message text>,* where *message text* contains:

- User name
- Group name
- Job or reservation name
- Queue
- List of vnodes that were provisioned, with the AOE that was provisioned
- Provision event (END)
- Provision status (SUCCESS or FAILURE)
- End time in seconds since epoch

Example printed when job stops provisioning:

```
"01/15/2009 12:34:15;p;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=END status=SUCCESS
   end_time=1231928812"
```

Example printed when provisioning for job failed:

```
"01/15/2009 12:34:15;p;108.mars;user=user1 group=group1 jobname=STDIN queue=workq
   prov_vnode=jupiter:aoe=osimg1+venus:aoe=osimg1 provision_event=END status=FAILURE
   end_time=1231928812"
```

Q

Job entered a queue. Not written for subjobs. PBS writes a new Q record each time the job is routed or moved to a new queue or to the same queue.

The Q record can include the following:

Table 19-7: Q Record: Job Queued

Entry	Explanation
account= <*account name*>	Written if job has a value for its Account_Name attribute
accounting_id= <*JID value*>	CSA JID, job container ID; value of job's accounting_id attribute
array_indices=<*array indices*>	Array indices job array was submitted with, if this is a job array. Not reported for subjobs.
ctime= <*creation time*>	Timestamp; time at which the job was created, in seconds since the epoch.
depend=<*dependencies*>	The job's dependencies, if any
etime= <*time when job became eligible to run*>	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "*Q*" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
group= <*group name*>	Group name under which the job executed. This is the job's egroup attribute.
jobname= <*job name*>	Name of the job
pcap_accelerator	Power cap for an accelerator. Corresponds to Cray capmc set_power_cap --accel setting.
pcap_node	Power cap for a node. Corresponds to Cray capmc set_power_cap --node setting.
pgov	Cray ALPS reservation setting for CPU throttling corresponding to p-governor.
project= <*project name*>	Job's project name when this record is written
qtime=<*time*>	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue= <*queue name*>	Name of the queue from which the job executed
Resource_List.<resource name>= <*resource value*>	List of resources requested by the job. Resources are listed individually, for example: `Resource_List.ncpus =16 Resource_List.mem =1048676kb`
resvID=<*reservation ID*>	ID of reservation job is in, if any
resvname=<*reservation name*>	Name of reservation job is in, if any
user=<*user name*>	The user name under which the job executed. This is the job's euser attribute.

R

Job information written when job is rerun via `qrerun` or node_fail_requeue action, or when MoM is restarted without the `-p` or `-r` options. Not written when job fails to start because the prologue rejects the job. Possible information includes:

Table 19-8: R Record: Job Rerun

Entry	Explanation
account= <*account name*>	Written if job has an "account name" string
accounting_id= <*JID value*>	CSA JID, job container ID
alt_id= <*alternate job ID*>	Optional alternate job identifier.

Table 19-8: R Record: Job Rerun

Entry	Explanation
ctime= *<creation time>*	Timestamp; time at which the job was created, in seconds since the epoch.
eligible_time= *<eligible time>*	Amount of time job has waited while blocked on resources, starting at creation time, in seconds.
end= *<time>*	Time in seconds since epoch when this accounting record was written. Includes time to delete files and free resources.
etime= *<time job became eligible to run>*	Timestamp; time in seconds since epoch when job most recently became eligible to run, i.e. was enqueued in an execution queue and was in the "Q" state. Reset when a job moves queues, or when a job is held then released. Not affected by qaltering.
exec_host= *<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
exec_vnode= *<vnode_list>*	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode. Parentheses may be missing if the exec_vnode string was entered without them while executing `qrun -H`.
Exit_status= *<exit status>*	The exit status of the previous start of the job. See "Job Exit Status Codes" on page 521 in the PBS Professional Administrator's Guide. The exit status of an interactive job is always recorded as 0 (zero), regardless of the actual exit status.
group=*<group name>*	The group name under which the job executed.
jobname=*<job name>*	The name of the job.
project=*<project name>*	The job's project name.
qtime=*<time job was queued>*	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue=*<queue name>*	The name of the queue in which the job is queued.
Resource_List.<resource name>= *<resource value>*	List of resources requested by the job. Resources are listed individually, for example: `Resource_List.ncpus =16 Resource_List.mem =1048676kb`
resources_used.<resource name> = <resource value>	List of resources used by the job. Written only when the server can contact the primary execution host MoM, as in when the job is `qrerun`, and only in the case where the job did start running.
run_count=*<count>*	The number of times the job has been executed.
session=*<session ID>*	Session ID of job.
start=*<start time>*	Time when job execution started most recently, in seconds since epoch.
user=*<user name>*	The user name under which the job executed.

r

Job has been resumed. Format:

<logfile date and time>;<record type>;<job ID string>;

S

Job execution started. The *message text* field contains the following:

Table 19-9: S Record: Job Start

Entry	Explanation
accounting_id= *<accounting string>*	An identifier that is associated with system-generated accounting data. In the case where accounting is CSA, *accounting string* is a job container identifier or JID created for the PBS job.
array_indices=*<array indices>*	Array indices job array was submitted with, if this is a job array. Not reported for subjobs.
ctime= *<creation time>*	Timestamp; time at which the job was created, in seconds since the epoch.
etime= *<time when job became eligible to run>*	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "*Q*" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
exec_host= *<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
group= *<group name>*	Group name under which the job will execute.
jobname= *<job name>*	Name of the job.
pcap_accelerator	Power cap for an accelerator. Corresponds to Cray capmc set_power_cap --accel setting.
pcap_node	Power cap for a node. Corresponds to Cray capmc set_power_cap --node setting.
pgov	Cray ALPS reservation setting for CPU throttling corresponding to p-governor.
project= *<project name>*	Job's project name at the start of the job.
qtime= *<time>*	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue= *<queue name>*	The name of the queue in which the job resides.
resources_assigned.<resource name>= *<resource value>*	**Not** a job attribute; simply a label for reporting job resource assignment. One resource per entry. Includes all allocated consumable resources. Consumable resources include ncpus, mem and vmem by default, and any custom resource defined with the *-n* or *-f* flags. A resource is not listed if the job does not request it directly or inherit it by default from queue or server settings. Actual amount of each resource assigned to the job by PBS. For example, if a job requests one CPU on a multi-vnode machine that has four CPUs per blade/vnode and that vnode is allocated exclusively to the job, even though the job requested one CPU, it is assigned all 4 CPUs.

Resource_List.<resource name>= *<resource value>*	List of resources requested by the job. Resources are listed individually, for example:
	
	`Resource_List.ncpus =16`
	
	`Resource_List.mem =1048676kb`

Table 19-9: S Record: Job Start

Entry	Explanation
resvID=*<reservation ID>*	ID of reservation job is in, if any
resvname=<*reservation name*>	Name of reservation job is in, if any
session= *<job session ID>*	Session number of job.
start=*<start time>*	Time when job execution started, in seconds since epoch.
user= <*username>*	The user name under which the job will execute.

s

A job's vnode request was trimmed via release_nodes() in an execjob_prologue or execjob_launch hook. The job's tolerate_node_failures attribute must be set to *all* or *job_start*. The *s* record shows the new trimmed vnode request. Format: *<date> <time>;s;<job ID>;user=<job owner> group=<group> project=<project> jobname=<job name> queue=<queue name> ctime=<ctime> qtime=<qtime> etime=<etime> start=<start time> exec_host=<exec_host> exec_vnode=<exec_vnode> Resource_List.<resource>=<value> Resource_List.<resource>=<value>...Resource_List.<resource>=<value>*

T

Job was restarted from a checkpoint file.

U

Unconfirmed advance, standing, job-specific ASAP, or maintenance reservation requested.

- For an advance, job-specific ASAP, or maintenance reservation, the *message text* field has this format:

  U:<reservation ID> requestor=<username>@<hostname>
- For a standing reservation, the *message text* field has this format:

  U:<reservation ID>;requestor=<username>@<hostname> recurrence_rule=<recurrence rule> timezone=<time-zone>

  Example: "U;S56.exampleserver;requestor=pbsuser@exampleserver recurrence_rule=FREQ=HOURLY;COUNT=2 timezone=Asia/Kolkata".

u

After vnode release, the u record shows job information for the phase that just finished. See also the c record, which shows the upcoming phase, and the e record, which shows the final phase. The u record's *message text* field contains the following:

Table 19-10: u Record: Phase Just Finished, After Vnode Release

Entry	Explanation
ctime=*<creation time>*	Timestamp; time at which the job was created, in seconds since the epoch.
etime=*<time when job became eligible to run>*	Timestamp; time in seconds since epoch when job became eligible to run, i.e. was enqueued in an execution queue and was in the "Q" state. Reset when a job moves queues, or is held then released. Not affected by qaltering.
exec_host=*<list of hosts and resources>*	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.

Table 19-10: u Record: Phase Just Finished, After Vnode Release

Entry	Explanation
exec_vnode=*<vnode_list>*	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode. Parentheses may be missing if the exec_vnode string was entered without them while executing `qrun -H`.
group= <*group name*>	Group name under which the job will execute.
jobname= <*job name*>	Name of the job.
project= <*project name*>	Job's project name at the start of the job.
qtime=<*time*>	Timestamp; the time that the job entered the current queue, in seconds since epoch.
queue=<*queue name*>	The name of the queue in which the job resides.
resources_used.<resource name> = <resource value>	List of resources used by the job. Written only when the server can contact the primary execution host MoM, as in when the job is `qrerun`, and only in the case where the job did start running.

Resource_List.<resource name>= <*resource value*>	List of resources requested by the job. Resources are listed individually, for example:
	 `Resource_List.ncpus =16`
	 `Resource_List.mem =1048676kb`

run_count=<*count*>	The number of times the job has been executed.
session=<`job` *session ID*>	Session number of job.
start=<*start time*>	Time when job execution started, in seconds since epoch.
user=<*username*>	The user name under which the job will execute.

Y

Reservation confirmed by the scheduler or altered. Written for all types of reservations.

- Advance, job-specific, or maintenance reservations:

  When an advance, job-specific, or maintenance reservation is confirmed for the first time, the Y record has this format:

  > *Y; <reservation ID> requestor=<requestor>@<server> start=<requested start time> end=<requested end time> vnodes=(<allotted vnodes>)*

  Example: "Y; R123.server requestor=Scheduler@svr start=1497264531 end=1497264651 nodes=(node1:ncpus=3)"

  The Y record is written when an advance, job-specific, or maintenance reservation alter request is confirmed. The Y record has the same format as for the first time the reservation is confirmed, but the requested field(s) are updated with new value(s):

  > *Y; <reservation ID> requestor=<requestor>@<server> start=<(new/original) start time> end=<(new/original) end time> nodes=(<allotted vnodes>)*

  Example: "Y; R123.server requestor=root@hostname start=1497264471 end=1497264651 nodes=(node1:ncpus=3)"

- Standing reservations:

  When a standing reservation is confirmed for the first time, the Y record has this format:

Y; <reservation ID> requestor=<requestor>@<server> start=<requested start time> end=<requested end time> nodes=(<allotted vnodes>) count=<count>

The *nodes* field is specific to the first occurrence.

Example: "Y; R123.server requestor=Scheduler@svr start=1497264531 end=1497264651 nodes=(node1:ncpus=3) count=3"

The Y record is written when a standing reservation alter request is confirmed. The Y record has the same format as as for the first time a standing reservation is confirmed, but the requested field(s) are updated with the new value(s), and the index of the next occurrence is appended. The *nodes* field is specific to the occurrence altered:

Y; <reservation ID> requestor=<requestor>@<server> start=<(new/original) start time> end=<(new/original) end time> nodes=(<allotted vnodes>) count=<count> index=<index of the altered occurrence>

Example: "Y; R123.server requestor=root@hostname start=1497264471 end=1497264651 nodes=(node1:ncpus=3) count=3 index=1"

The *allotted vnodes* is the value of the resv_nodes reservation attribute.

The *count* is the value of the reserve_count reservation attribute.

z

Job has been suspended. The *message string* contains the following:

- Values for the job's resources_used attribute
- Values for the job's resources_released attribute. This attribute is populated only when the server's restrict_res_to_release_on_suspend attribute is set; see section 5.9.6.2, “Job Suspension and Resource Usage”, on page 252.

19.4.1 Accounting Records for Job Arrays

Accounting records for job arrays and subjobs are the same as for jobs, except that subjobs do not have Q (job entered queue) records.

When a job array has been moved from one server to another, the subjob accounting records are split between the two servers.

When a job array goes from *Queued* to *Begin* state, we write one S for the whole job array.

The E record is written when a job array finishes. For example, [1] and [2] finish, but we delete [3] while it's running, so the job array gets an E record.

A job array is finished when all subjobs are in the *X* state.

19.5 Timeline for Accounting Messages

19.5.1 Timeline for Job Accounting Messages

The following is a timeline that shows when job and job array attributes and resources are recorded, and when they are written:

Table 19-11: Timeline for Job Accounting Messages

Job/Job Array Lifecycle	Accounting Record
Job is queued	Q
Job is moved	M
Application licenses are checked out	
Any required job-specific staging and execution directories are created	
PBS_JOBDIR and job's jobdir attribute are set to pathname of staging and execution directory	
If necessary, MoM creates job execution directory	
MoM creates temporary directory	
Files are staged in	
Just after job is sent to MoM	S T
primary execution host MoM tells sister MoMs they will run job task(s)	
MoM sets TMPDIR, JOBDIR, and other environment variables in job's environment	
MoM performs hardware-dependent setup: The job's cpusets are created, ALPS reservations are created	
The job script starts	
MoM runs user program	
Job starts an MPI process on sister vnode	
Job is suspended	z
Job is resumed	r
The job script finishes	
The obit is sent to the server	E, e
Any specified file staging out takes place, including `stdout` and `stderr`	
Files staged in or out are deleted	
Any job-specific staging and execution directories are removed	
The job's cpusets are destroyed	
Job files are deleted	E
Application licenses are returned to pool	

Table 19-11: Timeline for Job Accounting Messages

Job/Job Array Lifecycle	Accounting Record
Job is aborted by server	A
Job is checkpointed and held	C
Job is deleted	D
Periodic license information	L
Job is rerun via `qrerun` or node_fail_requeue	R
Job is restarted from a checkpoint file	T
`qdel` a subjob	D
`qrerun` a job	D
`qdel` a provisioning job with force	D
`qdel` any job with force	D
`qdel` a running job: kill job, then write record when MoM gets back to us	D
`qdel` a non-running job: write record now	D
Job array finishes	E
After a job is discarded after nodes go down on multi-vnode job	E
Job vnodes are released	c, u

19.5.2 Where Job Attributes are Recorded

Some accounting entries for job attributes have different names from their attributes. The following table shows the record(s) in which each job attribute is recorded and the entry name:

Table 19-12: Job Attributes in Accounting Records

Job Attribute	Record	Accounting Entry Name
accounting_id	E, Q, R, S	accounting_id
Account_Name	E, Q, R	account
accrue_type		
alt_id	E, R	alt_id
argument_list		
array		
array_id		
array_index		
array_indices_remaining		
array_indices_submitted	E, Q, S	array_indices
array_state_count		

Table 19-12: Job Attributes in Accounting Records

Job Attribute	Record	Accounting Entry Name
block		
Checkpoint		
comment		
create_resv_from_job		
ctime	c, E, e, Q, R, S, u	ctime
depend	Q	depend
egroup	c, E, e, Q, R, S, u	group
eligible_time	E, R	eligible_time
Error_Path		
estimated		
etime	c, E, e, Q, R, S, u	etime
euser	c, E, e, Q, R, S, u	user
executable		
Execution_Time		
exec_host	c, E, e, R, S, u	exec_host
exec_vnode	c, E, e, R, u	exec_vnode
Exit_status	E, R	Exit_status
forward_x11_cookie		
forward_x11_port		
group_list		
hashname		
Hold_Types		
interactive		
jobdir		
Job_Name	c, E, e, Q, R, S, u	jobname
Job_Owner		
job_state		
Join_Path		
Keep_Files		
Mail_Points		
Mail_Users		
mtime		
no_stdio_sockets		

Table 19-12: Job Attributes in Accounting Records

Job Attribute	Record	Accounting Entry Name
Output_Path		
pcap_accelerator	E, Q, S	
pcap_node	E, Q, S	
pgov	E, Q, S	
Priority		
project	c, E, e, Q, R, S, u	project
pset		
pstate		
qtime	c, E, e, Q, R, S, u	qtime
queue	c, E, e, Q, R, S, u	queue
queue_rank		
queue_type		
release_nodes_on_stageout		
Remove_Files		
Rerunable		
resources_released	z	resources_released
resources_used	c, E, e, R, u, z	resources_used
Resource_List	c, E, e, Q, R, S, u	Resource_List
resource_released_list		
run_count	c, E, e, R, u	run_count
run_version		
sandbox		
schedselect		
sched_hint		
server		
session_id	c, E, e, R, S, u	session
Shell_Path_List		
stagein		
stageout		
Stageout_status		
stime	c, E, e, R, S, u	start
Submit_arguments		
substate		

Table 19-12: Job Attributes in Accounting Records

Job Attribute	Record	Accounting Entry Name
sw_index		
tolerate_node_failures		
topjob_ineligible		
umask		
User_List		
Variable_List		

19.5.3 Timeline for Reservation Accounting Messages

The following table shows the timeline for when reservation accounting messages are recorded:

Table 19-13: Timeline for Reservation Accounting Messages

Reservation Lifecycle	Accounting Record
Unconfirmed reservation is created	U
Reservation is confirmed	Y
Reservation period begins	B, Y
Provisioning for reservation begins	P
Provisioning for reservation ends	p
Reservation period ends	F, Y
Reservation is altered	Y
Reservation is deleted by scheduler or server	K
Reservation is deleted by user via `pbs_rdel`	k

19.5.4 Where Reservation Attributes and Info are Recorded

Some accounting entries for reservation attributes have names that are different from their attributes. The following table shows the record(s) in which each reservation attribute is recorded and the entry name:

Table 19-14: Reservation Attributes/Info in Accounting Records

Reservation Attribute/Info	Record	Accounting Entry Name
Account_Name		
Authorized_Groups	B	Authorized_Groups
Authorized_Hosts	B	Authorized_Hosts
Authorized_Users	B	Authorized_Users
ctime	B	ctime

Table 19-14: Reservation Attributes/Info in Accounting Records

Reservation Attribute/Info	Record	Accounting Entry Name
delete_idle_time		
group_list		
hashname		
interactive		
Mail_Points		
Mail_Users		
mtime		
Priority		
queue	B	queue
reservation requestor	K, k, U, Y	requestor
reserve_count	Y	
reserve_duration	B	duration
reserve_end	B, Y	end
reserve_ID	Q	resvID
reserve_index		
reserve_job		
Reserve_Name	B, Q	name resvname
Reserve_Owner	B	owner
reserve_retry		
reserve_rrule	U (standing reservations)	recurrence_rule
reserve_start	B, Y	start
reserve_state		
reserve_substate		
reserve_type		
Resource_List	B	Resource_List
resv_nodes	B, Y	nodes
server		
timezone	U (standing reservation)	timezone
User_List		
Variable_List		

19.5.4.1 Jobs in Reservations

- The job's queue is recorded in its c, E, e, Q, R, S, and u records.
- The job's reservation name and reservation ID are written in its E, Q, and S records.

19.5.5 How MoM Polling Affects Accounting

MoM periodically polls for usage by the jobs running on her host, collects the results, and reports this to the server. When a job exits, she polls again to get the final tally of usage for that job.

Example 19-4: MoM polls the running jobs at times T1, T2, T4, T8, T16, T24, and so on.

The output shown by a `qstat` during the window of time between T8 and T16 shows the resource usage up to T8.

If the `qstat` is done at T17, the output shows usage up through T16. If the job ends at T20, the accounting log (and the final log message, and the email to the user if "`qsub -me`" was used in job submission) contains usage through T20.

The final report does not include the epilogue. The time required for the epilogue is treated as system overhead.

If a job ends between MoM poll cycles, resources_used.<resource name> numbers will be slightly lower than they are in reality. For long-running jobs, the error percentage will be minor.

See section 3.1.2, "Configuring MoM Polling Cycle", on page 36 for details about MoM's polling cycle.

19.6 Resource Accounting

Job resources are recorded in the Q (job queued; Resource_List only), S (job start), R (job rerun), E (job end), c (upcoming phase when job vnodes are released), u (just-finished phase when job vnodes are released), s (vnodes trimmed), e (usage during post-release phase), and z (job suspension) records.

Reservation resources are recorded in the B (reservation start) record.

19.6.1 Accounting Log Resource Entry Formats

When reporting resources in the accounting B, c, E, e, R, S, or u records, there is one entry per resource. Each resource is reported on a separate line.

Values for requested resources are written in the same units as those in the resource requests. Values for resources_used and resources_assigned are written in *kb*. A suffix is always written unless the quantity is measured in bytes.

19.6.2 Job Resource Accounting

The following table shows which job and reservation resources are recorded in the accounting log, and lists the records where they are recorded:

Table 19-15: Job Resources in Accounting Log

Resources	Record	Description

Resource_List	c
	E
	e
	Q
	R
	S
	u
		List of resources requested by the job. Resources are listed individually, for example:
		`Resource_List.ncpus =16`
		`Resource_List.mem =1048676kb`

resources_assigned	S	**Not** a job attribute; simply a label for reporting job resource assignment. One resource per entry. Includes all allocated consumable resources. Consumable resources include ncpus, mem and vmem by default, and any custom resource defined with the *-n* or *-f* flags. A resource is not listed if the job does not request it directly or inherit it by default from queue or server settings. Actual amount of each resource assigned to the job by PBS. For example, if a job requests one CPU on a multi-vnode machine that has four CPUs per blade/vnode and that vnode is allocated exclusively to the job, even though the job requested one CPU, it is assigned all 4 CPUs.
resources_released	z	Listed by vnode, consumable resources that were released when the job was suspended. Populated only when restrict_res_to_release_on_suspend server attribute is set. Set by server.

Table 19-15: Job Resources in Accounting Log

Resources	Record	Description
resources_used	c E e R (when `qrerun`) u z	Resources used by the job as reported by MoM. Typically includes ncpus, mem, vmem, cput, walltime, cpupercent. walltime does not include suspended time.
exec_host	c E e R S u	List of job hosts with host-level, consumable resources allocated from each host. Format: *exec_host=<host A>/<index>*<CPUs> [+<host B>/<index> * <CPUs>]* where *index* is task slot number starting at 0, on that host, and *CPUs* is the number of CPUs assigned to the job, *1* if omitted.
exec_vnode	c E e R u	List of job vnodes with vnode-level, consumable resources from each vnode. Format: *(<vnode A>:<resource name>=<resource amount>:...)+(<vnode B>:<resource name>=<resource amount>:...)* *resource amount* is the amount of that resource allocated from that vnode.

19.6.2.0.i Accounting Log Entries for min_walltime and max_walltime

The Resource_List job attribute contains values for min_walltime and max_walltime. For example, if the following job is submitted:

```
qsub -l min_walltime="00:01:00",max_walltime="05:00:00" -l select=2:ncpus=1 job.sh
```

This is the resulting accounting record:

```
…S……. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18 resources_assigned.ncpus=2
…R……. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18
…E……. Resource_List.max_walltime=05:00:00 Resource_List.min_walltime=00:01:00
    Resource_List.ncpus=2 Resource_List.nodect=2 Resource_List.place=pack
    Resource_List.select=2:ncpus=1 Resource_List.walltime=00:06:18…….
```

19.6.2.1 Reporting Resources Assigned to Job

The value reported in the resources_assigned accounting entry is the amount assigned to a job or that a job prevents other jobs from using, which is different from the amount the job requested or used. For example, if a job requests one CPU on a multi-vnode machine that has four CPUs per blade/vnode and that vnode is allocated exclusively to the job, even though the job requested one CPU, it is assigned all 4 CPUs. In this example, resources_assigned reports 4 CPUs, and resources_used reports 1 CPU.

The resources_assigned accounting entry is reported in the S record.

19.6.2.2 Reporting Resources Used by Job

Consumable job resources actually used by the job are recorded in the job's resources_used attribute. Values for resources_used are reported in the c, E, e, u, and z records, and the R record if the job is rerun, but not when the server loses contact with the primary execution host MoM.

You can use hooks to set values for a job's resources_used attribute for custom resources. These custom resources will appear in the accounting log, along with custom resources that are created or set in hooks. Other custom resources will not appear in the accounting log. See "Setting Job Resources in Hooks" on page 49 in the PBS Professional Hooks Guide.

PBS reports resources_used values for string resources that are created or set in a hook as JSON strings in the E record.

- If MoM returns a JSON object (a Python dictionary), PBS reports it in the E record in single quotes:

  ```
  resources_used.<resource_name> = '{ <MoM JSON item value>, <MoM JSON item value>, <MoM JSON item
      value>, ..}
  ```

  Example: MoM returns { "a":1, "b":2, "c":1,"d": 4} for resources_used.foo_str. We get:

  ```
  resources_used.foo_str='{"a": 1, "b": 2, "c":1,"d": 4}'
  ```

- If MoM returns a value that is not a JSON object, it is reported verbatim in the E record.

  Example: MoM returns "hello" for resources_used.foo_str. We get:

  ```
  resources_used.foo_str="hello"
  ```

19.6.2.3 Freeing Resources

The resources allocated to a job from vnodes are not released until all of those resources have been freed by all MoMs running the job. The end of job accounting record is not written until all of the resources have been freed. The end entry in the job E record includes the time to stage out files, delete files, and free the resources. This does not change the recorded walltime for the job.

19.6.2.4 Releasing Vnodes

When a job's vnodes are released via `pbs_release_nodes`, PBS writes the c and u records, and at the end of the job, PBS writes the e record.

If cgroups support is enabled, and `pbs_release_nodes` is called to release some but not all the vnodes managed by a MoM, resources on those vnodes are released.

19.6.3 Reservation Resource Accounting

The following table shows which reservation resources are recorded in the accounting log, and lists the records where they are recorded:

Table 19-16: Reservation Resources in Accounting Log

Resources	Record	Description
exec_host	B	List of vnodes allocated to the reservation

Resource_List	B	List of resources requested by the reservation. Resources are listed individually as, for example:
		`Resource_List.ncpus = 16`
		`Resource_List.mem = 1048676kb`

resv_nodes	B	Contents of resv_nodes reservation attribute

19.6.4 Platform-specific Resource Accounting Tools

19.6.4.1 Resource Accounting on Cray

Jobs that request only compute nodes are not assigned resources from login nodes. PBS accounting logs do not show any login node resources being used by these jobs.

Jobs that request login nodes are assigned resources from login nodes, and those resources appear in the PBS accounting logs for these jobs.

PBS performs resource accounting on the login nodes, under the control of their MoMs.

19.6.4.1.i Using Cray Resource Utilization Reporting

You can use Cray's Resource Utilization Reporting (RUR) to collect statistics on how compute nodes are used, and then use an execjob_epilogue hook to set custom resource values for each job. These custom resources are recorded in the job's E record. You can get more information on Cray's RUR at http://docs.cray.com. See document S-2393-51.

19.6.4.1.ii Using Comprehensive System Accounting

PBS supports Comprehensive System Accounting (CSA) on Cray machines running CLE 5.2. CSA runs on the compute nodes, under the control of the Cray system.

If CSA is enabled, PBS can request the kernel to write user job accounting data to accounting records. These records can then be used to produce reports for the user.

If PBS finds the CSA shared object libraries, and CSA is enabled, PBS can cause a workload management record to be written for each job. If MoM is configured for CSA support, MoM can issue CSA workload management record requests to the kernel. The kernel writes workload management accounting records associated with the PBS job to the system-wide process accounting file. The default for this file is `/var/csa/day/pacct`.

19.6.4.1.iii CSA Configuration Parameter

pbs_accounting_workload_mgmt <value>

MoM configuration parameter. Controls whether CSA accounting is enabled. The name does not start with a dollar sign. If set to "*1*", "*on*", or "*true*", CSA accounting is enabled. If set to "*0*", "*off*", or "*false*", CSA accounting is disabled. Values are case-insensitive. Default: "*true*"; enabled.

19.6.4.1.iv Requirements for CSA

CSA requires CLE 5.2.

CSA requires CSA support Linux kernel modules.

On the supported platforms, the PBS MoM is CSA-enabled. If CSA workload management and user job accounting are available, PBS can use them.

19.6.4.1.v Configuring MoM for CSA

CSA support is specified in the `pbs_accounting_workload_mgmt` line in MoM's Version 1 configuration file. CSA support is enabled by default; you must explicitly disable it if you want it disabled. If the `pbs_accounting_workload_mgmt` line is absent, CSA is still enabled.

To disable CSA support, modify `$PBS_HOME/mom_priv/config`, by setting `pbs_accounting_workload_mgmt` to *false*, *off*, or *0*.

To enable CSA support, either remove the `pbs_accounting_workload_mgmt` line, or set it to *true*, *on*, or *1*.

After modifying the MoM config file, either restart `pbs_mom` or send it SIGHUP.

19.6.4.1.vi Enabling Kernel CSA Support

In order for CSA user job accounting and workload management accounting requests to be acted on by the kernel, you need to make sure that the parameters CSA_START and WKMG_START in the `/etc/csa.conf` configuration file are set to "*on*" and that the system reflects this. You can check this by running the command:

```
csaswitch -c status
```

To set CSA_START to *"on"*, use the command:

```
csaswitch -c on -n csa
```

To set WKMG_START to *"on"*, use:

```
csaswitch -c on -n wkmg
```

Alternatively, you can use the CSA startup script `/etc/init.d/csa` with the desired argument (*on*/*off*); see the system's man page for `csaswitch` and how it is used in the `/etc/init.d/csa` startup script.

19.6.5 Changing Resource Values Reported in Accounting Logs

You can use an execution hook to set a value for resources_used, and this value is then recorded in the accounting log. Bear in mind that by the time an execjob_end hook runs, it's too late to change the accounting log; it's already written.

19.7 Options, Attributes, and Parameters Affecting Accounting

19.7.1 Options to `pbs_server` Command

-A <*accounting file*>

Specifies an absolute path name for the file to use as the accounting file. If not specified, the file is named for the current date in the `PBS_HOME/server_priv/accounting` directory.

Format: *String*

19.7.2 Options to `qsub` Command

-A <*accounting string*>

Accounting string associated with the job. Used for labeling accounting data and/or fairshare. Sets job's Account_Name attribute to <accounting string>.

Format: *String*

-W release_nodes_on_stageout=<value>

When set to *True*, all of the job's vnodes are released when stageout begins.

Cannot be used with vnodes tied to Cray X* series systems.

When the cgroups hook is enabled and this is used with some but not all vnodes from one MoM, resources on those vnodes that are part of a cgroup are not released until the entire cgroup is released.

The job's stageout attribute must be set for the release_nodes_on_stageout attribute to take effect.

19.7.3 Options to `qalter` Command

-A <*new accounting string*>

Replaces the accounting string associated with the job. Used for labeling accounting data and/or fairshare. Sets job's Account_Name attribute to <*new accounting string*>. This attribute cannot be altered once the job has begun execution.

Format: *String*

-W release_nodes_on_stageout=<value>

When set to *True*, all of the job's vnodes are released when stageout begins.

Cannot be used with vnodes tied to Cray X* series systems.

When cgroups is enabled and this is used with some but not all vnodes from one MoM, resources on those vnodes that are part of a cgroup are not released until the entire cgroup is released.

The job's stageout attribute must be set for the release_nodes_on_stageout attribute to take effect.

19.7.4 Job Attributes

Account_Name

PBS jobs have an attribute called Account_Name. You can use it however you want; PBS does not interpret it.

PBS does not use this accounting string by default. However, you can tell PBS to use the job's accounting string as the owner of the job for fairshare purposes. See section 4.9.19, "Using Fairshare", on page 140. PBS accepts the string passed by the shell as is.

Any character is allowed if the string is enclosed in single or double quotes. When you specify this string on the command line to a PBS utility or in a directive in a PBS job script, escape any embedded white space by enclosing the string in quotes.

You can set the initial value of a job's Account_Name attribute via the `-A <account string>` option to `qsub`. You can change the value of a job's Account_Name attribute via the `-A <new account string>` option to `qalter`.

Can be read and set by user, Operator, Manager.

Format: String that can contain any character

Default value: none.

Python attribute value type: *str*

accounting_id

Accounting ID for tracking accounting data not produced by PBS. May be used for a CSA job ID or job container ID.

Can be read by User, Operator, Manager.

No default value.

Format: *String*

Python attribute value type: *str*

alt_id

For a few systems, the session ID is insufficient to track which processes belong to the job. Where a different identifier is required, it is recorded in this attribute. If set, it is recorded in the end-of-job accounting record. May contain white spaces.

On Windows, holds PBS home directory.

Can be read by User, Operator, Manager.

No default value.

Format: *String*

Python attribute value type: *str*

release_nodes_on_stageout

When set to *True*, all of the job's vnodes are released when stageout begins.

Cannot be used with vnodes tied to Cray X* series systems.

When the cgroups hook is enabled and this is used with some but not all vnodes from one MoM, resources on those vnodes that are part of a cgroup are not released until the entire cgroup is released.

19.7.5 MoM Parameters

$logevent <*mask*>

Sets the mask that determines which event types are logged by `pbs_mom`. To include all debug events, use *0xffffffff*. See "Log Levels" on page 549 of the PBS Professional Reference Guide.

19.7.5.1 Cray-only MoM Initialization Values

pbs_accounting_workload_mgmt <*value*>

Controls whether CSA accounting is enabled. Name does not start with dollar sign. If set to "*1*", "*on*", or "*true*", CSA accounting is enabled. If set to "*0*", "*off*", or "*false*", accounting is disabled.

Default: "*true*"; enabled.

19.8 Accounting Caveats and Advice

If you use the cgroups hook to manage subsystems and create child vnodes, you get accurate accounting. If not, accuracy depends on whether or not your MPI is integrated with PBS.

19.8.1 Integrate MPIs for Accurate Accounting

PBS Professional is integrated with several implementations of MPI. When PBS is integrated with an MPI, PBS can track resource usage, control jobs, clean up job processes, and perform accounting for all of the tasks run under the MPI.

When PBS is not integrated with an MPI, PBS can track resource usage, clean up processes, and perform accounting only for processes running on the primary host. This means that accounting and tracking of CPU time and memory aren't accurate, and job processes on sister hosts cannot be signaled.

Follow the steps in section 10.1, “Integration with MPI”, on page 453.

19.8.2 MPI Integration under Windows

Under Windows, some MPIs such as MPICH are not integrated with PBS. With non-integrated MPIs, PBS is limited to tracking resources, signaling jobs, and performing accounting only for job processes on the primary vnode.

19.8.3 Using Hooks for Accounting

19.8.3.1 Use Hooks to Record Job Information

For each job, you can use execjob_prologue, execjob_epilogue, or exechost_periodic hooks to set resources_used values for custom resources, which are then recorded in the job's E record.

19.8.3.2 Use Hooks to Manage Job Accounting String

You can use a hook to assign the correct value for each job's Account_Name attribute. This can be useful both for your accounting records and if you use the job's Account_Name attribute as the job's owner for fairshare. See the PBS Professional Hooks Guide and section 4.9.19, “Using Fairshare”, on page 140.

20
Mixed Linux-Windows Operation

20.1 Introduction to Mixed Linux-Windows Operation

You can add Windows execution and client hosts to a Linux PBS complex, creating a *mixed-mode complex*. These Windows hosts must be in an Active Directory domain. Linux systems must use MUNGE rather than reserved-port authentication, and Windows users must be active directory users. Communication should be encrypted using TLS for improved security. The server needs to authenticate both Linux and Windows users. We describe how to set up a mixed-mode complex in this section.

On Windows, MoM automatically sets resources_available.arch to "windows" for the local vnode. Users submitting Windows jobs must request Windows hosts by specifying "windows" for the arch resource. For example:

```
qsub -lselect=1:arch=windows ...
```

Users submitting Windows jobs must cache their passwords at each execution and client host before submitting jobs, and each time their password changes. Job submitters use the pbs_login command to cache their passwords.

20.1.1 Caveats for Mixed Linux-Windows Operation

- You cannot submit a Linux job from a Windows client
- Group limits are not enforced for Windows jobs; for example, "set queue max_queued_res.ncpus = [g:<group name> = <limit>]" has no effect

20.2 Configuration

1. Start with a normal working Linux PBS complex. See the *PBS Professional Installation & Upgrade Guide*.

20.2.1 Configure Authentication

1. Configure MUNGE authentication for Linux clients and pwd for Windows clients.

   The default reserved-port (resvport) method is not secure for mixed-mode operation, because Windows does not have a concept of reserved ports. Follow the instructions in section 8.4, “Authentication for Daemons & Users”, on page 380. After you have integrated MUNGE, put this in the server's /etc/pbs.conf file:

   ```
   PBS_SUPPORTED_AUTH_METHODS=munge, pwd
   ```

2. Restart the PBS daemons. On each Linux host:

   ```
   systemctl restart pbs
   ```

or

```
<path to start/stop script> pbs restart
```

3. Make sure that you can submit jobs and that hooks work.

20.2.2 Windows Hosts and Users in Active Directory Domain

1. Make sure the new Windows execution and client hosts are part of the same Windows Active Directory domain.
2. Make sure that Active Directory Authentication works: verify that the users added to the AD domain can log in to all the Windows hosts.

20.2.3 Allow Linux Authentication of Windows Active Domain Users

You can use various methods to allow Linux hosts to authenticate Windows Active Domain users. We show an example using SSSD here.

1. On the Linux host running the server, and any hosts running extra comms, configure `sssd` so that the users of the Windows domain can log in to the Linux host on which `pbs_server` and `sssd` run. For an example, see section 8.4.5, "Configuring SSSD", on page 382. For information on configuring `sssd`, see https://access.redhat.com/documentation/en-us/red_hat_enterprise_linux/7/html-single/windows_integration_guide/index#sssd-ad-proc and https://access.redhat.com/articles/3023951.

   If you want the Linux host to automatically create a home directory for an Active Directory user if that home directory does not exist at login, you may have to set SELinux to permissive mode. This is optional.
2. Verify that `sssd` is correctly configured.
   a. Run the following commands:
      ```
      id <username>
      su - <username>
      <password>
      ```
   b. As a Windows domain user, `ssh` to the Linux host running `sssd`

20.2.4 Configure User Authorization

We recommend setting flatuid to *False* for the PBS complex, so that users need a `.rhosts` file to enable authorization. For example, to configure the `.rhosts` file so that user User1 can submit jobs from submission host Winclient1, make sure that there is a file named `.rhosts` in User1's home directory on the server host, and that this file contains the following entry:

```
Winclient1 User1
```

20.2.5 Install PBS on Windows Hosts

1. Install MoMs on your Windows execution hosts, and install the PBS client commands on your Windows client hosts. See section 3.7, "Installing PBS on Windows Hosts", on page 37.
2. Configure the remote file copy mechanism to be used by Windows execution hosts:
   - If you will use `scp` for your remote file copy mechanism, configure passwordless `ssh`; see section 15.6.7.1, "Enabling Passwordless Authentication", on page 567.
   - If you will use the $usecp MoM parameter to specify your remote file copy mechanism, you do not need to configure passwordless `ssh`, unless it is required by the MPI implementation you are using.
3. Create the parent vnode for each Windows host; see section 3.3.3, "Creating the Parent Vnode", on page 42:

```
qmgr -c "create node <name of parent vnode>"
```

20.2.6 Set Up TLS Encryption

Configure TLS encryption for daemon-daemon communication. For Windows authentication to work securely, we strongly recommend using TLS encryption in the complex. To set up TLS encryption, we need a CA certificate and TLS certificate key pair generated from any system with `openssl` set up. We will use the same key pair on all the server and comm hosts. For an example of how to configure PBS for TLS encryption, see section 8.5.2.2, "Example of Configuring PBS for TLS Encryption", on page 390.

20.3 Troubleshooting Mixed Linux-Windows Complex

- Job comment contains "failed to Impersonate Logged On User on <hostname>:job has bad password"

  The user might not be allowed to log on locally according to the local or global policy settings; MoM is unable to impersonate the job submitter in order to run the job. Check the Windows policy settings; make sure the user is allowed to log in to the execution host.
- Failed to send auth request

  ```
  auth: error returned: 15029
  auth: Failed to send auth request
  No support for requested service.
  cannot connect to server pbsserver3 (errno=15029)
  ```

  Check whether the server's PBS_SUPPORTED_AUTH_METHOD parameter includes pwd; add it if not. Restart the server and try again.
- User not known to the underlying authentication module

  ```
  auth: error returned: 15019
  auth: PAM authentication failed for testuser2 with error: User not known to the underlying
      authentication module
  ```

When this error occurs despite testuser2 existing and giving the correct password, it may be due to SSSD settings. One reason could be that 'use_fully_qualified_domain' is *True* in the SSSD settings. Change that to *False* and verify that the user can log in from the server using the following commands, in our example:

```
id username:
[pbsadmin@pbsserver3 ~]$ id testuser4
uid=775213102(testuser4) gid=775200513(domain users) groups=775200513(domain users)
su  - username:
[pbsadmin@pbsserver3 ~]$ su - testuser2
Password:
Last login: Mon Apr 20 13:40:32 UTC 2020 on pts/1
[testuser2@pbsserver3 ~]$
```

- Windows MoM fails to register

  After installing `pbs_mom` on Windows and executing `win_postinstall.py`, even though the postinstall script completes successfully, the server still shows state of the new Windows vnode as "state-unknown, down". In the comm logs there are repeated messages of authentication failure for the service account.

  Check for and delete a stale password file named ".pbs_cred.CR" from the home directory of the PBS service account used to run the Windows MoM.

- Vnode does not go to *free* state, and the following error message appears in the server logs

```
init_pam;libpam.so not found
validate_auth_data;Failed to initialize the library
tcp_pre_process;Failed to initialize the library
wait_request;process socket failed
```

  Check whether the `pam` library is installed. If it is installed, make sure that the PATH variable points to the location where the library is installed. The library name might be libpam.so.*. In this case, create a soft link to the library as shown in the example below:

```
ln -s /usr/lib64/libpam.so.0.83.1 /usr/lib64/libpam.so
```

- Files fail to stage out using `scp.exe` from `C:\Windows\System32\OpenSSH`

  With OpenSSH (`scp.exe`) installed in the `C:\Windows\System32` folder, stage out failures are observed as shown:

```
12/27/2019 00:25:58;0100;PBS_stage_file;Job;11.mixlin;User pbsuser passworded
12/27/2019 00:25:58;0080;PBS_stage_file;Job;sys_copy;CreateProcessAsUser(928,
    C:/Windows/System32/OpenSSH-Win64/scp.exe -Brv \PROGRA~2\PBS\home\spool\11.mixlin.OU
    "pbsuser@mixlin:/home/pbsuser/STDIN.o11") under acct pbsuser
    wdir=C:\Users\pbsuser\Documents\PBS Pro}}
12/27/2019 00:25:58;0080;PBS_stage_file;Fil;sys_copy;command:
    C:/Windows/System32/OpenSSH-Win64/scp.exe -Brv C:/PROGRA~2/PBS/home/spool/11.mixlin.OU
    pbsuser@mixlin:/home/pbsuser/STDIN.o11 status=10002, try=1
```

  This is caused by Windows WOW64 filesystem redirection, since PBS is a 32-bit application. See Microsoft article https://docs.microsoft.com/en-us/windows/win32/winprog64/file-system-redirector.

  Replace "Sysetm32" with "Sysnative" in the PBS_SCP parameter in `pbs.conf` and restart the PBS_MOM service. You do not need to move or reinstall OpenSSH from `C:\Windows\System32 path`.

21
Problem Solving

Additional information is always available online at the PBS website, www.pbsworks.com. The last section in this chapter tells you how to get additional assistance from the PBS Support staff.

21.1 Debugging Tools

21.1.1 Debugging Commands

The following commands will provide helpful debugging information: `qstat`, `tracejob`, `qmgr`, and `pbsnodes`.

21.1.2 Setting Corefile Size

To set the size of the core file for a PBS daemon, you can set PBS_CORE_LIMIT in `pbs.conf`. Set this on the machine where the daemon runs. This can be set to an integer number of bytes or to the string "unlimited". If this is unset, the limit is inherited from the shell environment, which you can check via `uname -c`.

21.1.3 Using the debuginfo RPM Package

PBS is shipped with debuginfo package(s). When you unzip the PBS product download package the debuginfo package(s) can be found alongside the other PBS packages containing the server etc.

Normally, you do not need to install any debuginfo package(s). You only need to install the debuginfo package(s) when the support team recommends doing so to aid in diagnosing a problem. The contents of the debuginfo package files are automatically installed in the default location for your Linux distribution, typically under `/usr/lib/debug` and `/usr/src/debug`.

The debuginfo package(s) names are platform-dependent. When you install a debuginfo package, nothing additional is installed in `PBS_HOME` or `PBS_EXEC`.

21.1.4 Finding PBS Version Information

Use the `qstat` command to find out what version of PBS Professional you have.

```
qstat -fB
```

In addition, each PBS command will print its version information if given the `--version` option. This option cannot be used with other options.

21.1.5 Troubleshooting and Hooks

PBS is shipped with tools for debugging hooks. See "Debugging Hooks", on page 159 of the PBS Professional Hooks Guide.

You may wish to disable hook execution in order to debug PBS issues. To verify whether hooks are part of the problem, disable each hook by setting its enabled attribute to *False*.

21.2 Security and Permissions Problems

21.2.1 Directory Permission Problems

If for some reason the access permissions on the PBS file tree are changed from their default settings, a component of the PBS system may detect this as a security violation, and refuse to execute. If this is the case, an error message to this effect will be written to the corresponding log file. You can run the `pbs_probe` command to check (and optionally correct) any directory permission (or ownership) problems. See "pbs_probe" on page 82 of the PBS Professional Reference Guide for details on usage of the `pbs_probe` command.

21.2.1.1 Correcting Permissions Problems on Linux

You can use the `pbs_probe` command to detect and repair file and directory permissions problems. You can run `pbs_probe` in report mode or fix mode; in report mode, it reports the errors found; in fix mode, it attempts to fix detected problems, and reports any problems it could not fix.

To fix permissions errors, log into the host you wish to check, and run the following command:

```
pbs_probe -f
```

See the `pbs_probe(8B)` manual page.

21.2.1.2 Correcting Permissions Problems on Windows

You can use the `pbs_mkdirs` command to correct file and directory permissions problems on Windows. The command checks and if necessary repairs the permissions of configuration files such as `pbs_environment` and `mom_priv/config`. You should run the `pbs_mkdirs` command only while the PBS MoMs are stopped.

To repair permissions on an execution host, log into the host and run the following commands:

```
net stop pbs_mom
pbs_mkdirs mom
net start pbs_mom
```

21.3 Troubleshooting Jobs

21.3.1 Job Held Due to Invalid Password

If a job fails to run due to an invalid password, then the job is held with hold type *p* (bad password), its comment field updated with why it failed, and an email is sent to the owner for remedy action. Root or administrator can release the hold via qrls. See "qhold" on page 148 of the PBS Professional Reference Guide and "qrls" on page 181 of the PBS Professional Reference Guide.

21.3.2 Requeueing a Job "Stuck" on a Down Vnode

PBS Professional will detect if a vnode fails when a job is running on it, and will automatically requeue and schedule the job to run elsewhere. If the user marked the job as "not rerunnable" (i.e. via the `qsub -r n` option), then the job will be deleted rather than requeued. If the affected vnode is on the primary execution host, the requeue will occur quickly. If it is another vnode in the set assigned to the job, it could take a few minutes before PBS takes action to requeue or delete the job. However, if the auto-requeue feature is not enabled, or if you wish to act immediately, you can manually force the requeueing and/or rerunning of the job. See section 9.6.2, "Node Fail Requeue: Jobs on Failed Vnodes", on page 445.

If you wish to have PBS simply remove the job from the system, use the "`-Wforce`" option to `qdel:`

qdel -Wforce <job ID>

If instead you want PBS to requeue the job, and have it immediately eligible to run again, use the "`-Wforce`" option to `qrerun`

qrerun -Wforce <job ID>

See "Job Input & Output Files", on page 31 of the PBS Professional User's Guide.

21.3.3 Job Cannot be Executed

If a user receives a mail message containing a job ID and the line "Job cannot be executed", the job was aborted by MoM when she tried to place it into execution. The complete reason can be found in one of two places, MoM's log file or the standard error file of the user's job. If the second line of the message is "See Administrator for help", then MoM aborted the job before the job's files were set up. The reason will be noted in MoM's log. Typical reasons are a bad user/group account, checkpoint/restart file, or a system error. If the second line of the message is "See job standard error file", then MoM had created the job's file and additional messages were written to standard error. This is typically the result of a bad resource request.

21.3.4 Running Jobs with No Active Processes

On very rare occasions, PBS may be in a situation where a job is in the *Running* state but has no active processes. This should never happen as the death of the job's shell should trigger MoM to notify the server that the job exited and end-of-job processing should begin. If this situation is noted, PBS offers a way out. Use the `qsig` command to send SIGNULL, signal 0, to the job. If MoM finds there are no processes then she will force the job into the exiting state. See "qsig" on page 193 of the PBS Professional Reference Guide.

21.3.5 Jobs that Can Never Run

If backfilling is being used, the scheduler looks at the job being backfilled around and determines whether that job can never run.

If backfilling is being used, the scheduler determines whether that job can or cannot run now, and if it can't run now, whether it can ever run. If the job can never run, the scheduler logs a message saying so.

The scheduler only considers the job being backfilled around. That is the only job for which it will log a message saying the job can never run.

This means that a job that can never run will sit in the queue until it becomes the most deserving job. Whenever this job is considered for having small jobs backfilled around it, the error message "resource request is impossible to solve: job will never run" is printed in the scheduler's log file. If backfilling is not being used, this message will not appear.

If backfilling is not being used, the scheduler determines only whether that job can or cannot run now. The scheduler won't determine if a job will ever run or not.

21.3.6 Job Comments for Problem Jobs

PBS can detect when a job cannot run with the current unused resources and when a job will never be able to run with all of the configured resources. PBS can set the job's comment attribute to reflect why the job is not running.

If the job's comment starts with "Can never run", the job will never be able to run with the resources that are currently configured. This can happen when:

- A job requests more of a consumable resource than is available on the entire complex
- A job requests a non-consumable resource that is not available on the complex

For example, if there are 128 total CPUs in the complex, and the job requests 256 CPUs, the job's comment will start with this message.

If the job's comment starts with "Not running", the job cannot run with the resources that are currently available. For example, if a job requests 8 CPUs and the complex has 16 CPUs but 12 are in use, the job's comment will start with this message.

You may see the following comments. R is for "Requested", A is for "Available", and T is for "Total":

```
"Not enough free nodes available"
"Not enough total nodes available"
"Job will never run with the resources currently configured in the complex"
"Insufficient amount of server resource <resource name> (R | A | T | <requested value>
   !=<available values for requested resource>)
"Insufficient amount of queue resource <resource name> (R | A | T | <requested value> !=<available
   values for requested resource>)
"Error in calculation of start time of top job"
"Can't find start time estimate"
```

The "Can Never Run" prefix may be seen with the following messages:

```
"Insufficient amount of resource <resource name> (R | A | T | <requested value> !=<available
   values for requested resource>)"
"Insufficient amount of Server resource <resource name> (R | A | T | <requested value>
   !=<available values for requested resource>)"
"Insufficient amount of Queue resource <resource name> (R | A | T | <requested value> !=<available
   values for requested resource>)"
"Not enough total nodes available"
"can't fit in the largest placement set, and can't span psets"
```

21.3.7 Bad UID for Job Execution

For a job to be accepted by the PBS server, the user at the submitting host must pass an ruserok() test.

From the RCMD(3) man page:

> The `iruserok`() and `ruserok`() functions take a remote host's IP address or name, respectively, two user names and a flag indicating whether the local user's name is that of the superuser. Then, if the user is NOT the superuser, it checks the `/etc/hosts.equiv` file. If that lookup is not done, or is unsuccessful, the .rhosts in the local user's home directory is checked to see if the request for service is allowed.

If this file does not exist, is not a regular file, is owned by anyone other than the user or the superuser, or is writable by anyone other than the owner, the check automatically fails. Zero is returned if the machine name is listed in the hosts.equiv file, or the host and remote user name are found in the .rhosts file; otherwise `iruserok`() and `ruserok`() return *-1*. If the local domain (as obtained from `gethostname(2)`) is the same as the remote domain, only the machine name need be specified.

If the server attribute flatuid is set to true, this test is skipped and the job is accepted based on the submitting users name alone (with obvious security implications).

You can run the following command:

```
Qmgr: set server flatuid=true
```

Flatuid or not, to run as a user other than the job owner (the submitter) you must have authorization to do so. Otherwise, any user could run a job as any other user. You authorize for userA to run a job as userB the same way you authorize userA@host1 to run a job as userA on host2 when flatuid is Not SET, i.e. see .ruserok() and .rhosts.

Here is a test program to see if ruserok passes for a given user and host. There are two use cases:

- User submitting job from remote host to server getting unexpected "Bad UID" message. That is, user doesn't have access when he thinks he should.
- User(s) can delete, etc other user(s) jobs. That is, one user is able to act as what he thinks is a different user, server sees them as being equivalent.

Build this with "cc ruserok.c -o ruserok"

Usage (run on the PBS server system):

```
ruserok remote_host remote_user1 local_user2
```

where:

remote_host: the host from which the job is being submitted, or where the PBS client command is issued

remote_user1: the username of the user submitting the job, or issuing the client command

loca_user2: the username of the user remote_user1 is trying to submit the job as, or owner of the job that remote_user1 is trying to act on with the client command

```
#include <errno.h>
#include <stdio.h>
#include <unistd.h>
int main(int argc, char *argv[])
{
    int rc;
    char hn[257];
    if (argc != 4)
        { fprintf(stderr, "Usage: %s remote_host remote_user1 local_user2\n", argv[0]); return 1;
    }
    if (gethostname(hn, 256) < 0)
        { perror("unable to get hostname"); return 2; }
    hn[256] = '\0';
    printf("on local host %s, from remote host %s\n", hn, argv[1]);
    rc = ruserok(argv[1], 0, argv[2], argv[3]);
    if (rc == 0)
        printf("remote user %s is allowed access as local user %s\n", argv[2], argv[3]);
    else
        printf("remote user %s is denied access as local user %s\n", argv[2], argv[3]);
    return 0;
}
```

21.3.8 Windows: Bad UID for Job Execution

If, when attempting to submit a job to a remote server, `qsub` reports:

```
BAD uid for job execution
```

Then you need to add an entry in the remote system's `.rhosts` or `hosts.equiv` pointing to your Windows machine. Be sure to put in all hostnames that resolve to your machine. See section 2.3.6, "User Authorization Under Windows", on page 15.

If remote account maps to an Administrator-type account, then you need to set up a `.rhosts` entry, and the remote server must carry the account on its acl_roots list.

21.3.9 New Jobs Not Running

If PBS loses contact with the Altair License Server, any jobs currently running will not be interrupted or killed. The PBS server will continually attempt to reconnect to the license server, and re-license the assigned vnodes once the contact to the license server is restored.

No new jobs will run if PBS server loses contact with the ALM license server.

21.3.10 Job Stuck in Exiting State

A job can be stuck in the Exiting state if the user submits the job from a directory where the user does not have write access. You can forcefully delete the job:

21.3.10.1 qdel -Wforce <job ID>

21.4 Troubleshooting Daemons

21.4.1 Server Host Bogs Down After Startup

If the server host becomes unresponsive a short time after startup, the server may be trying to contact the wrong license server.

21.4.1.1 Symptoms

15 seconds to one or two minutes after you start the PBS server, the system becomes unresponsive.

21.4.1.2 Problem

The problem may be caused by the pbs_license_info server attribute pointing to an old FLEX license server. This attribute should point to the new ALM license server. See the *PBS Works Licensing Guide*.

21.4.1.3 Treatment

On some Linux systems, the effects of memory starvation on subsequent responsiveness may be long-lasting. Therefore, instead of merely killing and restarting the PBS server, we recommend rebooting the machine.

Take the following steps:

1. Reboot the machine into single-user mode.
2. Determine the correct value for pbs_license_info and set the PBS_LICENSE_INFO entry in `pbs.conf` to this value.
3. Reboot, or change `runlevel` to multi-user.
4. Using `qmgr`, set the pbs_license_info server attribute to the correct value:

   ```
   # qmgr -c "set server pbs_license_info = <port>@<license server hostname>"
   # qmgr -c "set server scheduling= true"
   ```

5. Stop the PBS server process.
6. Continue normally.

21.4.2 Server Does Not Start

The server may not start due to problems with the data service. Call PBS technical support; see "Technical Support" on page iii. For more on the PBS data service, see "pbs_dataservice" on page 61 of the PBS Professional Reference Guide.

21.4.3 Primary Server Periodically Restarting

If the primary server keeps restarting, an unknown secondary server may be contacting it. This can happen when PBS_PRIMARY and PBS_SECONDARY are missing from `pbs.conf`, but a secondary server has been started.

21.4.4 PBS Data Service Does Not Start

- You may need to create the data service management account. This must be creating before installing PBS. See "Create PBS Data Service Management Account" on page 23 in the PBS Professional Installation & Upgrade Guide.
- If you see an error message saying "PBS data service is running on another host - cannot start", there may be a problem with the lock file in `$PBS_HOME/dataservice/pbs_dblock`:
  - Problem during failover between two hosts, where the primary host still has a lock on the file
  - Ungraceful shutdown, where the primary host has an incorrectly, still-locked, lock file; look at the primary server host.
  - File system issues that interfere with the locking, unlocking, and/or access, of the lock file.

21.4.5 Server Dies Inexplicably

Check the data service. When the data service dies, the server automatically goes down too.

21.4.6 Data Service Running When PBS Server is Down

You can use the `pbs_dataservice` command to stop the data service. See "pbs_dataservice" on page 61 of the PBS Professional Reference Guide.

21.4.7 Scheduler Cannot Reliably Contact Server

If you see a series of 15031 errors, this can happen when PBS_PRIMARY and PBS_SECONDARY are missing from `pbs.conf`, but a secondary server has been started.

21.4.8 PBS Daemon Will Not Start

If the PBS server, MoM, or scheduler fails to start up, it may be refusing to start because it has detected permissions problems in its directories or on one or more of its configuration files, such as `pbs_environment` or `mom_priv/config`.

21.4.9 Troubleshooting Windows Daemon Problems

21.4.9.1 Windows: MoMs Do Not Start

- In the case where the PBS daemons, the Active Directory database, and the domain controller are all on the same host, some PBS MoMs may not start up immediately. If the Active Directory services are not running when the PBS MoMs are started, the MoMs won't be able to talk to the domain controller. This can prevent the PBS MoMs from starting. As a workaround, wait until the host is completely up, then retry starting the failing MoM.

  Example:

  ```
  net start pbs_mom
  ```
- In a domained environment, if the PBS service account is a member of any group besides "Domain Users", the install program will fail to add the PBS service account to the local Administrators group on the install host. Make sure that the PBS service account is a member of only one group, "Domain Users" in a domained environment.
- If the MoM fails to start up because of permission problems on some of its configuration files like `pbs_environment` or `mom_priv/config`, then correct the permission by running:

  ```
  pbs_mkdirs mom
  ```

21.5 Troubleshooting Vnodes

21.5.1 Vnodes Down

The PBS server determines the state of hosts (*up* or *down*), by communicating with MoM on the host. The state of vnodes may be listed by two commands: `qmgr` and `pbsnodes`

```
Qmgr: list node @active
pbsnodes -a
Node jupiter  state = state-unknown, down
```

A vnode in PBS may be marked "*down*" in one of two substates. For example, the state above of vnode "jupiter" shows that the server has not had contact with MoM since the server came up. Check to see if a MoM is running on the vnode. If there is a MoM and if the MoM was just started, the server may have attempted to poll her before she was up. The server should see her during the next polling cycle in 10 minutes. If the vnode is still marked "state-unknown, down" after 10+ minutes, either the vnode name specified in the server's node file does not map to the real network hostname or there is a network problem between the server host and the vnode.

If the vnode is listed as:

```
pbsnodes -a
Node jupiter state = down
```

then the server has been able to ping MoM on the vnode in the past, but she has not responded recently. The server will send a "ping" PBS message to every free vnode each ping cycle, 10 minutes. If a vnode does not acknowledge the ping before the next cycle, the server will mark the vnode down.

21.5.2 Bad Vnode on Startup

If, when the server starts up, one or more vnodes cannot be resolved, the server marks the bad vnode(s) in state "*state-unknown, down*".

21.6 Troubleshooting Client Commands

21.6.1 Windows: Client Commands Slow

PBS caches the IP address of the local host, and uses this to communicate between the daemons. If the cached IP address is invalidated, PBS can become slow. In both scenarios, jobs must be killed and restarted.

21.6.1.1 Scenario: Wireless Router, DHCP Enabled

The system is connected to a wireless router that has DHCP enabled. DHCP returned a new IP address for the server short name, but DNS is resolving the server full name to a different IP address.

The IP address and server full name have become invalid due to the new DHCP address. PBS has cached the IP address of the server full name.

Therefore, the PBS server times out when trying to connect to the scheduler and local MoM using the previously cached IP address. This makes PBS slow.

Symptom:

1. PBS is slow.
   a. Server logs show "Could not contact scheduler".
   b. `pbsnodes -a` shows that the local node is down.
2. First IP addresses returned below don't match:

```
cmd.admin> pbs_hostn -v <server_short_name>
cmd.admin> pbs_hostn -v <server_full_name>
```

Workaround: cache the correct new IP address of the local server host.

1. Add the address returned by `pbs_hostn -v <server_short_name>` (normally the DHCP address) to `%WINDIR%\system32\drivers\etc\hosts file` as follows:
   `<DHCP address> <server_full_name> <server_short_name>`
2. Restart the MoM:

```
cmd.admin> net stop pbs_mom
cmd.admin> net start pbs_mom
```

21.6.2 Windows: qstat Errors

If the `qstat` command produces an error such as:

```
illegally formed job identifier.
```

This means that the DNS lookup is not working properly, or reverse lookup is failing. Use the following command to verify DNS reverse lookup is working

```
pbs_hostn -v hostname
```

If however, `qstat` reports "No Permission", then check `pbs.conf`, and look for the entry "PBS_EXEC". `qstat` (in fact all the PBS commands) will execute the command "`PBS_EXEC\sbin\pbs_iff`" to do its authentication. Ensure that the path specified in `pbs.conf` is correct.

21.6.3 Clients Unable to Contact Server

If a client command (such as `qstat` or `qmgr`) is unable to connect to a server there are several possibilities to check. If the error return is 15034, "No server to connect to", check (1) that there is indeed a server running and (2) that the default server information is set correctly. The client commands will attempt to connect to the server specified on the command line if given, or if not given, the server specified by SERVER_NAME in `pbs.conf`.

If the error return is `15007`, "`No permission`", check for (2) as above. Also check that the executable `pbs_iff` is located in the search path for the client and that it is setuid root. Additionally, try running `pbs_iff` by typing:

```
pbs_iff -t server_host 15001
```

Where *`server_host`* is the name of the host on which the server is running and `15001` is the port to which the server is listening (if started with a different port number, use that number instead of `15001`). Check for an error message and/or a non-zero exit status. If `pbs_iff` exits with a non-zero status, either the server is not running or was installed with a different encryption system than was `pbs_iff`.

21.7 Troubleshooting PBS Licenses

21.7.1 Wrong License Server: Out of Memory

If you run out of memory shortly after startup, the server may be looking for the wrong license server. See section 21.4.1, “Server Host Bogs Down After Startup”, on page 676.

21.7.2 Unable to Connect to License Server

If PBS cannot contact the license server, the server will log a message:

```
"Unable to connect to license server at pbs_license_info=..."
```

If the license server location is incorrectly initialized (e.g. if the host name or port number is incorrect), PBS may not be able to pinpoint the misconfiguration as the cause of the failure to reach a license server.

If PBS cannot detect a license server host and port when it starts up, the server logs an error message:

```
"Did not find a license server host and port (pbs_license_info=<X>). No external license server
   will   be contacted"
```

21.7.3 Insufficient Minimum Licenses

If the PBS server cannot get the number of licenses specified in pbs_license_min from the license server, the server will log a message:

```
"checked-out only <X> CPU licenses instead of pbs_license_min=<Y> from license server at host <H>,
   port <P>. Will try to get more later."
```

21.7.4 Wrong Type of License

If the PBS server encounters a proprietary license key that is of the wrong type, the server will log the following message:

```
"license key #1 is invalid: invalid type or version".
```

21.8 Crash Recovery

PBS daemons could terminate unexpectedly either because the host machine stops running or because the daemon itself stops running. The daemon may be killed by mistake, or may (rarely) crash. The server may terminate if the filesystem runs out of space.

21.8.1 Recovery When Host Machine Stops

If the host machine stops running, no special steps are required, since PBS will be started when the machine starts.

21.8.1.1 Execution Host Stops

If the host machine is an execution host, any jobs that were running on that host were terminated when the machine stopped, and when MoM is restarted, she will report to the server that those jobs are dead, and begin normal activity. The server will automatically restart any jobs that can be restarted.

Shutting down one host of a multi-host job will cause that job to be killed. The job will have to be rerun; restarting the MoM on the stopped host with the -p option will not help the job. See "pbs_mom" on page 72 of the PBS Professional Reference Guide.

21.8.1.2 Server/scheduler/communication Host Stops

If the host machine is the server/scheduler/communication host, no data is lost and no jobs are lost, because the server writes everything to disk. The server is restarted automatically upon machine startup.

The scheduler is started automatically upon machine startup. The scheduler starts fresh each cycle, so it does not lose data.

21.8.2 Recovery When Daemon Stops

For more detailed information on starting and stopping PBS, see "Starting & Stopping PBS on Linux" on page 159 in the PBS Professional Installation & Upgrade Guide.

21.9 Other Troubleshooting

21.9.1 Problem With Dynamic Resource

If you need to debug a dynamic resource being supplied by an external script, it may help to follow these steps:

1. Set the scheduler's log_events parameter to 4095 (everything is logged)
   ```
   qmgr -c "set sched <scheduler name> log_events = 4095"
   ```
2. Send a SIGHUP to the scheduler (pbs_sched)
3. The scheduler log will contain the value the scheduler reads from the external script

21.9.2 Cannot Create Formula or Hook

You must run `qmgr` at the server host when operating on the server's job_sort_formula attribute or on hooks. For example, attempting to create the formula at another host will result in the following error:

```
qmgr obj= svr=default: Unauthorized Request  job_sort_formula
```

21.9.3 Windows: PBS Cannot Locate Configuration File

If PBS is installed on a hard drive other than `C:`, it may not be able to locate the `pbs.conf` global configuration file. If this is the case, PBS will report the following message:

```
E:\Program Files\PBS\exec\bin>qstat -
pbsconf error: pbs conf variables not found:
PBS_HOME PBS_EXEC
No such file or directory
qstat: cannot connect to server UNKNOWN (errno=0)
```

To correct this problem, set PBS_CONF_FILE to point `pbs.conf` to the right path. Normally, during PBS Windows installation, this would be set in system `autoexec.bat` which will be read after the Windows system has been restarted. Thus, after PBS Windows installation completes, be sure to reboot the Windows system in order for this variable to be read correctly.

21.9.4 Filesystem Runs Out of Space

If your filesystem has run out of space, the server may experience errors or may crash. If the server is still running, you need only to free up enough space. If the server has crashed, you must restart it. See “Server: Starting, Stopping, Restarting” on page 163 in the PBS Professional Installation & Upgrade Guide.

21.9.5 Unrecognized Timezone Variable

Problem: you see this message:

```
pbs_rsub: Bad time specification(s)
```

Reason: The time zone is not specified correctly in PBS_TZID. On later Linux updates, the system's zoneinfo files may have some countries represented under different names from those in previous releases. For example, *Asia/Calcutta* has been replaced by *Asia/Kolkata*.

In order to create reservations, the PBS server must recognized the PBS_TZID environment variable at the submission host. The appropriate zone location for the submission host can be obtained from the machine on which the PBS Professional server is installed.

- On Linux platforms, either use the `tzselect` command, if it is available, or look in the underlying operating system's `zone.tab` timezone location file, which may be found under `/usr/share/zoneinfo/zone.tab`. While the PBS server is running and can contact the execution machine, use the Linux `tzselect` utility to determine the value for PBS_TZID.
- On all other platforms, look in the list of libical supported zoneinfo locations available under `$PBS_EXEC/lib/ical/zoneinfo/zones.tab`.

21.10 Getting Help

If the material in the PBS manuals is unable to help you solve a particular problem, you may need to contact the PBS Support Team for assistance. The PBS Professional support team can be reached directly via email and phone; contact information is on the inside front cover of each manual.

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