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1 User Guide

1.1 Overview of Basic User Tasks

Univa Grid Engine offers the following basic commands, tools and activities to accomplish common user tasks in the cluster.

TABLE: Basic Tasks and Their Corresponding Commands

Task	Command
Submit Jobs	qsub, qresub, qrsh, qlogin, qsh, qmake, qtcsh
Check Job Status	qstat
Modify Jobs	qalter, qhold, qrls
Delete Jobs	qdel
Check Job Accounting After Job End	qacct
Display Cluster State	qstat, qhost, qselect, qquota
Display Cluster Configuration	qconf

The next sections provide detailed descriptions of how to use these commands in a Univa Grid Engine cluster.

1.2 A Simple Workflow Example

Using Univa Grid Engine from the command line requires sourcing the settings file to set all necessary environment variables. The settings file is located in the "<Univa Grid Engine installation path>/<Univa Grid Engine cell>/common" directory. This directory contains two settings files: `settings.sh` for bourne shell, bash and compatible shells, and `settings.csh` for csh and tcsh.

For simplicity, this document refers to the <Univa Grid Engine installation path> as `$SGE_ROOT` and the <Univa Grid Engine cell> as `$SGE_CELL`. Both environment variables are set when the settings file is sourced.

Source the settings file. Choose one of the following commands to execute based on the shell type in use.

- bourne shell/bash:

```
# . $SGE_ROOT/$SGE_CELL/common/settings.sh
```

- csh/tcsh:

```
# source $SGE_ROOT/$SGE_CELL/common/settings.csh
```

Now that the shell is set up to work with Univa Grid Engine, it is possible to check which hosts are available in the cluster by running the `qhost` command.

Sample `qhost` output:

```
# qhost
HOSTNAME                ARCH         NCPU  LOAD  MEMTOT  MEMUSE  SWAPTO  SWAPUS
----------------------------------------------------------------------------------
global                  -               -     -       -       -       -       -
kailua                  lx-amd64        4  1.03    7.7G    2.2G    8.0G     0.0
halape                  lx-x86          2  0.00  742.8M   93.9M  752.0M     0.0
kahuku                  lx-amd64        2  0.01  745.8M  103.8M  953.0M     0.0
```

The sample `qhost` output above shows three hosts available, all of which run Linux (lx-), two in 64 bit (amd64), one in 32 bit mode (x86). One provides 4 CPUs; the other two just 2 CPUs. Two hosts are idle but have approximately 740 MB RAM available, while the third is loaded by 25% (LOAD divided by NCPU) and has 7.7 GB RAM in total.

This sample cluster has more than enough resources available to run a simple example batch job. Use the `qsub` command to submit a batch job. From the example job scripts in `$SGE_ROOT/examples/jobs`, submit `sleeper.sh`.

```
# qsub $SGE_ROOT/examples/jobs/sleeper.sh
Your job 1 ("Sleeper") has been submitted
```

The `qsub` command sent the job to the Qmaster to determine which execution host is best suited to run the job. Follow the job's different stages with the `qstat` command:

- Immediately after submission, the job is in state "qw" ("queued, waiting") in the pending job list.

`qstat` shows the submit time (when the job was submitted to the Qmaster from the `qsub` command on the submit host).

```
# qstat
job-ID  prior   name       user         state submit/start at     queue           slots ja-ta
-----------------------------------------------------------------------------------------
      1 0.00000 Sleeper    jondoe       qw    03/10/2011 19:58:35                   1
```

- A few seconds later, `qstat` shows the job in state "r" (running) and in the run queue "all.q" on host "kahuku".

Since the job is running, `qstat` shows the start time (when the job was started on the execution host). A priority was automatically assigned to the job. Priority assignment is explained later in the document.

```
# qstat
job-ID  prior   name       user         state submit/start at     queue           slots ja-ta
-----------------------------------------------------------------------------------------
      1 0.55500 Sleeper    jondoe       r     03/10/2011 19:58:42 all.q@kahuku        1
```

- [changed]Between the states "qw" and "r", the job is in state "t" ("transferring") for a short time. Occasionally, this state can also be seen in the `qstat` output.[/changed]

While a job is running, use the `qstat -j <job-ID>` command to display its status:

```
# qstat -j 1
==============================================================
job_number:                 1
exec_file:                  job_scripts/1
submission_time:            Thu Mar 11 19:58:35 2011
owner:                      jondoe
uid:                        1000
group:                      users
gid:                        100
sge_o_home:                 /home/jondoe
sge_o_log_name:             jondoe
sge_o_path:                 /gridengine/bin/lx-amd64:/usr/local/sbin:/usr/local/bin:/usr/sbin
sge_o_shell:                /bin/tcsh
sge_o_workdir:              /gridengine
sge_o_host:                 kailua
account:                    sge
hard resource_list:         hostname=kailua
mail_list:                  jondoe@kailua
notify:                     FALSE
job_name:                   Sleeper
jobshare:                   0
shell_list:                 NONE:/bin/sh
env_list:
job_args:                   3600
script_file:                /gridengine/examples/jobs/sleeper.sh
binding:                    NONE
usage    1:                 cpu=00:00:00, mem=0.00000 GBs, io=0.00003, vmem=8.008M, maxvmem=8
binding    1:               NONE
scheduling info:            (Collecting of scheduler job information is turned off)
```

This simple sleeper job does nothing but sleep on the execution host. It doesn't need input, but it outputs two files in the home directory of the user who submitted the job: `Sleeper.o1` and `Sleeper.e1`. The `Sleeper.e1` file contains whatever the job printed to stderr, and it should be empty if the job ran successfully. The `Sleeper.o1` file contains what the job printed to stdout, for example:

```
Here I am. Sleeping now at: Thu Mar 10 20:01:10 CET 2011
Now it is: Thu Mar 10 20:02:10 CET 2011
```

Univa Grid Engine also keeps records of this job, as shown with the `qacct` command:

```
# qacct -j 1
==============================================================
qname        all.q
hostname     kailua
group        users
owner        jondoe
project      NONE
department   defaultdepartment
jobname      Sleeper
jobnumber    10
taskid       undefined
account      sge
priority     0
qsub_time    Thu Mar 10 19:58:35 2011
start_time   Thu Mar 10 19:58:42 2011
```

```
end_time     Thu Mar 10 19:59:43 2011
granted_pe   NONE
slots        1
failed       0
exit_status  0
ru_wallclock 61
ru_utime     0.070
ru_stime     0.050
ru_maxrss    1220
ru_ixrss     0
ru_ismrss    0
ru_idrss     0
ru_isrss     0
ru_minflt    2916
ru_majflt    0
ru_nswap     0
ru_inblock   0
ru_oublock   176
ru_msgsnd    0
ru_msgrcv    0
ru_nsignals  0
ru_nvcsw     91
ru_nivcsw    8
cpu          0.120
mem          0.001
io           0.000
iow          0.000
maxvmem      23.508M
arid         undefined
```

Refer to the `accounting(5)` man page for the meaning of all the fields output by the `qacct` command.

1.3 Displaying Univa Grid Engine Status Information

1.3.1 Cluster Overview

Several commands provide different perspectives on Univa Grid Engine cluster status information.

- `qhost` displays the status of Univa Grid Engine hosts, queues and jobs from the host perspective.
- `qstat` shows information about jobs, queues, and queue instances.
- `qconf` command, which is mainly used by the administrator for configuring the cluster, also shows the configuration of the cluster. Use it to understand why the cluster makes some decisions or is in a specific state.

1.3.2 Hosts and Queues

Univa Grid Engine monitoring and management centers around two main configuration object types: hosts and queues.

- A host represents a node in the cluster, physical or virtual. Each host has an associated host configuration object that defines the properties of that host. In addition, Univa Grid Engine has a global host configuration object that defines default values for all host properties. Any host that either does not have an associated host configuration object or has a host configuration object that does not set values for all host properties will inherit all or some property values from the global host configuration object.
- A queue is a set of global configuration properties that govern all instances of the queue. An instance of a queue on a specific host inherits its queue configuration properties from the queue. A queue instance may, however, explicitly override some or all of the queue configuration properties.
- Jobs are executed on a host within the context of a queue instance. Pending jobs wait in a global pending job list where they wait to be assigned by the scheduler to a queue instance.

Univa Grid Engine provides the following commands to display the states of these objects or to configure them:

- `qhost` shows the cluster status from the execution host perspective.
- `qstat` shows the cluster status from the job or queue perspective.
- `qconf` displays the cluster configuration and allows administrators to change configurations.

1.3.2.1 qhost

The `qhost` command shows the cluster status from the execution host perspective.

```
# qhost
```

Calling just `qhost` by itself prints a table that lists the following information about the execution hosts:

- architectures
- number of cores
- current load
- total RAM
- currently used RAM
- total swap space
- currently used swap space

The line "global" appears there, representing the global host, a virtual configuration object that provides defaults for all attributes of the real hosts that are not filled by real data. It's listed here just for completeness.

```
# qhost -q -j
```

- Using the "-j" option, `qhost` lists all currently running jobs beneath the hosts on which they are running.
- Using the "-q" option, `qhost` displays all queues that have instances on a host

beneath the corresponding host.
- Using both switches at once, it's possible to get a comprehensive overview over the cluster in a relatively compact output format.

To prevent lengthy output in larger clusters, `qhost` provides several options to filter the output.

- Use the "-h hostlist" option to display only the information about the listed hosts.
- Use the "-l attr=val,..." option to specify more complex filters. See section "Requestable Attributes" for more details.

For example, the following command displays only hosts of a specific architecture:

```
# qhost -l arch=lx-amd64
```

- Use the "-u user,..." option to show only jobs from the specified users. This implies the "-j" option.
- Use the "-F [attribute]" option to list either all the resources an execution host provides or just the selected ones.

See the `qhost(1)` man page for a detailed description of all options.

1.3.2.2 qstat

To view the cluster from the queue or job perspective, use the `qstat` command.

- Without any option, the `qstat` command lists all jobs of the current user.
- The "-ext" option can be added to most options of `qstat` and causes more attributes to be printed.
- With the "-u "*"" option (the asterisk must be enclosed in quotes!), the jobs of all users are displayed. With "-u <user,...>" only the jobs of the specified users are listed.
- With the "-g c" option, the status of all cluster queues is displayed.
- [changed]The "-j <job-ID> option prints information about the specified job of the current user. With a list of job-IDs or "*", this information is printed for the specified jobs or all jobs of the current user.
- The "-j" option without any job-ID prints information about all peding jobs of the current user.[/changed]

```
# qstat -f
```

- The "-f" option shows the full output of all queue instances with the jobs running in them (by default, just the jobs of the current user; add '-u "*"' to get all jobs listed for all users).

```
# qstat -F
```

- The "-F" option shows all resources the queue instances provide.

The following are several options to filter queues:

- by name (-q queue_list)
- by any provided resource (-l resource_list)
- by queue state (-qs {a|c|d|o|s|u|A|C|D|E|S})
- by parallel environments (-pe pe_list)
- access permissions for specific users (-U user_list) and to filter out queue instances where no job of the current or specified user(s) is running.

Jobs can also be filtered.

- by state (-s {p|r|s|z|hu|ho|hs|hd|hj|ha|h|a})
- by the job submitting user (-u user_list)

1.3.3 Requestable Resources

Each Univa Grid Engine configuration object (global, queue, host) has several resources whose values are either reported by loadsensors, reported by the OS or configured by a manager or an operator. These are resources such as the execution host architecture, number of slots in the queue, current load of the host or configured complex variables. A job can request that it be executed in an environment with specific resources. These requests can be hard or soft: a hard request denotes that a job can run only in an environment that provides at least the requested resource, while a soft request specifies that the job should be executed in an environment that fulfills all soft requests as much as possible. In all commands, no matter if they are made for job submission or if they are made for listing the provided resources, the option to specify the requested resources is always "-l <resource>=<value>". Each resource has a value of one of the following types:

- boolean, integer
- float
- string
- regular expression string

For example, the following command submits a job that can run on hosts with Solaris on a 64-bit Sparc CPU:

```
# qsub -l arch=sol-sparc64 job
```

By default, this is a hard request. To specify it as a soft request, the command would change to the following:

```
# qsub -soft -l arch=sol-sparc64 job
```

The "-soft" option denotes that all following "-l resource=value" requests should be seen as soft requests. With "-hard" the requests can be switched back to hard requests. This can be switched as often as necessary, as shown in the following example:

```
# qsub -soft -l arch=sol-sparc64 -hard -l slots>4 -soft -l h_vmem>300M -hard -l num_cpus>2 jo
```

Using wildcards in resource requests is also permitted.

```
# qsub -l arch="sol-*" job
```

This command requests the job to be scheduled on any Solaris host. (NOTE: The quotes (") are necessary to prevent the shell from expanding the asterisk "*").

To show the list of resources a queue instance provides, enter the following command:

```
# qstat -F
```

Sample `qstat` output is shown below.

```
queuename                      qtype resv/used/tot. load_avg arch          states
---------------------------------------------------------------------------------
all.q@kailua                   BIPC  0/0/40         1.14     lx-amd64
      hl:arch=lx-amd64
      hl:num_proc=4
      hl:mem_total=7.683G
      hl:swap_total=7.996G
      hl:virtual_total=15.679G
      hl:load_avg=1.140000
      hl:load_short=1.150000
      hl:load_medium=1.140000
      hl:load_long=1.310000
      hl:mem_free=2.649G
      hl:swap_free=7.996G
      hl:virtual_free=10.645G
      hl:mem_used=5.034G
      hl:swap_used=0.000
      hl:virtual_used=5.034G
      hl:cpu=17.100000
      hl:m_topology=SCTTCTT
      hl:m_topology_inuse=SCTTCTT
      hl:m_socket=1
      hl:m_core=2
      hl:m_thread=4
      hl:np_load_avg=0.285000
      hl:np_load_short=0.287500
      hl:np_load_medium=0.285000
      hl:np_load_long=0.327500
      qf:qname=all.q
      qf:hostname=kailua
      qc:slots=40
      qf:tmpdir=/tmp
      qf:seq_no=0
      qf:rerun=0.000000
      qf:calendar=NONE
      qf:s_rt=infinity
      qf:h_rt=infinity
      qf:s_cpu=infinity
      qf:h_cpu=infinity
      qf:s_fsize=infinity
      qf:h_fsize=infinity
      qf:s_data=infinity
      qf:h_data=infinity
      qf:s_stack=infinity
      qf:h_stack=infinity
      qf:s_core=infinity
      qf:h_core=infinity
      qf:s_rss=infinity
      qf:h_rss=infinity
```

```
qf:s_vmem=infinity
qf:h_vmem=infinity
qf:min_cpu_interval=00:05:00
```

The resource list consists of three fields: <type>:<name>=<value>. The type is composed of two letters.

- The first letter denotes the origin of this resource.
  - ♦ "h" for host
  - ♦ "q" for queue
- The second letter denotes how the value is acquired.
  - ♦ "l" for load sensor
  - ♦ "f" for fixed, i.e. statically configured in the cluster, host or queue configuration
  - ♦ "c" for constant

1.3.4 User Access Permissions and Affiliations

In Univa Grid Engine, there are three general categories of users:

TABLE: User Categories

User Category	Description
managers	By default, there is always one default manager, the Univa Grid Engine administrator. Managers have universal permission in Univa Grid Engine.
operators	Operators have the permissions to modify the state of specific objects, e.g. enable or disable a queue.
other users	All other users only have permission to submit jobs, to modify and delete their own jobs, and to get information about the cluster status.

Managers are defined by the global manager list, which can be accessed through `qconf` options:

TABLE: `qconf` Options for Updating the Global Manager List

Option	Description
-am user_list	add user(s) to the manager list
-dm user_list	delete user(s) from the manager list
-sm	show a list of all managers

`qconf` provides the similar options for operators:

TABLE: `qconf` Options for Updating the Operator List

Option	Description
-ao user_list	add user to the operator list
-do user_list	delete user from the operator list

-so	show a list of all operators

By default, all users known to the operating system can use Univa Grid Engine as normal users.

Each object of Univa Grid Engine uses the configuration values set in "user_list" and "xuser_list" to determine who is allowed to use an object. The "user_list" explicitly allows access, whereas the "xuser_list" explicitly disallows access. This access is controlled through corresponding but opposite values. For example, the lists have values "acl" and "xacl" which function exactly opposite of each other. If a user is disallowed in the global cluster configuration (by using "xacl"), he may not use any object of Univa Grid Engine: he may not submit any job, but he can still get information from the cluster using `qstat`, `qhost` and so on.

Users mentioned in the "user_list" are allowed to use Grid Engine, but users mentioned in the "xuser_list" are disallowed. If a user is mentioned in both, the "xuser_list" takes precedence, so he is disallowed to use the object. If a "user_list" is defined, only users mentioned there are allowed to use the object. If a "xuser_list" is defined and the "user_list" is undefined, then all users except the ones mentioned in the "xuser_list" are allowed to use the object.

Note that the "user_list" and "xuser_list" accept only user sets, not user names. So it's necessary to define user sets before using these options of `qconf`.

TABLE: `qconf` Options for Updating the User List

Option	Description
-au user_list listname_list	add user(s) to user set list(s)
-Au fname	add user set from file
-du user_list listname_list	delete user(s) from user set list(s)
-dul listname_list	delete user set list(s) completely
-mu listname_list	modify the given user set list
-Mu fname	modify user set from file
-su listname_list	show the given user set list
-sul	show a list of all user set lists

A user set contains more information than just the names of the users in this set: see the man page access_list(5) for details. User sets can be defined by specifying UNIX users and primary UNIX groups, which must be prefixed by an '@' sign. There are two types of user sets: Access lists (type "ACL") and departments (type "DEPT). Pure access lists allow enlisting any user or group in any access list. When using departments, each user or group enlisted may only be enlisted in one department, in order to ensure a unique assignment of jobs to departments. To jobs whose users do not match with any of the users or groups enlisted under entries the defaultdepartment is assigned.

TABLE: Man Pages to See for Further Reference

Subject	Man Pages

"user_list" and "xuser_list"	sge_conf(5), queue_conf(5), host_conf(5) and sge_pe(5)
"acl" and "xacl" lists	project(5)
user lists format	access_list(5)
options to specify users and user sets	qconf(1)

1.4 Submitting Batch Jobs

1.4.1 What is a Batch Job?

A batch job is a single, serial work package that gets executed without user interaction. This work package can be any executable or script that can be executed on the execution host. Attached to this work package are several additional attributes that define how Univa Grid Engine handles the job and that influence the behavior of the job.

1.4.2 How to Submit a Batch Job

From the command line, batch jobs are submitted using the `qsub` command. Batch jobs can also be submitted using the deprecated GUI `qmon` or using the DRMAA interface.

Batch jobs are typically defined by a script file located at the submit host. This script prepares several settings and starts the application that does the real work. Univa Grid Engine transfers this script to the execution host, where it gets executed. Alternately, the script can be read from `stdin` instead of from a file. For a job that is just a binary to be executed on the remote host, the binary is typically already installed on the execution host, and therefore does not need to be transferred from the submit host to the execution host.

1.4.2.1 Example 1: A Simple Batch Job

To submit a simple batch job that uses a job script and default attributes, run the following command:

```
# qsub $SGE_ROOT/examples/jobs/simple.sh
```

If this command succeeds, the `qsub` command should print the following note:

```
Your job 1 ("simple.sh") has been submitted
```

Now check the status of the job while the job is running:

```
# qstat
```

If `qstat` doesn't print any information about this job, it has already finished. Note that `simple.sh` is a short running job.

The output of the job will be written to ~/simple.sh.o1 and the error messages to ~/simple.sh.e1, where "~" is the home directory on the execution host of the user who

submitted the job.

1.4.2.2 Example 2: An Advanced Batch Job

`qsub` allows several attributes and requirements to be defined using command line options at the time the job is submitted. These attributes and requirements can affect how the job gets handled by Univa Grid Engine and how the job script or binary is executed. For example, the following command defines these attributes of the job:

```
# qsub -cwd -S /bin/xyshell -i /data/example.in -o /results/example.out -j y example.sh arg1
```

TABLE: Explanation of Command Line Options in Example 2

Option	Description
-cwd	The job will be executed in the same directory as the current directory
-S /bin/xyshell	The shell `/bin/xyshell` will be used to interpret the job script.
-i /data/example.in	The file "/data/example.in" on the execution host will be used as input file for the job.
-o /results/example.out	The file "/results/example.out" on the execution host will be used as output file for the job.
-j y	Job output to stderr will be merged into the "/results/example.out" file.
example.sh arg1 arg2	The job script is "example.sh" must exist locally and gets transferred to the execution host by Univa Grid Engine. arg1 and arg2 will be passed to this job script.

1.4.2.3 Example 3: Another Advanced Batch Job

```
# qsub -N example3 -P testproject -p -27 -l a=lx-amd64 example.sh
```

TABLE: Explanation of Command Line Options in Example 3

Option	Description
-N example2	The job will get the name "example3" instead of the default name which is the name of the job script.
-P testproject	The job will be part of the project "testproject".
-p -27	The job will be scheduled with a lower priority than by default.
-l a=lx-amd64	The job can get scheduled only to a execution host that provides the architecture "lx-amd64".
example.sh	The job script without any arguments.

1.4.2.4 Example 4: A Simple Binary Job

```
# qsub -b y firefox
```

The "-b y" option tells Univa Grid Engine that this is a binary job; the binary does already exist on the execution host and doesn't have to be transferred by Univa Grid Engine from the submit to the execution host.

See the `qsub(5)` man page for an explanation of all possible `qsub` options.

1.4.3 Specifying Requirements

`qsub` provides three options to specify the requirements that must be fulfilled in order to run the job on the execution host. These are requirements like the host architecture, available memory, required licenses, specific script interpreters installed, and so on.

These resource requirements are specified on the `qsub` command line using the "-l" option.

For example, to ensure the job gets scheduled only to a host that provides the architecture type "lx-x86", i.e. Linux on a x86 compatible 32 bit CPU, issue the following `qsub` option:

```
# qsub -l arch=lx-x86 my_job.sh
```

Specifying several requirements at once and using wildcards inside a requirement are possible, as in the following example:

```
# qsub -l a="sol-*|*-amd" -l h="node??" job.sh
```

This example specifies that the job requests must be scheduled to a host whose architecture string starts wit "sol-" and/or ends with "amd64". At the same time, the hostname of the execution host must start with "node" and have exactly two additional trailing characters.

There are two different kinds of requests: hard and soft requests.

- A hard request must be fulfilled in order to schedule the job to the host.
- A soft request should be fulfilled. Grid Engine tries to fulfill as many soft requests as possible.

Be default, all requests specified by the "-l" option are hard requests. The "-soft" option switches the behavior: starting with the "-soft" option, all subsequent requests are considered soft requests. A "-hard" option in the command line switches back to hard requests. "-hard" and "-soft" can be specified as often as necessary.

Example:

```
# qsub -soft -l host="node??" -hard -l h_vmem=2G -l arch="sol*" -soft -l cpu=4
```

As described above in the section "Requestable Resources", the attributes that are provided by all queue instances can be listed using `qstat`:

```
# qstat -F
```

To specify a particular queue instance, use the -q option:

```
# qstat -F -q all.q@kailua
```

As an alternative to specifying job requirements on the command line each time a job is submitted, default requirements can be specified by the job submitting user and the Univa Grid Engine administrator.

Requirements are evaluated in the following order:

- Request files
- Requests in job script
- Command line

Options defined later (e.g., at command line) override options defined earlier (e.g., in the job script). Note that soft and hard requirements are collected separately.

1.4.3.1 Request Files

Request files allow options to be set automatically for all jobs submitted. Request files are read in the following order:

1. The global request file $SGE_ROOT/$SGE_CELL/default/sge_request
2. The private request file $HOME/.sge_request
3. The application specific request file $cwd/.sge_request
4. The qsub command line

Since the request files are read in order, any option defined in more than one of them is overridden by the last-read occurrence, except for options that can be used multiple times on a command line. The resulting options are used as if they were written in the `qsub` command line, while the real `qsub` command line is appended to it, again overriding options that were specified in one of the three files. At any time, the "-clear" option can be used to discard all options that were defined previously.

In these request files, each line can contain one or more options in the same format as in the `qsub` command line. Lines starting with the hash sign (#) in the first column are ignored. See the `sge_request(5)` man page for additional information.

1.4.3.2 Requests in the Job Script

Submit options can also be defined in the jobs script. Each line of the job script that starts with "#$" or with the prefix that is defined using the "-C" option is considered to be a line that contains submit options, as in the following example:

```
#!/bin/sh

#$ -P testproject
#$ -o test.out -e test.err
```

```
echo "Just a test"
```

These options are read and parsed before the job is submitted and are added to the job object. The location where in the job script these options are defined does not matter, but the order matters - if two options override each other, the last one wins.

1.5 Using Job Classes to Prepare Templates for Jobs [since 8.1]

When Univa Grid Engine jobs are submitted then various submit parameters have to be specified either as switches which are passed to command line applications or through corresponding selections in the graphical user interface. Some of those switches define the essential characteristics of the job, others describe the execution context that is required so that the job can be executed successfully. Another subset of switches needs to be specified only to give Univa Grid Engine the necessary hints on how to handle a job correctly so that it gets passed through the system quickly without interferring with other jobs.

In small and medium sized clusters with a limited number of different job types this is not problematic. The number of arguments that have to be specified can either be written into default request files, embedded into the job script, put into an option file (passed with `-@` of `qsub`) or they can directly be passed at the command line.

Within larger clusters or when many different classes of jobs should run in the cluster then the situation is more complex and it can be challenging for a user to select the right combination of switches with appropriate values. Cluster managers need to be aware of the details of the different job types that should coexist in the cluster so that they can setup suitable policies in line with the operational goals of the site. They need to instruct the users about the details of the cluster setup so that these users are able to specify the required submission requests for each job they submit.

Job classes have been introduced in Univa Grid Engine 8.1 to be able to:

- specify job templates that can be used to create new jobs.
- reduce the learning curve for users submitting jobs.
- avoid errors during the job submission or jobs which may not fit site requirements.
- ease the cluster management for system administrators.
- provide more control to the administrator for ensuring jobs are in line with the cluster set-up.
- define defaults for all jobs that are submitted into a cluster.
- improve the performance of the scheduler component and thereby the throughput in the cluster.

1.5.1 Examples Motivating the Use of Job Classes

Imagine you have users who often make mistakes specifying memory limits for a specifc application called *memeater*. You want to make it easy for them by spcifying meaningful defaults but you also want to give them the freedom to modify the memory limit default

according to their needs. Then you could use the following job class configuration (only an excerpt of the full configuration is shown):

```
jcname          memeater
variant_list    default
owner_list      NONE
user_list       NONE
xuser_list      NONE
...
CMDNAME         /usr/local/bin/memeater
...
l_hard          {~}{~}h_vmem=6GB
...
```

Without going into the specifics of the job class syntax, the above job class will use a default of 6 GB for the memory limit of the job. It will, however, be feasible for users to modify this limit. Here are two examples for how users would submit a job based on this job class. The first maintaining the default, the second modifying it to 8 GB (again without going into the details of the syntax being used here):

- qsub -jc memeater
- qsub -jc memeater -l h_vmem=8GB

Now assume a slightly modified scenario where you want to restrict a certain group of users called *novice* to only use the preset of 6 GB while another group of users called *expert* can either use the default or can modify the memory limit. The following job class example would accomplish this. And the trick is that job classes support so called variants as well as user access lists:

```
jcname          memeater
variant_list    default, advanced
owner_list      NONE
user_list       novice, [advanced=expert]
xuser_list      NONE
...
CMDNAME         /usr/local/bin/memeater
...
l_hard          h_vmem=6GB,[{~}advanced={~}h_vmem=6GB]
...
```

With this job class configuration, the novice users would only be able to submit their job using the first command example below while expert users could use both examples:

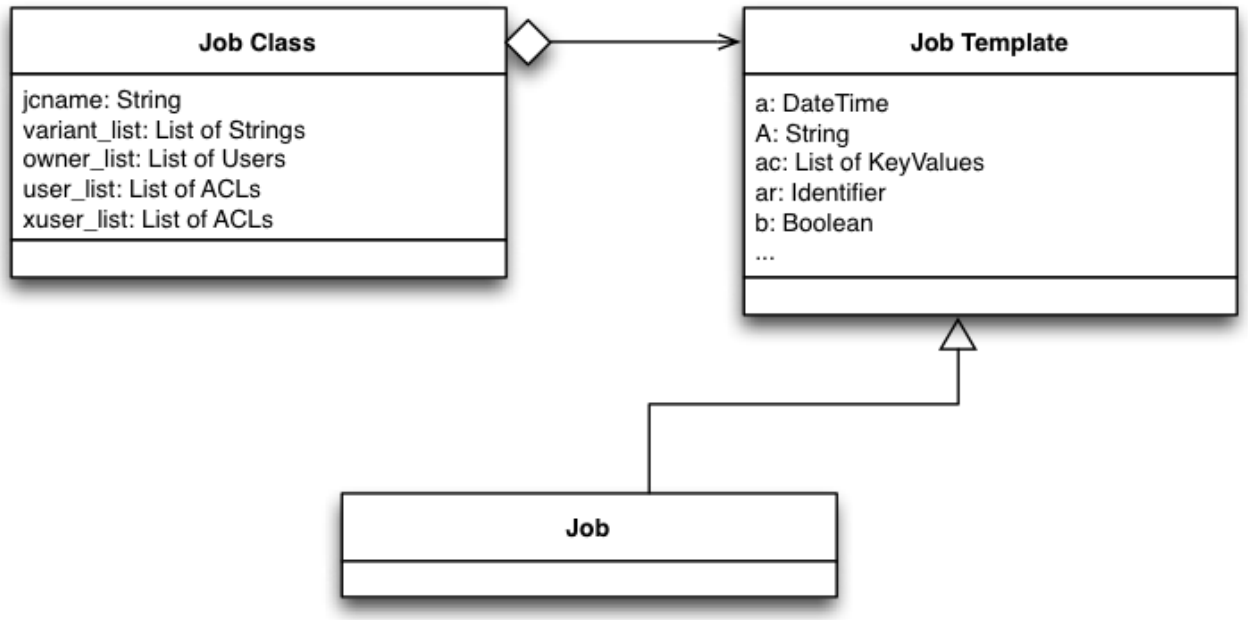
- qsub -jc memeater
- qsub -jc memeater.advanced -l h_vmem=8GB

The two use cases for job classes above are only snippets for all the different scenarios to which job classes may be applied and they only provide a glimps onto the features of job classes. The next sections describe all attributes forming a job class object, commands that are used to define job classes as well as how these objects are used during job submission to form new jobs. A set of examples with growing functionality will illustrate further use cases. This will be followed by describing how job classes can be embedded with other parts of a

Univa Grid Engine configuration to extract the maximum benefit from job classes. Finally, specific means for monitoring job class jobs will be shown.

1.5.2 Defining Job Classes

A job class is a new object type in Univa Grid Engine 8.1. Objects of this type can be defined by managers and also by users of a Univa Grid Engine Cluster to prepare templates for jobs. Those objects can later on be used to create jobs.



Like other configuration objects in Univa Grid Engine each job class is defined by a set of configuration attributes. This set of attributes can be divided into two categories. The first category contains attributes defining a job class itself and the second category all those which form the template which in turn eventually gets instantiated into new jobs.

1.5.2.1 Attributes describing a Job Class

Following attributes describe characteristics of a job class:

Job Class Attributes

Attribute	Value specification
`jcname`	The `jcname` attribute defines a name that uniquely identifies a job class. Please note that `NO_JC` and `ANY_JC` are reserved keywords that cannot be used as names for new job classes. There is one particular job class with the special name `template`. It acts as template for **all** other job classes and the configuration of this job class

	template can only be adjusted by users having the manager role in Univa Grid Engine. This gives manager accounts control about default settings, some of which also can be set so that they must not be changed (see below for more information on how to enforce options).
variant_list	Job classes may, for instance, represent an application type in a cluster. If the same application should be started with various different settings in one cluster or if the possible resource selection applied by Univa Grid Engine system should depend on the mode how the application should be executed then it is possible to define one job class with multiple variants. A job class variant can be seen as a copy of a job class that differs only in some aspects from the original job class. The variant_list job class attribute defines the names of all existing Job Class variants. If the keyword NONE is used or when the list contains only the word default then the job class has only one variant. If multiple names are listed here, that are separated by commas, then the job class will have multiple variants. The default variant always has to exist. If the variant_list attribute does not contain the word default then it will be automatically added by the Univa Grid Engine system. Other commands that require a reference of a job class can either use the jcname to refer to the default variant of a job class or they can reference a different variant by combining the jcname with the name of a specific variant. Both names have to be separated by a dot (.) character.
owner_list	The owner_list attribute denotes the ownership of a job class. As default the user that creates a job class will be the owner. Only this user and all managers are allowed to modify or delete the job class object. Managers and owners can also add additional user names to this list to give these users modify and delete permissions. If a manager creates a job class then the owner_list will be NONE to express that only managers are allowed to modify or delete the corresponding job class. Even if a job class is owned only by managers it can still be used to create new jobs. The right to derive new jobs from a job class can be restricted with the user_list and xuser_list attributes explained below.
user_list	The user_list job class parameter contains a comma separated list of Univa Grid Engine user access list names or user names. User names have to be prefixed with a percent character (%). Each user referenced in the user_list and each user in at least one of the enlisted access lists has the right to derive new jobs from this job class using the -jc switch of one of the submit commands. If the user_list parameter is set to NONE (the default) any user can use the job class to create new jobs if access is not explicitly excluded via the xuser_lists parameter described below. If a user is contained both in an access list enlisted in xuser_lists and user_lists the user is denied access to use the job class.
xuser_list	The xuser_list job class contains a comma separated list of Univa Grid Engine user access list names or user names. User names have to be prefixed with a percent character (%). Each user referenced in the xuser_list and each user in at least one of the enlisted access lists is not allowed to derive new jobs from this job class. If the xuser_list

	parameter is set to NONE (the default) any user has access. If a user is contained both in an access list enlisted in xuser_lists and user_lists the user is denied access to use the job class.

1.5.2.2 Example 1: Job Classes - Identity, Ownership, Access

Below you can find an example for the first part of a sleeper job class. It will be enhanced in each of the folowing chapters to illustrate the use of job classes.

```
jcname        sleeper
variant_list  NONE
owner_list    NONE
user_list     NONE
xuser_list    NONE
...
```

sleeper is the unique name that identifies the job class (jcname sleeper). This job class defines only the default variant because no other variant names are specified (variant_list NONE). The job class does not specify an owner (owner_list NONE) as a result it can only be changed or deleted by users having the manager role. Managers and all other users are allowed to derive new jobs from this job class. Creating new jobs is not restricted (user_list NONE; user_list NONE).

1.5.2.3 Attributes to Form a Job Template

Additionally to the attributes mentioned previously each job class has a set of attributes that form a job template. In most cases the names of those additional attributes correspond to the names of command line switches of the qsub command. The value for all these additional attributes might either be the keyword UNSPECIFIED or it might be the same value that would be passed with the corresponding qsub command line switch.

All these additional job template attributes will be evaluated to form a virtual command line when a job class is used to instantiate a new job. All attributes for which the corresponding value contains the UNSPECIFIED keyword will be ignored whereas all others define the submit arguments for the new job that will be created.

All template attributes can be divided in two groups. There are template attributes that accept simple attribute values (like a character sequence, a number or the value yes or no) and there are template attributes that allow to specify a list of values or a list of key/value pairs (like the list of resource requests a job has or the list of queues where a job might get executed).

The table below contains all available template attributes. The asterisk character (*) tags all attributes that are list based. Within the description the default for each attribute is documented that will be used when the keyword UNSPECIFIED is used in the job class definition.

Job Class Attributes to Form a Job Template

Attribute	Value specification

a	Specifies the time and date when a job is eligible for execution. If unspecified the job will be immediately eligible for execution. Format of the character sequence is the same as for the argument that might be passed with `qsub -a`.
A	Account string. The string ?sge? will be used when there is no account string specified or when it is later on removed from a job template or job specification.
ac *	List parameter defining the name/value pairs that are part of the job context. Default is an empty list.
ar	Advance reservation identifier used when jobs should be part of an advance reservation. As default no job will be part of an advance reservation.
b	`yes` or `no` to express if the command should be treated as binary or not. The default for this parameter is `no`, i.e. the job is treated as a script.
binding	Specifies all core binding specific settings that should be applied to a job during execution. Binding is disabled as default.
CMDARG *	Defines a list of command line arguments that will be passed to `CMDNAME` when the job is executed. As default this list is empty.
CMDNAME *	Specified either the job script or the command name when binary submission is enabled (`b yes`). Please note that script embedded flags within specified job scripts will be ignored.
c_interval	Defines the time interval when a checkpoint-able job should be checkpointed. The default value is 0.
c_occasion	Letter combination that defines the state transitions when a job should be triggered to write a checkpoint. Default is 'n' which will disable checkpointing.
ckpt	Checkpoint environment name which specifies how to checkpoint the job. No checkpoint object will be referenced as default.
cwd	Specifies the working directory for the job. Path aliasing will not be used when this value is specified in a job class. In case of absence the home directory of the submitting user will be used as directory where the job is executed.
dl	Specifies the deadline initiation time for a job (see the chapter about deadline urgency in the administrators guide for more information). As default jobs have do defined deadline.
e *	List parameter that defines the path for the error file for specific execution hosts. As default the file will be stored in the home directory of the submitting user and the filename will be the combination of the job name and the job id.
h	`yes` or `no` to indicate if a job should be initially in hold state. The default is `no`.
hold_jid *	List parameter to create initial job dependencies between new jobs and already existing ones. The default is an empty list.

hold_jid_ad *	List parameter to create initial array job dependencies between new array jobs and already existing ones. The default is an empty list.
i *	List parameter that defines the path for the input file for specific execution hosts.
j	yes or no to show if error and output stream of the job should be joined into one file. Default is no.
js	Defines the job share of a job relative to other jobs. The default is 0.
l_hard *	List parameter that defines hard resource requirements of a job in the form of name/value pairs. The default is an empty list.
l_soft *	List parameter defining soft requests of a job. The default is an empty list.
mbind	Specifies memory binding specific settings that should be applied to a job during execution. Memory binding is disabled as default.
m	Character sequence that defines the circumstances when mail that is related to the job should be send. The default is 'n' which means no mails should be send.
M *	List parameter defining the mail addresses that will be used to send job related mail. The default is an empty list.
masterq *	List parameter that defines the queues that might be used as master queues for parallel jobs. The default is an empty list.
N	Default name for jobs. For jobs specifying a job script which are submitted with qsub or the graphical user interface the default value will be the name of the job script. When the script is read from the stdin stream of the submit application then it will be STDIN. qsh and qlogin jobs will set the job name to INTERACTIVE. qrsh jobs will use the first characters of the command line up to the first occurrence of a semicolon or space character.
notify	yes or no to define if warning signals will be send to a jobs if it exceeds any limit. The default is no
now	yes or no to specify if created jobs should be immediate jobs. The default is no.
o *	List parameter that defines the path for the output file for specific execution hosts.
P	Specifies the project to which this job is assigned.
p	Priority value that defines the priority of jobs relative to other jobs. The default priority is 0.
pe_name	Specifies the name of the parallel environment that will be used for parallel jobs. PE name pattern are not allowed. As default there is no name specified and as a result the job is no parallel job.
pe_range	Range list specification that defines the amount of slots that are required to execute parallel jobs. This parameter must be specified when also the pe_name parameter is specified.
q_hard *	

	List of queues that can be used to execute the job. Queue name pattern are not allowed. The default is an empty list.
q_soft *	List of queues that are preferred to be used when the job should be executed. Queue name pattern are not allowed. The default is an empty list.
R	yes or no to indicate if a reservation for this job should be done. The default is no.
r	yes or no to identify if the job will be rerun-able. The default is no.
S *	List parameter that defines the path of the shell for specific execution hosts. The default is an empty list.
shell	yes or no to specify if a shell should be executed for binary jobs or if the binary job should be directly started. The default is yes
t	Defines the task ID range for array jobs. Jobs are no array jobs as default.
V	yes or no. yes causes that all environment variables active during the submission of a job will be exported into the environment of the job.
v *	List of environment variable names and values that will be exported into the environment of the job. If also V yes is specified then the variable values that are active during the submission might be overwritten.

1.5.2.4 Example 2: Job Classes - Job Template

Second version of the sleeper job class defining job template attributes for the default variant:

```
jcname          sleeper
variant_list    NONE
owner_list      NONE
user_list       NONE
xuser_list      NONE
A               UNSPECIFIED
a               UNSPECIFIED
ar              UNSPECIFIED
b               yes
binding         UNSPECIFIED
c_interval      UNSPECIFIED
c_occasion      UNSPECIFIED
CMDNAME         /bin/sleep
CMDARG          60
ckpt            UNSPECIFIED
ac              UNSPECIFIED
cwd             UNSPECIFIED
display         UNSPECIFIED
dl              UNSPECIFIED
e               UNSPECIFIED
h               UNSPECIFIED
hold_jid        UNSPECIFIED
i               UNSPECIFIED
j               UNSPECIFIED
js              UNSPECIFIED
l_hard          UNSPECIFIED
l_soft          UNSPECIFIED
m               UNSPECIFIED
M               UNSPECIFIED
masterq         UNSPECIFIED
```

```
mbind           UNSPECIFIED
N               Sleeper
notify          UNSPECIFIED
now             UNSPECIFIED
o               UNSPECIFIED
P               UNSPECIFIED
p               UNSPECIFIED
pe_name         UNSPECIFIED
q_hard          UNSPECIFIED
q_soft          UNSPECIFIED
R               UNSPECIFIED
r               UNSPECIFIED
S               /bin/sh
shell           UNSPECIFIED
V               UNSPECIFIED
v               UNSPECIFIED
```

Most of the job template attributes are `UNSPECIFIED`. As a result the corresponding attributes will be ignored and the defaults of the submit client will be used when new jobs are created. When a job is derived from this job class then it will create a job using binary submission `(b yes)` to start the script `/bin/sleep` `(CMDNAME /bin/sleep)`. 60 will be passed as command line argument to this script `(CMDARG 60)`. The name of the job that is created will be Sleeper `(N Sleeper)` and the shell `/bin/sh` will be used to start the command `(S /bin/sh)`.

The definition of the sleeper job class is complete. Now it can be used to submit new jobs:

```
> qsub -jc sleeper
Your job 4097 ("Sleeper") has been submitted

> qsub -S /bin/sh -N Sleeper -b y /bin/sleep
Your job 4098 ("Sleeper") has been submitted
```

Job 4097 is derived from a job class whereas job 4098 is submitted conventionally. The parameters specified in the sleeper job class are identical to the command line arguments that are passed to qsub command to submit the jobs. As a result both jobs are identical. Both use the same shell and job command and therefore they will sleep for 60 seconds after start. The only difference between the two jobs is the submit time and the job id. Users that try to change both jobs after they have been submitted will also encounter an additional differences. It is not allowed to change the specification of job 4097. The reason for this is explained in the next chapter.

1.5.2.5 Access Specifiers to Allow Deviation

Access specifiers are character sequences that can be added to certain places in job class specifications to allow/disallow operations that can be applied to jobs that are derived from that job class. They allow you to express, for instance, that job options defined in the jobs class can be modified, deleted or augmented when submitting a job derived from a job class. This means the job class owner can control how the job class can be used by regular users being allowed to derive jobs from this job class. This makes using job classes simple for the end user (because of a restricted set of modifications). It also avoids errors as well as the need to utilize Job Submission Verifiers for checking on mandatory options.

Per default, if no access specifiers are used, all values within job classes are fixed. This means that jobs that are derived from a job class cannot be changed. Any attempt to adjust a job during the submission or any try to change a job after it has been submitted (e.g. with `qalter`) will be rejected. Also managers are not allowed to change the specification of defined in a job class when submitting a job derived from the job class.

To soften this restriction, job class owners and users having the manager role in a job class can add access specifiers to the specification of a job class to allow deviation at certain places. Access specifiers might appear before each value of a job template attribute and before each entry in a list of key or key/value pairs. The preceding access specifier defines which operations are allowed with the value that follows.

The full syntax for a job class template attribute is defined as <jc_templ_attr>:

```
<jc_templ_attr> := <templ_attr> | <list_templ_attr>
<templ_attr> := <attr_name> ? ? <attr_access_specifier>(<attr_value>|"UNSPECIFIED")
<list_templ_attr> := <list_attr_name> ? ? <attr_access_specifier> <list_attr_value>
<list_attr_value> := <access_specifier> ( (<list_entry> [ ?,? <access_specifier> <list_entry>,
<attr_access_specifier> :=  <access_specifier>
```

Please note the distinction between `<attr_access_specifier>` and `<access_specifier>`. `<attr_access_specifier>` is also an `<access_specifier>` but it is the first one that appears in the definition of list based job template attributes and it is the reason why two access specifiers might appear one after another. The first access specifier regulates access to the list itself whereas the following ones define access rules for the entries in the list they are preceding.

These access specifiers (`<access_specifier>`) are available:

Available Access Specifiers

Access Specifier	Description
	The absence of an access specifier indicates that the corresponding template attribute (or sublist entry) is fixed. Any attempt to modify or delete a specified value or any attempt to add a value where the keyword UNSPECIFIED was used will be rejected. It is also not allowed to add additional entries to lists of list based attributes if a list is fixed.
`{-}`	Values that are tagged with the `{-}` access specifier are removable. If this access specifier is used within list based attributes then removal is only allowed if the list itself is also modifiable. If all list entries of a list are removable then also the list itself must be removable so that the operation will be successful.
`{~}`	Values that are prefixed with the `{~}` access specifier can be changed. If this access specifier is used within list based attributes then the list itself must also be modifiable.

{~−} or {−~}	The combination of the {−} and {~} access specifiers indicates that the value it precedes is modifiable and removable.
{+}UNSPECIFIED or {+...}<list_attr_value>	The {+} access specifier can only appear in combination with the keyword UNSPECIFIED or before list attribute values but not within access specifiers preceding list entries. If it appears before list attribute values it can also be combined with the {~} and {−} access specifiers. This access specifier indicates that something can be added to the specification of a job after it has been submitted. For list based attributes it allows that new list entries can be added to the list.

1.5.2.6 Example 3: Job Classes - Access Specifiers

Here follows the third refinement of the sleeper job class giving its users more flexibility:

```
jcname          sleeper
variant_list    NONE
owner_list      NONE
user_list       NONE
xuser_list      NONE
A               UNSPECIFIED
a               UNSPECIFIED
ar              UNSPECIFIED
b               yes
binding         UNSPECIFIED
c_interval      UNSPECIFIED
c_occasion      UNSPECIFIED
CMDNAME         /bin/sleep
CMDARG          60
ckpt            UNSPECIFIED
ac              UNSPECIFIED
cwd             UNSPECIFIED
display         UNSPECIFIED
dl              UNSPECIFIED
e               UNSPECIFIED
h               UNSPECIFIED
hold_jid        UNSPECIFIED
i               UNSPECIFIED
j               UNSPECIFIED
js              UNSPECIFIED
l_hard          {~+}{~}a=true,b=true,{-}c=true
l_soft          {+}UNSPECIFIED
m               UNSPECIFIED
M               UNSPECIFIED
masterq         UNSPECIFIED
mbind           UNSPECIFIED
N               {~-}Sleeper
notify          UNSPECIFIED
now             UNSPECIFIED
o               UNSPECIFIED
P               UNSPECIFIED
p               UNSPECIFIED
pe_name         UNSPECIFIED
q_hard          UNSPECIFIED
```

```
q_soft          UNSPECIFIED
R               UNSPECIFIED
r               UNSPECIFIED
S               /bin/sh
shell           UNSPECIFIED
V               UNSPECIFIED
v               UNSPECIFIED
```

Now it is allowed to modify or remove the name of sleeper jobs `(N {~-}Sleeper)`. Users deriving jobs from this class are allowed to add soft resource requests `(l_soft {+}UNSPECIFIED)`. New hard resource requests can be added and the ones which are specified within the job class can be adjusted `(l_hard {~+}...)` but there are additional restrictions: The access specifiers preceding the resource requests `(l_hard ...{~}a=true,b=true,{-}c=true)` allow the modification of the resource `a`, the deletion of the resource `c` whereas the value of resource `b` is fixed (no access specifier). Users that try to submit or modify jobs that would violate one of the access specifiers will receive an error message and the request is rejected.

Here are some examples for commands that will be successful:

```
> qsub -jc sleeper -N MySleeperName
> qsub -jc sleeper -soft -l new=true
> qsub -jc sleeper -l a=false,b=true,new=true
```

Here you can see some commands that will be rejected:

```
> qsub -jc sleeper /path/to/my_own_sleeper (CMDNAME is not modifiable)
> qsub -jc sleeper -l a=false,b=false,new=true (l_hard has requested resource b=true. This cann
> qsub -jc sleeper -S /bin/tcsh (S job template attribute does not allow to modify the shell)
```

1.5.2.7 Different Variants of the same Job Class

Job classes represent an application type in a cluster. If the same application should be started with various different settings or if the possible resource selection applied by the Univa Grid Engine system should depend on the mode how the application should be executed then it is possible to define one job class with multiple variants. So think of it as a way to use the same template for very similar types of jobs, yet with small variations.

The `variant_list` job class attribute defines the names of all existing job class variants. If the keyword `NONE` is used or when the list contains only the word `default` then the job class has only one variant. If multiple names are listed here, separated by commas, then the job class will have multiple variants. The `default` variant always has to exist. If the `variant_list` attribute does not contain the word `default` then it will be automatically added by the Univa Grid Engine system upon creating the job class.

Attribute settings for the additional job class variants are specified similar to the attribute settings of queue instances or queue domains of cluster queues. The setting for a variant attribute has to be preceded by the variant name followed by an equal character (?=?) and enclosed in brackets (?[? and ?]?).

The position where access specifiers have to appear is slightly different in this case. The next example will show this (see the `l_soft` and `N` attributes).

1.5.2.8 Example 4: Job Classes - Multiple Variants

The following example shows the excerpt of the sleeper job class with three different variants

```
jcname          sleeper
variant_list    default,short,long
owner_list      NONE
user_list       NONE
xuser_list      NONE
A               UNSPECIFIED
a               UNSPECIFIED
ar              UNSPECIFIED
b               yes
binding         UNSPECIFIED
c_interval      UNSPECIFIED
c_occasion      UNSPECIFIED
CMDNAME         /bin/sleep
CMDARG          60,[short=5],[long=3600]
ckpt            UNSPECIFIED
ac              UNSPECIFIED
cwd             UNSPECIFIED
display         UNSPECIFIED
dl              UNSPECIFIED
e               UNSPECIFIED
h               UNSPECIFIED
hold_jid        UNSPECIFIED
i               UNSPECIFIED
j               UNSPECIFIED
js              UNSPECIFIED
l_hard          {~+}{~}a=true,b=true,{-}c=true
l_soft          {+}UNSPECIFIED,[{~+}long={~}d=true]
m               UNSPECIFIED
M               UNSPECIFIED
masterq         UNSPECIFIED
mbind           UNSPECIFIED
N               {~-}Sleeper,[{~-}short=ShortSleeper],[long=LongSleeper]
notify          UNSPECIFIED
now             UNSPECIFIED
o               UNSPECIFIED
P               UNSPECIFIED
p               UNSPECIFIED
pe_name         UNSPECIFIED
q_hard          UNSPECIFIED
q_soft          UNSPECIFIED
R               UNSPECIFIED
r               UNSPECIFIED
S               /bin/sh
shell           UNSPECIFIED
V               UNSPECIFIED
v               UNSPECIFIED
```

The sleeper job class has now three different variants `(variant_list default,short,long)`. To reference a specific job class variant the name of the job class has to be combined with the name of the variant. Both names have to be separated by a dot

("."). If the variant name is omitted then automatically the default variant is referenced.

```
> qsub -l sleeper
Your job 4099 ("Sleeper") has been submitted

> qsub -l sleeper.short
Your job 4100 ("ShortSleeper") has been submitted

> qsub -l sleeper.long
Your job 4101 ("LongSleeper") has been submitted
```

The returned message from the submit commands already indicats that there are differences between the three jobs. The jobs have different names. Compared to the other jobs, the job 4101 has an additional soft resource request `d=true (l_soft ...,[{~+}long={~}d=true])`. Job 4100 that was derived from the `sleeper.short` job class variant has no soft requests. Nothing was explicitely specified here for this variant and therefore it will implicitely use the setting of the `sleeper.default` job class variant `(l_soft {+}UNSPECIFIED,...)`. Moreover, the job name (see the `N` attribute) can be modified or removed for the default and short variant but is fixed for the long variant.

1.5.2.9 Enforcing Cluster Wide Requests with the Template Job Class

After a default installation of Univa Grid Engine 8.1 there exists one job class with the name `template`. This job class has a special meaning and it cannot be used to create new jobs. Its configuration can only be adjusted by users having the manager role. This jobs class acts as parent job class for all other job classes that are created in the system.

The values of job template attributes in this template job class and the corresponding access specifiers restrict the allowed settings of all corresponding job template attributes of other job classes. As default the `{+}UNSPECIFIED` add access specifier and keyword is used in the template job class in combination with all job template attributes. Due to that any setting is allowed to other job class attributes after Univa Grid Engine 8.1 has been installed.

This parent-child relationship is especially useful when all jobs that are submitted into a cluster are derived from job classes. Managers might then change the settings within the template. All other existing job classes that violate the settings will then switch into the configuration conflict state. The owners of those job classes have to adjust the settings before new jobs can be derived from them. All those users that intend to create a new job class that violates the settings of the template job class will receive an error.

You will also want to use the template job class to enforce restrictions on the access specifiers which can be used in job classes. Since any job class, whether create by a manager account or by regular users, is derived from the template job class those derived job classes are bound to stay within the limits defined by the template job class. So parameters which have been defined as fixed in the template job class, for instance, cannot be modified in any job class created by a manager or user. Likewise, parameters which have a preset value but are configured to allow deletion only cannot be modified in derived job classes. The following table shows the allowed transitions:

Allowed Access Specifier Transitions

Access Specifier in Template JC	Allowed Access Specifier in Child JC
...	...
UNSPECIFIED	UNSPECIFIED
{~}...	{~}... ...
{-}...	{-}... {~}... UNSPECIFIED ...
{-~}...	{-~}... {-}... {~}... UNSPECIFIED ...
{+}...	{+}... {-~}... {-}... {~}... UNSPECIFIED ...

1.5.3 Relationship Between Job Classes and Other Objects

To fully integrate job classes into the already existing Univa Grid Engine system the possibility is provided to create new relations between current object types (like queues, resource quotas, JSV) and job classes.

1.5.3.1 Resources Available for Job Classes

The profile of a job is defined by the resource requirements and other job attributes. Queues and host objects define possible execution environments where jobs can be executed. When a job is eligible for execution then the scheduler component of the Univa Grid Engine system tries to find the execution environment that fits best according to all job specific attributes and the configured policies so that this job can be executed.

This decision making process can be difficult and time consuming especially when certain jobs having special resource requirements should only be allowed to run in a subset of the available execution environments. The use of job classes might help here because job classes will give the scheduler additional information on which execution environments will or will not fit for a job. The need to evaluate all the details about available resources of an execution environment and about the job's requirements will be reduced or can be completely eliminated during the decision making process.

This is achieved by an additional paramter in the queue configuration which provides a direct association between queues and one or multiple job classes. This paramter is called `jc_list` and might be set to the value `NONE` or a list of job classes or job class variant names. If a list of names is specified then the special keyword ANY_JC and/or NO_JC might

be used within the list to filter all those jobs that are in principle allowed to run in this queues. The following combinations are useful:

Useful Values for the `jc_list` Attribute of a Queue

Value	Description
`NONE`	No job may enter the queue.
`ANY_JC`	Jobs may enter the queue that were derived from a job class.
`NO_JC`	Only jobs may enter the queue that were **not** derived from a job class.
`ANY_JC, NO_JC`	Any job, independent if it was derived from a job class or not, may be executed in the queue. This is the default for any queue that is created in a cluster.
`<list of JC names>`	Only those jobs may get scheduled in the queue if they were derived from one of the enlisted job classes.
`NO_JC, <list of JC names>`	Only those jobs that were not derived from a job class or those that were derived from one of the enlisted job classes can be executed here.

This relationship helps the scheduler during the decision making to eliminate queues early without the need to further look at all the details like resource requirements.

Managers of Grid Engine Clusters may want to take care that there is at least one queue in the cluster available that use the `ANY_JC` keyword. Otherwise jobs of users who have defined their own job class will not get cluster resources. Also at least one queue using the `NO_JC` keyword may need to be available. Otherwise conventionally submitted jobs will not get scheduled.

1.5.3.2 Defining Job Class Limits

Resource quota sets can be defined to influence the resource selection in the scheduler. The `jcs` filter within a resource quota rule may contain a comma separated list of job class names. This parameter filters for jobs requesting a job class in the list. Any job class not in the list will not be considered for the resource quota rule. If no `jcs` filter is used, all job classes and jobs with no job class specification match the rule. To exclude a job class from the rule, the name can be prefixed with the exclamation mark (!). ?!*? means only jobs with no job class specification.

1.5.3.3 Example: Resource Quota Set Using a Job Class Filter

```
name max_virtual_free_on_lx_hosts_for_app_1_2
description "quota for virtual_free restriction"
enabled true
limit users {user1,user2} hosts {@lx_host} jcs {app1, app2} to vf=6G
limit users {*} hosts {@lx_host} jcs {other_app, !*} to vf=4G
```

The example above restricts `user1` and `user2` to `6G` `virtual_free` memory for all jobs derived from of job class `app1` or `app2` on each Linux host part of the `@lx_hosts` host

group. All users that either do not derive from a job class or request the job class named `other_app` will have a limit of `4G`.

1.5.3.4 JSV and Job Class Interaction

During the submission of a job multiple Job Submission Verifiers can be involved that verify and possibly correct or reject a job. With conventional job submission (without job classes) each JSV will see the job specification of a job that was specified at the command line via switches and passed parameters or it will see the job parameters that were chosen within the dialogs of the GUI.

When Jobs are derived from a job class then the process of evaluation via JSV scripts is the same but the job parameters that are visible in client JSVs are different. A client JSV will only see the requested job class via a parameter named `jc` and it will see all those parameters that were specified at the command line. All parameters that are defined in the job class itself cannot be seen.

Job classes will be resolved within the `sge_qmaster` process as soon as a request is received that tries to submit a job that should be derived from a job class. The following steps are taken (simplified process):

```
1) Create a new job structure

2) Fill job structure with defaults values

3) Fill job structure with values defined in the job class
   (This might overwrite default values)

4) Fill job structure with values defined at the command line
   (This might overwrite default values and values that were defined in the job class)

5) Trigger server JSV to verify and possibly adjust the job
   (This might overwrite default values, JC values and values specified at the command line)

6) Check if the job structure violates access specifiers
```

If the server JSV changes the `jc` parameter of the job in step 5 then the submission process restarts from step 1 using the new job class for step 3.

Please note that the violation of the access specifiers is checked in the last step. As result a server JSV is also not allowed to apply modifications to the job that would violate any access specifiers defined in the job class specification.

1.5.4 Commands to Adjust Job Classes

1.5.4.1 Creating, Modifying and Deleting Job Classes

Job Classes can be created, modified or deleted with the following commands.

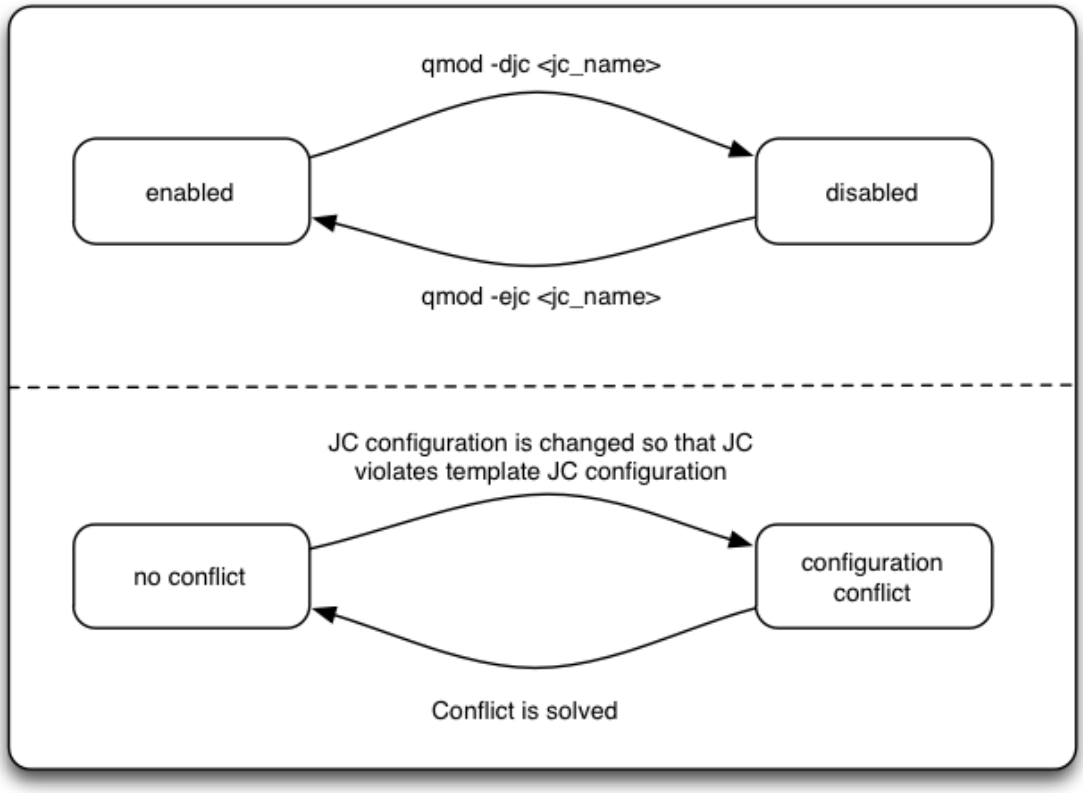
- `qconf -ajc <jcname>`
  This is the command to add a new job class object. It opens an editor and shows the

default parameters for a job class. After changing, saving necessary values and closing the editor, a new job class is created.

- `qconf -Ajc <filename>`
  Adds a new job class object with its specification being stored in the specified file.
- `qconf -djc <jcname>`
  Deletes a job class object with the given name.
- `qconf -mjc <jcname>`
  Opens an editor and shows the current specification of the job class with the name `<jcname>`. After changing attributes, saving the modifications and closing the editor, the object is modified accordingly.
- `qconf -Mjc <filename>`
  Modifies a job class object from file.
- `qconf -sjc <jcname>`
  Shows the current specification of the job class with the name `<jcname>`.
- `qconf -sjcl`
  Shows all names of existing job class objects that exist in a cluster.

1.5.4.2 States of Job Classes

Job Classes have a combined state that is the result of following the sub states: *enabled/disabled*, *no conflict/configuration conflict*



The *enabled/disabled* state is a manual state. A state change from *enabled* to *disabled* can be triggered with the `qmod -djc <jcname>` command. The command `qmod -ejc <jcname>` command can be used to trigger a state change from *disabled* to enabled. Job

Classes in the *disabled* state cannot be used to create new jobs.

The *no conflict/configuration conflict* state is an automatic state that cannot be changed manually. Job classes that do not violate the configuration of the `template` job class are in the *no conflict* state. A job class in this state can be used to create new jobs (if it is also in *enabled* state). If the `template` job class or a derived job class is changed so that either a configuration setting or one of the access specifiers of the `template` job class is violated then the derived job class will automatically switch from the *no conflict* into the *configuration conflict* state. This state will also be left automatically when the violation is eliminated.

1.5.5 Using Job Classes to Submit New Jobs

Job Classes that are in the *enabled* and *no conflict* state can be used to create new jobs. To do this a user has to pass the `-jc` switch in combination with the name of a job class to a submit command like `qsub`. If the user has access to this job class then a new job will be created and all job template attributes that are defined in the job class will be used to initialize the corresponding parameters in the submitted job.

Depending on the access specifiers that are used in the job class it might be allowed to adjust certain parameters during the submission of the job. In this case additional switches and parameters might be passed to the submit command. All these additionally passed parameters will be used to adjust job parameters that where derived from the job class.

Additionally to the typical switches that are used to define job parameters there is a set of switches available that allow to remove parameters or to adjust parts of list based parameters in a job specification. The same set of switches can also be used with the modification command `qalter` to adjust job parameters after a job has already been created.

- `qsub/qalter -clearp <attr_name>`
  The `-clearp` switch allows to remove a job parameter from the specification of a job as if it was never specified. What this means depends on the job parameter that is specified by `<attr_name>`. For all those attributes that would normally have a default value this default value will be set for all others the corresponding attribute will be empty. Parameter names that can be specified for `<attr_name>` are all the ones that are specified in the table above showing job template attribute names.

- `qsub/qalter -clears <list_attr_name> <key>`
  This switch allows to remove a list entry in a list based attribute of a job specification. `<list_attr_name>` might be any name of a job template attribute that is tagged with the asterisk (*) in the the table above. `<key>` has to be the name of the key of the sublist entry for key/value pairs or the value itself that should be removed when the list contains only values

- `qsub/qalter -adds <list_attr_name> <key> <value>`
  `-adds` adds a new entry to a list based parameter.

- `qsub/qalter -mods <list_attr_name> <key> <value>`
  The `-mods` switch allows to modify the value of a key/value pair within a list based job parameter.

1.5.6 Example: Submit a Job Class Job and Adjust Some Parameters

Assume that the following job class is defined in you cluster:

```
jcname          sleeper
variant_list    default,short,long
owner_list      NONE
user_list       NONE
xuser_list      NONE
A               UNSPECIFIED
a               UNSPECIFIED
ar              UNSPECIFIED
b               yes
binding         UNSPECIFIED
c_interval      UNSPECIFIED
c_occasion      UNSPECIFIED
CMDNAME         /bin/sleep
CMDARG          60,[short=5],[long=3600]
ckpt            UNSPECIFIED
ac              UNSPECIFIED
cwd             UNSPECIFIED
display         UNSPECIFIED
dl              UNSPECIFIED
e               UNSPECIFIED
h               UNSPECIFIED
hold_jid        UNSPECIFIED
i               UNSPECIFIED
j               UNSPECIFIED
js              UNSPECIFIED
l_hard          {~+}{~}a=true,b=true,{-}c=true
l_soft          {+}UNSPECIFIED,[{~+}long={~}d=true]
m               UNSPECIFIED
M               UNSPECIFIED
masterq         UNSPECIFIED
mbind           UNSPECIFIED
N               {~-}Sleeper,[{~-}short=ShortSleeper],[{~-}long=LongSleeper]
notify          UNSPECIFIED
now             UNSPECIFIED
o               UNSPECIFIED
P               UNSPECIFIED
p               UNSPECIFIED
pe_name         UNSPECIFIED
q_hard          UNSPECIFIED
q_soft          UNSPECIFIED
R               UNSPECIFIED
r               UNSPECIFIED
S               /bin/sh
shell           UNSPECIFIED
V               UNSPECIFIED
v               UNSPECIFIED
```

Now it is possible to submit jobs and to adjust the parameters of thos jobs during the submission to fit specific needs:

```
1) qsub -jc sleeper -N MySleeper
2) qsub -jc sleeper.short -clearp N
3) qsub -jc sleeper.short -clears l_hard c -adds l_hard h_vmem 5G
```

```
4) qsub -jc sleeper.long -soft -l res_x=3
```

The first job that is submitted (1) will be derived from the sleeper.default job class variant but this job will get the name `MySleeper`.

Job (2) uses the sleeper.short job class but the job name is adjusted. The `-clearp` switch will remove the job name that is specified in the job class. Instead it will get the default job name that would have been assigned without specifying the name in any explicit way. This will be derived from the last part of the script command that will be executed. This script is `/bin/sleep`. So the job name of the new job will be `sleep`.

When job (3) is created the list of hard resource requirements is adjusted. The resource request `c` is removed and the `h_vmem=5G` resource request is added.

During the submission of job (4) The list of soft resource request is completely redefined. The use of the `-l` will completely replace already defined soft resource requests if any have been defined.

Please note that it is not allowed to trigger operations that would violate any access specifiers. In consequence, the following commands would be rejected:

```
5) qsub -jc sleeper -hard -l res_x 3 (This would remove the a and b resource requests)
6) qsub -jc sleeper /bin/my_sleeper 61 (Neither CMDNAME nor the CMDARGs are modifiable)
```

1.5.7 Status of Job Classes and Corresponding Jobs

The `-fjc` switch of the `qstat` command can be used to display all existing job classes and jobs that have been derived from them.

```
> qstat -fjc
job class                                                                    O U states
----------------------------------------------------------------------------------------
sleeper.default                                                                X
  42145 0.55500 Sleeper    user         r     05/15/2012 15:30:47     1
  42146 0.55500 Sleeper    user         r     05/15/2012 15:30:47     1
  42147 0.55500 Sleeper    user         r     05/15/2012 15:30:47     1
  42148 0.55500 Sleeper    user         r     05/15/2012 15:30:47     1
----------------------------------------------------------------------------------------
sleeper.long                                                                   X d
----------------------------------------------------------------------------------------
sleeper.short                                                                  X
  42149 0.55500 ShortSleep user        r     05/15/2012 15:30:57     1
  42150 0.55500 ShortSleep user        r     05/15/2012 15:30:57     1
  42151 0.55500 ShortSleep user        r     05/15/2012 15:30:57     1
----------------------------------------------------------------------------------------
template.default
```

The *O* column shows if the user executing the `qstat` command is the owner of the job class and the *U*-column is tagged with an *X* if the corresponding job class can be used by that user to derive new jobs.

The states column will show the character *d* if the corresponding job class variant is in *disabled* state and a *c* if the class is in the *configuration conflict* state. In all other cases the column will be empty. This indicates that the job class variant can be used to create a new job.

1.6 Monitoring and Controlling Jobs

1.6.1 Getting Status Information on Jobs

The command line tool **qstat** delivers all the available status information for jobs. *qstat* supplies various possibilities to present the available information.

TABLE: The Most Common Ways to Use `qstat`

Command	Description
qstat	Without options, *qstat* lists all jobs but without any queue status information.
qstat -f	The *-f* option causes qstat to display a summary information of all cause including its load accompanied by the list of all queued as also all pending jobs.
qstat -ext	The *-ext* option causes qstat to displays usage information and the ticket consumption of each job.
qstat -j <job_id>	The *-j* option causes qstat to display detailed information of a currently queued job.

Examples:

```
# qstat
job-ID  prior   name       user         state submit/start at     queue
---------------------------------------------------------------------------------------------
      4 0.55500 job1       user1        r     04/28/2011 09:35:34 all.q@host1
      5 0.55500 job2       user1        r     04/28/2011 09:35:34 all.q@host2
      6 0.55500 job3       user1        r     04/28/2011 09:35:34 all.q@host2

# qstat -f
queuename                      qtype resv/used/tot. load_avg arch          states
---------------------------------------------------------------------------------
all.q@host1                    BIPC  0/3/10         0.04     lx-amd64
     16 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     18 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     23 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
---------------------------------------------------------------------------------
all.q@host2                    BIPC  0/3/10         0.04     lx-x86
     15 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     19 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     22 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
---------------------------------------------------------------------------------
all.q@host3                    BIPC  0/3/10         0.04     sol-amd64
     14 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     17 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     21 0.55500 Sleeper    user1        t     04/28/2011 09:36:44     1
---------------------------------------------------------------------------------
```

```
all.q@host4                   BIPC  0/3/10         1.35     lx-amd64
     20 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     24 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
     25 0.55500 Sleeper    user1        r     04/28/2011 09:36:44     1
```

It is also possible to be informed by the Univa Grid Engine system via mail on the status change of a job. To use this feature it necessary to set the *-m* option while submitting the job. This option is available for *qsub*, *qsh*, *qrsh*, *qlogin* and *qalter*.

TABLE: Mail Options to Monitor Jobs

Option	Description
b	Send mail at the beginning of a job.
e	Send mail at the end of a job.
a	Send mail when job is aborted or rescheduled.
s	Send mail when job is suspended.
n	Send no mail (default).

Example: Univa Grid Engine will send mail at the beginning as well as the end of the job:

```
# qsub -m be test_job.sh
```

1.6.2 Deleting a Job

To delete a job, the **qdel** binary is used.

TABLE: Optional `qdel` Parameters

Parameter	Description
-f <job_id[s]>	Forces the deletion a job even if the responsible execution host does not respond.
<job_id > -t <range>	Deletes specific tasks of an array job. It is also possible to delete a specific range of array jobs.
-u <user_list>	Deletes all job of the specified user.

The behavior of how Univa Grid Engine handles a forced deletion can be altered by using the following qmaster parameters. This option can be set via **qconf -mconf** as **qmaster_params**.

TABLE: `qmaster` Parameters for Forced Job Deletion

Parameter	Description
ENABLE_FORCED_QDEL	If this parameter is set, users are allowed to force job deletion on their own jobs. Otherwise

	only the Univa Grid Engine managers are allowed to perform those actions.
ENABLE_FORCED_QDEL_IF_UNKNOWN	If this parameter is set, qdel <job_id> will automatically invoke a forced job deletion if the host, where the job is running, is of *unknown status*.

Examples:

Delete all jobs in the cluster (only possible for Univa Grid Engine managers):

```
# qdel -u "*"
```

Delete tasks 2-10 out of array job with the id 5:

```
# qdel 5 -t 2-10
```

Forced deletion of jobs 2 and 5:

```
# qdel -f 2 5
```

1.6.3 Re-queuing a Job

A job can be rescheduled only if its *rerun* flag is set. This can be done either at time of submission via the *-r* option of **qsub**, or belatedly via the *-r* option of **qalter** as well as via the *rerun* configuration parameter for queues. This *rerun* configuration can be set with **qconf -mq <queue_name>**.

Examples:

```
# qsub -r yes <job_script>
```

```
# qalter -r yes <job_id>
```

There are two different ways to reschedule jobs.

Examples:

Reschedule a job:

```
# qmod -rj <job_id[s]>
```

Reschedule all jobs in a queue:

```
# qmod -rq <queue|queue_instance>
```

Rescheduled jobs are designated **Rr** (e.g. shown by *qstat*).

Example:

```
# qstat -f
queuename                      qtype resv/used/tot. load_avg arch          states
---------------------------------------------------------------------------------
all.q@host1                    BIPC  0/2/10         0.01     lx-amd64
    53 0.55500 Sleeper     user1        Rr    05/02/2011 15:31:10     2
---------------------------------------------------------------------------------
all.q@host2                    BIPC  0/2/10         0.01     lx-x86
    53 0.55500 Sleeper     user1        Rr    05/02/2011 15:31:10     2
---------------------------------------------------------------------------------
all.q@host3                    BIPC  0/1/10         0.03     sol-amd64
    53 0.55500 Sleeper     user1        Rr    05/02/2011 15:31:10     1
---------------------------------------------------------------------------------
all.q@host4                    BIPC  0/0/10         0.06     lx-amd64
```

1.6.4 Modifying a Waiting Job

To change attributes of a pending job **qalter** is used.

qalter is able to change most of the characteristics of a job even those which were set as embedded flags in the script files. Consult the submit(1) main page in regards to the options that can be altered (e.g. the job script).

1.6.4.1 Altering Job Requirements

It is also possible to alter the requirements of a pending job which have been defined via the **-l** flag at time or submission.

Example:

Submit a job to host1

```
# qsub -l h=host1 script.sh
```

Alter the host-requirement of this job (with the assumed job-id 45) to host2

```
# qalter -l h=host2 45
```

Note
By altering requested requirements the with **-l**, keep in mind that the requirements become the new requirements thus the requirements which do **not** require change must be re-requested.

Example:

Submit a job with the requirement to run on host1 and and on queue2:

```
# qsub -l h=host1,q=queue2 script.sh
```

Alter the host-requirement of this job (with the assumed job-id 45) to host5 and re-request queue2 as requirement

```
# qalter -l h=host5,q=queue2 45
```

If queue2 is NOT stated in the qalter-call, the job will run on any available queue in host5.

1.6.4.2 Changing Job Priority

To change the priority of a job the **-p** option of **qalter** can be used. It is possible to alter the priority within the range between **-1023** and **1024** whereas a negative number decreases priority and a positive one to increases it.

If not submitted differently, the default priority is 0.

As previously mentioned, a user can only alter his own jobs and in this case, a user is only able to **decrease** the priority of a job. To increase the priority, the user needs to be either Univa Grid Engine administrator or Univa Grid Engine manager.

Examples:

Increase the job priority of job 45:

```
# qalter -p 5 45
```

Decrease the job priority of 45:

```
# qalter -p -5 45
```

1.6.5 Obtaining the Job History

To get the history of a job and its accounting information use **qacct**.

qacct parses the accounting file written by *qmaster* and lists all available information for a given job. This includes accounting data such as wall-clock time, cpu-time or memory consumption as also the host where job ran and e.g. the exit-status of the job script. The default Univa Grid Engine accounting file resists in *<sge_root>/<cell>/common/accounting*. See **accounting(5)** for more information e.g. how the file is composed and what information is stored in it.

Example: Show the accounting information of job 65:

```
# qacct -j 65
==============================================================
qname        all.q
hostname     host1
group        users
owner        user1
project      NONE
department   defaultdepartment
jobname      Sleeper
jobnumber    65
taskid       undefined
account      sge
priority     0
qsub_time    Mon May  9 14:27:32 2011
start_time   Mon May  9 14:27:35 2011
```

```
end_time      Mon May  9 14:28:20 2011
granted_pe    mytestpe
slots         5
failed        0
exit_status   0
ru_wallclock 45
ru_utime      0.026
ru_stime      0.019
ru_maxrss     1856
ru_ixrss      0
ru_ismrss     0
ru_idrss      0
ru_isrss      0
ru_minflt     10649
ru_majflt     0
ru_nswap      0
ru_inblock    0
ru_oublock    24
ru_msgsnd     0
ru_msgrcv     0
ru_nsignals   0
ru_nvcsw      101
ru_nivcsw     26
cpu           0.045
mem           0.000
io            0.000
iow           0.000
maxvmem       17.949M
arid          undefined
```

1.7 Other Job Types

1.7.1 Array Jobs

Array jobs are, as mentioned in Types of Workloads being Managed by Univa Grid Engine, those that start a batch job or a parallel job multiple times. Those simultaneously-run jobs are called tasks. Each job receives an unique ID necessary to identify each of them and distribute the workload over the array job.

Submit an array job:

The default output- and error-files are *job_name.[o|e]job_id* and *job_name.[o|e]job_id.task_id*. This means that Univa Grid Engine creates an output- and an error-file for each task plus one for the superordinate array-job. To alter this behavior use the -o and -e option of qsub. If the redirection options of qsub are use (-o and/or -e), the results of the individual will be merged into the defined one.

TABLE: Available Pseudo Environment Variables

Pseudo env variable	Description
$USER	User name of the submitting user
$HOME	Home directory of the submitting user

$JOB_ID	ID of the job
$JOB_NAME	Name of the job
$HOSTNAME	Hostname of the execution host
$SGE_TASK_ID	ID of the array task

The -t option of qsub indicates the job as an array job. The -t option has the following syntax:

```
qsub -t n[-m[:s]] <batch_script>
```

TABLE: `-t` Option Syntax

n	indicates the start-id.
m	indicates the max-id.
s	indicates the step size.

Examples:

qsub -t 10 array.sh submits a job with 1 task where the task-id is 10.

qsub -t 1-10 array.sh submits a job with 10 tasks numbered consecutively from 1 to 10.

qsub -t 2-10:2 array.sh submits a jobs with 5 tasks numbered consecutively with step size 2 (task-ids 2,4,6,8,10).

Besides the pseudo environment variables already mentioned, the following variables are also exposed which can be used in the script file:

TABLE: Pseudo Environment Variables Available for Scripts

Pseudo env variable	Description
$SGE_TASK_ID	ID of the array task
$SGE_TASK_FIRST	ID of the first array task
$SGE_TASK_LAST	ID of the last array task
$SGE_TASK_STEPSIZE	step size

Example of an array job script:

```
#!/bin/csh

# redirect the output-file of the batch job
#$ -o /tmp/array_out.$JOB_ID
# redirect the error-file of the batch job
#$ -e /tmp/array_err.$JOB_ID

# starts data_handler with data.* as input file
/tmp/data_handler -i /tmp/data.$SGE_TASK_ID
```

Alter an array job:

It is possible to change the attributes of array jobs. But the changes will only affect the pending tasks of an array job. Already running tasks are untouched.

Configuration variables (see *sge_conf(5)*):

max_aj_instances indicates the maximum number of instances of an array job which can run simultaneously.

max_aj_tasks indicates the maximum number of tasks a array job can have.

It is also possible to limit the maximum number of concurrently running tasks of an array job via the *-tc* switch of qsub.

Example:

Submit a job with 20 tasks but only 10 of then can run concurrently. *qsub -t 1-20 -tc 10 array.sh*

1.7.2 Interactive Jobs

Usually, Univa Grid Engine uses its own built-in mechanism to establish a connection to the execution host. It is possible to change this to e.g. ssh or telnet, of course.

Configuration variable	Description
qlogin_command	Command to execute on local host if qlogin is started.
qlogin_daemon	Daemon to start on execution host if qlogin is started.
rlogin_command	Command to execute on local host if qrsh is started **without** a command name as argument to execute remotely.
rlogin_daemon	Daemon to start on execution host if qrsh is started **without** a command name as argument to execute remotely.
rsh_command	Command to execute on local host if qrsh is started **with** a command name as argument to execute remotely.
rsh_daemon	Daemon to start on execution host if qrsh is started **with** a command name as argument to execute remotely.

Example of a qlogin configuration:

```
qlogin_command   /usr/bin/telnet
qlogin_daemon    /usr/sbin/in.telnetd
```

The configured commands (qlogin_command, rlogin_command and rsh_command) are started with the execution host, the port number and, in case of rsh_command, also the

command name to execute as arguments.

Example:

```
/usr/bin/telnet exec_host 1234
```

Consult sge_conf(5) for more information.

1.7.2.1 qrsh and qlogin

qrsh without a command name as argument and qlogin submit an interactive job to the queuing system which starts a remote session on the execution host where the current local terminal is used for I/O. This is similar to rlogin or a ssh session without a command name.

qrsh with a command executes the command on the execution host and redirects the I/O to the current local terminal. By default, qrsh with command does not open a pseudo terminal (PTY), other than qlogin and qrsh without command, on the execution host. It simply pipes the in- and output to the local terminal. This behavior can by changed via the *-pty yes* option as there are applications that rely on a PTY.

Those jobs can only run in INTERACTIVE queues unless the jobs are not explicitly marked as non-immediate job using the *-now no* option.

1.7.2.2 qtcsh

qtcsh is a fully compatible extension of the UNIX C-shell clone tcsh (it is based on tcsh version 6.08). qtcsh provides an ordinary tcsh with the capacity to run certain defined applications distributed within the Univa Grid Engine system. Those defined applications will run in the background as an interactive qrsh call and has to be pre-defined in the **.qtask**-file.

.qtask file format:

```
[!]<app-name> <qrsh-options>
```

The optional exclamation point indicates that the users .qtask file is not allowed to overwrite the global .qtask file if set.

Example:

```
# This causes within a qtcsh-session that all rm-calls are invoked via qrsh on the denoted host
rm -l h=fileserver_host
```

This means that a

```
rm foo
```

within an qtcsh-session will be translated into

```
qrsh -l =h fileserver_host rm foo
```

1.7.2.3 qmake

qmake facilitates the possibility to distribute Makefile processing in parallel over the Univa Grid Engine. It is based on GNU Make 3.78.1. All valid options for qsub and qrsh are also available for qmake. Options which has to be passed to GNU Make has to be placed after the "--"-separator.

Syntax:

```
qmake [ options ] -- [ gmake options ]
```

Typical examples how to use qmake:

```
qmake -cwd -v PATH -pe compiling 1-10 -- -debug
```

This call changes the remote execution host into the current working directory, exports the **$PATH** environment variable and requests between 1 and 10 slots in the parallel environment *compiling*. This call is listed as one job in the Univa Grid Engine system.

This means that Univa Grid Engine starts up to 10 qrsh sessions depending on available slots and what is needed by GNU Make. The option -debug will, as it is after the "--"-separator, be passed to the GNU Make instances.

As there is no special architecture requested, Univa Grid Engine assumes the one set in the environment variable **$SGE_ARCH**. If it is not set, qmake will produce a warning and start the make process on any available architecture.

```
qmake -l arch=lx26-amd64 -cwd -v PATH --
```

Other than the example above, qmake is not bound to a parallel environment in this case. qmake will start an own qrsh job for every GNU Make rule listed in the Makefiles.

Furthermore, qmake support two different modes of invocation:

Interactive mode: qmake invoked by command line implicitly submits a qrsh-job. On this master machine the parallel make procedures will be started and qmake will distribute the make targets and steps to the other hosts which are chosen.

Batch mode: If qmake with the **--inherit** option is embedded in a simple batch script the qmake process will inherit all resource requirements from the calling batch job. Eventually declared parallel environments (pe) or the *-j* option in the qmake line within the script will be ignored.

Example:

```
#!/bin/csh
qmake --inherit --
```

Submit:

```
qsub -cwd -v PATH -pe compiling 1-10 <shell_script>
```

1.7.2.4 qsh

qsh opens a **xterm** via an interactive X-windows session on the execution host. The display is directed either to the X-server indicated by the *$DISPLAY* environment variable or the one which was set by the *-display* qsh command line option. If no display is set, Univa Grid Engine tries to direct the display to 0.0 of the submit host.

1.7.3 Parallel Jobs

A parallel job runs simultaneously across multiple execution hosts. To run parallel jobs within the Univa Grid Engine system it is necessary to set up **parallel environments** (pe). It is customary is to have several of such parallel environments e.g. for the different MPI implementations which are used or different ones for tight and loose integration. To take advantage of parallel execution, the application has to support this. There are a dozen software implementations that support parallel tasks like *OpenMPI*, *LAM-MPI*, *MPICH* or *PVM*.

Univa Grid Engine supports two different ways of executing parallel jobs:

- Loose Integration

  Univa Grid Engine generates a custom machine file listing all execution hosts chosen for the job. Univa Grid Engine does not control the parallel job itself and its distributed tasks. This means that there is no tracking of resource consumption of the tasks and no way to delete runaway tasks. However, it is easy to set up and nearly all parallel application technologies are supported.

- Tight Integration

  Univa Grid Engine takes control of the whole parallel job execution. This includes spawning and controlling of all parallel tasks. Unlike the *Loose Integration* Univa Grid Engine is able to track the resource usage correctly including all parallel tasks as also to delete runaway tasks via *qdel*. However the parallel applications has to support the tight Univa Grid Engine integration (e.g. OpenMPI which has to be built with *--enable-sge*).

1.7.3.1 Parallel Environments

Setup a parallel environment

```
qconf -ap my_parallel_env
```

This will create a parallel environment with the name *my_parallel_env*. In the opening editor it is possible to change the properties of the pe.

TABLE: Properties of the Parallel Environment (PE)

Property	Description
pe_name	The name of the parallel environment. This one has to be specified at job submission.
slots	The maximum number of slots which can be used/requested concurrently.
user_lists	User-sets which are allowed to use this pe. If NONE is set, everybody is allowed to use this pe.
xuser_lists	User-sets which are **not** allowed to use this pe. If NONE is set, everybody is allowed to use this pe.
start_proc_args	This command is started prior the execution of the parallel job script.
stop_proc_args	This command proceeds the execution of the parallel job script finished.
allocation_rule	The allocation rule is interpreted by the scheduler and helps to determine the distribution of parallel processes among the available execution hosts. There are three different rules available: • **<int>:** This defines the number of max processes allocated at each host. • **$fill_up:** All available slots on a host will be used (filled up). If there are no more slots available on this particular host, the remaining processes will be distributed to the next host. • **$round_robin:** All processes of a parallel job will be uniformly distributed of the Univa Grid Engine system.
control_slaves	This options is in control when the parallel environment is loose or tightly integrated.
job_is_first_task	This parameter indicates if the job submitted already contains one of the parallel tasks.
urgency_slots	For pending jobs with a slot range pe request, the number of slots is not determined. This setting specifies the method to be used by Univa Grid Engine to assess the number of slots such jobs might finally get. These methods are available: • **<int>:** This integer number is used as prospective number of slots. • **min:** The slot range minimum is used as prospective number of slots. • **max:** The slot range maximum is used as prospective number of slots. • **avg:** The average of all numbers occurring within the job's pe range request is assumed.

accounting_summary	If set to *TRUE*, the accounting summary of all tasks are combined in one single accounting record otherwise every task is stored in an own accounting record. This option is only considered if *control_slaves* is also set.

TABLE: Examples and Templates for MPI and PVM

Example/Template	Parallel Environment
/SGE_ROOT/mpi/	MPI and MPICH
/SGE_ROOT/pvm/	PVM

See sge_pe(5) for detailed information.

1.7.3.2 Submitting Parallel Jobs

TABLE: Parameters to Submit a Parallel Job

<table>
<tr><th>Parameter</th><th>Description</th></tr>
<tr><td>-pe parallel_environment n[-[m]][-]m</td><td>This parameter indicates that this is a parallel job.
Note
For declaring the parallel_environment the wildcard character * is allowed (e.g. mpi*).

TABLE: Allowed Range Specifications for Job
<table><tr><th>Allowed Range Specification</th><th>Description and Example</th></tr><tr><td>n-m</td><td>Minimum n slots and Maximum m slots

2-10</td></tr><tr><td>m</td><td>This is an abbreviation for m-m. Exactly m slots are needed.

10</td></tr><tr><td>-m</td><td>This is an abbreviation for 1-m.

-10</td></tr><tr><td>n-</td><td>At least n slots are needed but as much as possible slots are wanted.

10-</td></tr></table></td></tr>
<tr><td>-masterq queue</td><td>With this parameter it is possible to define on which queue the master task has run.</td></tr>
</table>

Example:

```
qsub -pe mpi_pe 4-10 -masterq super.q mpi.sh
```

See submit(1) for more information.

1.7.3.3 Parallel Jobs and Core Binding

Parallel jobs can exploit the core binding feature in different ways. The following sections provides an overview of there different methods which can be used.

1.7.3.3.1 Using the -binding pe Request

One possibility of assigning CPU cores to a job is using the "pe" flag of the binding option itself. The following example demonstrates requesting two cores per host, as well as two slots per host, on all two hosts where the parallel job runs.

```
qsub -binding pe linear:2 -pe fixed2 4 ...
```

Note, that the parallel environment fixed2 contains following fixed allocation rule:

```
allocation_rule 2
```

The allocation rule enforces the scheduler to select two slots per host, while the binding request enforces the scheduler to select 2 free cores per host.

After dispatching the parallel job, the selected cores are marked as used in the scheduler. This can be displayed using the qhost -F m_topology_inuse topology string. The selected cores of a specific parallel job are displayed in the **qstat -j <jobno>** output in the binding output.

```
binding                1:    host_10=0,0:0,1, host_12=0,0:0,1
```

This means that on *host_10* the job got core 0 and core 1 on the socket 0 and on *host_12* the same core selection was done.

With using the **-binding pe** option the scheduler does its decision and marks those cores as used but on the execution side no real core binding done (in contrast to the **-binding set** (which equals just **-binding**) option. What Univa Grid Engine does is that it writes its decision to the **pe_hostfile** in the last column. This file is usually exploited by tight parallel jobs integration.

In the example it looks as follows:

```
host_10 2 all.q@macsuse 0,0:0,1
host_12 2 all.q@u1010 0,0:0,1
```

Using these <socket,core> pairs which are separated by a ":" sign the parallel job can exploit the information and bind the parallel jobs on these cores. Note, that when having multiple queue instances on a host and the parallel job spans over different queue instances on the same host, that multiple entries for one host in the "pe_hostfile" exists. Since the binding is a "per host" decision (as it is a per host request) all decisions for on particular host but different

queue instances on that host are the same. Since version 8.1. different decisions for different hosts can be made. Hence a "pe_hostfile" can also look like below.

```
host_10 2 all.q@macsuse 1,2:1,2
host_12 2 all.q@u1010 0,0:0,1
```

One example how to exploit this information to bind the parallel tasks on different cores is using the "rankfile" of OpenMPI. With the rankfile it can be controlled how OpenMPI binds each individual rank to a separate core. This can massively improve the performance of OpenMPI. Like for other tight integrations such a rankfile must be created based on the "pe_hostfile" information. Univa Grid Engine contains an example in the *$SGE_ROOT/mpi/openmpi_rankfile* product directory.

1.7.3.3.2 Using the SGE_BINDING Environment Variable

1.7.4 Jobs with Core Binding [update 8.1]

Note
The output of qstat -j changed in 8.1 with respect to the final binding done per job task. Before just one topology string was reported (for the master task), since 8.1 core bindings on all hosts where the parallel job runs are showed as lists of <socket>,<core> tuples.

Note
Since version 8.1 regardless of the binding mode (env, pe, or set) the SGE_BINDING environment variable will always be available.

Today's execution hosts are usually multi-socket and multi-core systems with a hierarchy of different caches and a complicated internal architecture. In many cases it is possible to exploit the execution host's topology in order to increase the user application performance and therefore the overall cluster throughput. Another important use case is to isolate jobs on the execution hosts from another in order to guarantee better run-time stability and more fairness in case of overallocation of the host with execution threads. The Univa Grid Engine provides a complete subsystem, which not just provides information about the execution host topology, it also allows the user to force the application to run on specific CPU cores. Another use is so that the administrator can ensure via JSV scripts that serial user jobs are using just one core, while parallel jobs with more granted slots can be run on multiple CPU cores. In Univa Grid Engine core binding on Linux execution hosts is turned on by default, while on Solaris hosts it must be enabled per execution host by the administrator (see Enabling and Disabling Core Binding).

Note
Run the utilbin/<ARCH>/loadcheck -cb command in order to figure out the support of core binding on the specific execution hosts.

In Univa Grid Engine version 8.1 the component, which is responsible for core selection on execution hosts was moved from the execution host component into the scheduler component. Hence it is possible now to guarantee a specific binding for a job because the

scheduler searches just for hosts which can fulfill the requested binding.

1.7.4.1 Showing Execution Host Topology Related Information

By default, the qhost output shows the number of sockets, cores and hardware supported threads on Linux kernel versions 2.6.16 and higher and on Solaris execution hosts:

```
> qhost
HOSTNAME                ARCH         NCPU NSOC NCOR  NTHR LOAD  MEMTOT  MEMUSE  SWAPTO  SWAPUS
----------------------------------------------------------------------------------------------
global                  -               -    -    -     -       -       -       -       -
host1                   lx-amd64        1    1    1     1  0.16  934.9M  150.5M 1004.0M     0.0
host2                   lx-amd64        4    1    4     1  0.18    2.0G  390.8M    2.0G     0.0
host3                   lx-amd64        1    1    1     1  0.06  492.7M   70.2M  398.0M     0.0
```

There are also several topology related host complexes defined after an Univa Grid Engine standard installation:

```
> qconf -sc
...
m_core              core       INT         <=    YES         NO         0        0
m_socket            socket     INT         <=    YES         NO         0        0
m_thread            thread     INT         <=    YES         NO         0        0
m_topology          topo       RESTRING    ==    YES         NO         NONE     0
m_topology_inuse    utopo      RESTRING    ==    YES         NO         NONE     0
m_topology_numa     numa       RESTRING    ==    YES         NO         NONE     0
m_cache_l1          mcache1    MEMORY      <=    YES         NO         0        0
m_cache_l2          mcache2    MEMORY      <=    YES         NO         0        0
m_cache_l3          mcache3    MEMORY      <=    YES         NO         0        0
m_numa_nodes        nodes      INT         <=    YES         NO         0        0
```

The host specific values of the complexes can be shown in the following way:

```
> qstat -F m_topology,m_topology_inuse,m_socket,m_core,m_thread

queuename                      qtype resv/used/tot. load_avg arch          states
---------------------------------------------------------------------------------
all.q@host1                    BIPC  0/0/10         0.00     lx26-amd64
        hl:m_topology=SC
        hl:m_topology_inuse=SC
        hl:m_socket=1
        hl:m_core=1
        hl:m_thread=1
---------------------------------------------------------------------------------
all.q@host2                    BIPC  0/0/10         0.00     lx26-amd64
        hl:m_topology=SCCCC
        hl:m_topology_inuse=SCCCC
        hl:m_socket=1
        hl:m_core=4
        hl:m_thread=4
---------------------------------------------------------------------------------
all.q@host3                    BIPC  0/0/10         0.00     lx26-amd64
        hl:m_topology=SC
        hl:m_topology_inuse=SC
```

```
hl:m_socket=1
hl:m_core=1
hl:m_thread=1
```

m_topology and m_topology_inuse are topology strings. They encode sockets (S), cores (C), and hardware supported threads (T). Hence SCCCC denotes one socket host with a quad core CPU and SCTTCTTSCTTCTT would encode a two socket system with a dual-core CPU on each socket, which supports hyperthreading. The difference between the two strings is that m_topology remains unchanged, even when core bound jobs are running on the host, while m_topology_inuse displays the cores, which are currently occupied (with lowercase letters). For example SccCC denotes a quad-core CPU, which has <GEfullname> jobs bound on the first and second core.

m_socket denotes the number of sockets on the host.

m_core is the total number of cores, the host offers.

m_thread is the total number of hardware supported threads the host offers.

m_topology_numa is an enhanced topology string. In addition to the S, C, and T keywords there are [and] characters which are marking a specific NUMA node on the execution host. A NUMA (non-uniform memory access) node is a particular area for which the memory latency is the same (usually it is per socket memory).

1.7.4.2 Requesting Execution Hosts Based on the Architecture

In order to request specific hosts for a job, all the complexes described in the sub-section above can be used. Because and are regular expression strings (type RESTRING) special symbols like * can be used as well.

In the following example a quad core CPU is requested:

```
> qsub -b y -l m_topology=SCCCC sleep 60
```

This does not correspond to:

```
> qsub -b y -l m_core=4,m_socket=1 sleep 60
```

Because the latter request does also match to a hexacore or higher CPU because m_core is defined as "<=".

In order to get an host with a free (currently unbound) quadcore CPU:

```
> qsub -b y -l m_topology_inuse=SCCCC sleep 60
```

In order to get an host with at least one quad core CPU, wich is currently not used by a core bound job:

```
> qsub -b y -l m_topology_insuse="*SCCCC*" sleep 60
```

1.7.4.3 Requesting Specific Cores

Note
Topology selections (socket/core selections) are not part of a resource reservation yet. Hence jobs submitted with a specific binding and -R y might not be started even when a reservation was done. This can be prevented when using the -binding linear request and aligning the amount of slots per host to the amount of cores per host.

Univa Grid Engine supports multiple schemata in order to request cores on which the job should be bound. Several adjoined cores can be specified with the `linear:<amount>` request. In some cases it could be useful to distribute the job over sockets, this can be achieved with the `striding:<stepsize>:<amount>` request. Here the `stepsize</core> denotes the distance between two successive cores. The stepsize can be aligned with a <code>m_topology` request in order to get the specific architecture. The most flexible request schema is `explicit:<socket,core>[:<socket,core>[...]]`. Here the cores can be selected manually based on the socket number and core number.

Examples:

Bind a job on two successive cores if possible:

```
> qsub -b y -binding linear:2 sleep 60
```

Request a two-socket dual-core host and bind the job on two cores, which are on different sockets:

```
> qsub -b y -l m_topology=SCCSCC -binding striding:2:2 sleep 60
```

Request a quad socket hexa-core execution host and bind the job on the first core on each socket:

```
> qsub -b y -l m_topology=SCCCCCCSCCCCCCSCCCCCCSCCCCCC -binding explicit:0,0:1,0:2,0:3,0 sleep
```

1.7.5 NUMA Aware Jobs: Jobs with Memory Binding and Enhanced Memory Management [since 8.1]

Note
Only jobs running on lx-amd64 execution hosts are able to be set to use a specific memory allocation strategy. The loadcheck -cb utility will show more information about the capabilities of the execution host. May not work with older Linux kernels or with missing libnuma system library.

Since todays execution hosts are not only multi-core hosts but also having a NUMA architecture there is a need to align jobs with the particular memory allocation strategy. Univa Grid Engine 8.1 allows you to do so by using the **-mbind** submission parameter alone or combination with the **-binding** parameter as well as with the following memory related complex **m_mem_free**. Advantages can be more stable and under certain circumstances faster job run-times and better job isolation. With Univa Grid Engine 8.1 following complexes

are additionally created during installation time:

TABLE: NUMA related complexes

Complex Name	Description
m_topology_numa	The NUMA topology string which displays the NUMA nodes of the specific architecture.
m_mem_free	Displays the amount of free memory available on the execution host. Used for requesting NUMA memory globally on host as well as implicitly on the different NUMA nodes, depending on the schedulers decision (source /proc/meminfo and scheduler internal accounting).
m_mem_used	Displays the amount of used memory in the host.
m_mem_total	Displays the amount of total memory on the host (source /proc/meminfo).
m_mem_free_n0 - m_mem_free_n3	Displays the amount of free memory the node (source /sys/devices/system/node/node0/meminfo and scheduler internal accounting).
m_mem_used_n0 - m_mem_used_n3	Displays the amount of used memory on the node (total - free).
m_mem_total_n0 - m_mem_total_n3	Displays the amount of total memory the node (source /sys/devices/system/node/node0/meminfo).
m_cache_l1	Amount of level 1 cache on the execution host.
m_cache_l2	Amount of level 2 cache on the execution host.
m_cache_l3	Amount of level 3 cache on the execution host.
m_numa_nodes	Amount of NUMA nodes on the execution host.

The **-mbind** parameter has following effect:

TABLE: The -mbind submission parameter

Parameter	Description	Dependencies
-mbind cores	The job prefers memory on local NUMA nodes (default), but the job is also allowed to use memory from other NUMA nodes.	**required**: **-binding** optional: -l m_mem_free=<mem_per_slot>
-mbind cores:strict	The job is only allowed allocate memory on the local NUMA node.	see *-mbind cores*
-mbind round_robin	The memory allocated by the job is provided by the OS in an interleaved fashion.	optional: -l m_mem_free=<mem_per_slot>
-mbind nlocal	Sets implicitly core binding as well as memory binding strategy	**required**: **-l m_mem_free=<mem_per_slot>** not

	chosen by the scheduler.	allowed: -binding

There is a special memory consumable which can be used in conjunction with the **-mbind** parameter: **m_mem_free**. This complex holds the total amount of free memory on all NUMA nodes of the execution host. The value is derived from the actual load reported by the execution host as well as from the load calculated by the scheduler based on the memory requests. The minimum of both values is the observed value of **m_mem_free**. In case the execution host has different NUMA nodes, the memory status of those is shown in the **m_mem_fee_n<NODE>** complex values. Accordingly, there are complexes showing the total amount of memory per node as well as the used memory per node.

After installation the **m_mem_free** consumables are initialized on host level through setting the host *complex_values* field to the specific values. They can be showed by the *qconf -se <exechostname>* command.

Note
Resource reservation with core binding or memory affinity when m_mem_free is used is currently not fully supported. This means that for specific implicit memory requests (memory per NUMA node/socket) no reservation is done.

If the job can't run due to a non-valid binding or missing memory the job can get a reservation on the (not on core or per socket memory resources), but only when the requested memory is lower than the actual amount of memory (m_mem_free). In order to overcome this issue the reporting of m_mem_free as load value can be turned off with execd_params DISABLE_M_MEM_FREE=1 (qconf -mconf).

Depending on the **-mbind** request, the **-binding** request, the **m_mem_free** request and the amount of **slots** (parallel environment jobs) the scheduler seeks an appropriate execution host, which can fulfill the requests and decrements the amount of memory automatically for the chosen NUMA nodes.

1.7.5.1 Memory Allocation Strategy round_robin

This memory allocation strategy sets the memory policy of the jobs process into an **interleaved** mode. This results in that memory allocations are distributed over different memory regions. If the job is scheduled to hosts which don?t support this, the OS default memory allocation is done.

When memory allocation strategy **round_robin** was requested together with the special resource m_mem_free than the requested amount of memory is decremented from the **m_mem_free** variable. Additionally the per socket memory (**m_mem_free_n***N*) is decremented equally from all sockets of the selected execution host.

When it is not possible to distribute the amount of free memory equally (because one or more of the NUMA nodes don?t offer that amount of memory), then the host is skipped.

For parallel jobs, when requested **m_mem_free** together with *-mbind round_robin*, the amount of **m_mem_free** actually decremented on a particular host depends on the amount of

granted slots on this host and at the same time it limits (the socket with the least amount of free memory) the amount of slots which can be granted, when needed.

For example: When 4 slots are granted on a particular host, the amount of **m_mem_free** is multiplied by 4. Hence each socket has to offer (m_mem_free * 4) / <amount_of_NUMA_sockets> bytes free on each socket.

Examples:

```
qsub -mbind round_robin -binding striding:2:4 mem_consuming_job.sh
```

This results in a job which runs on a 2 quad core socket machine with memory affinity set to interleaved (to all memory banks on the host) for best possible memory throughput for certain job types.

```
qsub -mbind round_robin mem_consuming_job.sh
```

This results in a job which runs unbound and takes memory in an interleaved fashion.

```
qsub -mbind round_robin -binding linear:2 -pe mytestpe 4 -l m_mem_free=2G -b y sleep 13
```

Let's assume here that mytestpe has an allocation rule of pe_slots. Then the job is running on a host which offers 4*2GB=8GB of m_mem_free as well as on each NUMA node (m_mem_free_nX) at least 8GB/<amount of nodes> free memory. The memory consumable m_mem_free is decrement by 8GB and all consumables representing a NUMA node (m_mem_free_n0 to m_mem_free_nX) are decremented by 8GB/<amount of nodes> memory. The same behavior can be seen when ?-binding? strategy is changed to any of the available ones, or even when ?-binding? is not selected.

1.7.5.2 Memory Allocation Strategy cores and cores:strict

This memory allocation strategy takes memory **from all NUMA nodes where the job is bound** to (with core binding) into account. If no core binding (-binding) was requested the job is rejected during submission time. Depending on the parameter the memory request is either **restricted** to local NUMA nodes (*cores:strict*) only or **local memory is preferred** (*cores*).

If the memory request, which comes with the job submission command, can not be fulfilled (because NUMA node *N* offers not as much memory) the node is skipped by the scheduler. On 64bit Linux internally the system call **mbind** (see *man mbind*) is executed.

The requested memory (when using *-l m_mem_free*) is decremented from **m_mem_free** as well as from the NUMA nodes (**m_mem_free_n***N*) where the job is bound to. When a job gets for example 2 cores on socket 1 and one core on socket 2 then the amount of memory on **m_mem_free_n1** is decremented by the total amount of requested memory divided by the amount of granted cores (here 3) multiplied by the amount of granted cores on the particular NUMA node (here 2). The consumable **m_mem_free_n2** is charged by half of this amount of memory.

Strict means: Only local memory on NUMA node allowed.

Without any keyword the memory allocation strategy is set on Linux to the ?**preferred**? mode, that means the job gets memory from the near node as long as there is free memory. When there is no more free memory it is allowed to use memory from a greater distance.

Examples:

```
qsub -mbind cores -binding linear:1 /bin/sleep 77
```

The job gets bound to a free core. The memory requests are preferred on the same NUMA node. If there is no more memory free the next memory request is taken from a node with an higher distance to the selected core.

```
qsub -mbind cores -binding linear:1 -l m_mem_free=2G /bin/sleep 77
```

The job gets bound to a free core only on a NUMA node which currently offers 2GB. The memory requests are preferred on the same NUMA node. If there is no more memory free the next memory request is taken from a node with an higher distance to the selected core. The requested memory is debited from nX_mem_free consumable (memory job-request / amount of occupied cores on node).

Warning: This could cause out of memory errors on strict jobs in case of overflows. Hence mixing strict with preferred jobs is not recommended.

```
qsub -mbind cores:strict -binding linear:1 /bin/sleep 77
```

The job gets bound to a free core. The memory is always taken from the local NUMA node. If there is no more memory free on the NUMA node the program gets by the next program break extension (brk()) an out of memory exception.

```
qsub -mbind cores:strict -binding striding:2:4 -pe mytestepe 2 -l m_mem_free=2G /bin/sleep 77
```

Complete parallel job requests 2G * 2 slots = 4GB memory and 2 cores on two sockets (quad core processors). Assumption: Each core needs 2 GB. The job gets scheduled to a particular host if both NUMA nodes (here both sockets) offer each 2GB m_mem_free_nX. If not the host is skipped. The particular consumables are decremented by that amount.

```
qsub -mbind cores /bin/sleep 77
```

The job gets rejected because the binding is missing.

1.7.5.3 Memory Allocation Strategy nlocal

This memory allocation strategy automatically allocates cores and set an appropriate memory allocation strategy for single-threaded or multi-threaded (parallel environments with allocation_rule pe_slots) depending on the memory request and the execution hosts characteristics (free sockets/cores and free memory on the specific NUMA nodes).

Note
Requirements: No core binding request set (otherwise the job is rejected), but a mandatory request for the **m_mem_free consumable**. If this consumable is not requested the job is

rejected.

1.7.5.3.1 -mbind nlocal with Sequential Jobs

The **nlocal** strategy is intended to use for sequential as well for multi-threaded jobs in order to get stable job run-time results as well highest amount of memory throughput. The only requirement for the jobs is the amount of memory the job needs per slot (-l m_mem_free=<mem>). When multiple slots are needed then a parallel environment with the allocation rule "pe_slots" (so that the job is not distributed to different hosts) is required. The behavior is undefined with PEs having other allocation rules configured. The scheduler tries to place jobs on sockets which offers most free cores and have additionally the required amount of memory free on the specific NUMA node (m_mem_free_n<node>). If the required amount of memory is more than each socket has installed the job will run on one socket exclusively if one is completely free (with out any coure-bound jobs). If the required memory is more than free memory each NUMA node (socket) can offer, but less than installed memory on the NUMA nodes, the host is skipped. In this scenario the job has either to wait until the required amount of memory is free on this host or it can run an a more appropriate host.

On NUMA execution nodes the scheduler tries to do following for **sequential jobs**:

- If the host can?t fulfill the **m_mem_free** request then the host is skipped.
- If the job requests more ram than free on each socket *but* less than installed on the sockets the host is skipped.
- If memory request is **smaller** than amount of free memory on a socket, try to bind the job to **one core on the socket** and decrement the amount of memory on this socket (m_mem_free_n<nodenumber>). The global host memory m_mem_free on this host is decremented as well.
- If memory request is **greater** than the amount of free memory on any socket, find an unbound socket and bind it there completely and allow memory overflow. Decrement from m_mem_free as well as from m_mem_free_n<socketnumber> and the remaining memory round robin from the remaining sockets.
- If both are not possible go to the next host.

1.7.5.3.2 -mbind nlocal with Parallel Jobs

Parallel jobs are handled in the scheduler the following way (only *pe_slots* PEs are supported, the behavior for other allocation rules is unspecified):

- Hosts that doesn?t offer m_mem_free memory are skipped (of course hosts that doesn't offer the amount of free slots requested are skipped as well).
- If the amount of requested slots is **greater** than the amount of **cores per socket**. The job is dispatched to the host without any binding.

- If the amount of requested slots is **smaller** than the amount of **cores per socket** do following:
    - If there is any socket which offers enough memory (m_mem_free_n<N>) and enough free cores bind the job to these cores and set memory allocation mode to **cores:strict** (so that only local memory requests can be done by the job).
    - If this is not possible try to find a socket which is completely unbound and has **more** than the required amount of memory **installed** (m_mem_total_n<N>). Bind the job to the complete socket, decrement the memory on that socket at m_mem_free_n<N> (as well as host globally on m_mem_free), and set the memory allocation strategy to **cores** (**preferred** usage of socket local memory).

If nothing matches then the host is skipped.

1.7.5.4 Other examples

The following example demonstrated how a parallel job with 4 threads (requesting the parallel environment testpe for 4 slots (allocation_rule $pe_slots) each needed 1 gigabyte of memory is submitted (4 gigabye for the job in total):

```
qsub -mbind cores:strict -binding linear:4 -pe testpe 4 -l m_mem_free=1G testjob.sh
```

For this job the scheduler skips all hosts which do not have 4 slots, 4 cores as well as 4 gigabyte free (according to the m_mem_free value). If a host is found it is first tried to accommodate the job on one single socket, if it is not possible then a distribution over the least amount of sockets is tried. If the host does not fulfill the memory request on the chosen socket / NUMA node (m_mem_free_n<node>) the host is discarded. Otherwise the job gets assigned the specific cores as well as the particular amount of memory on the machine as well on the NUMA nodes. Hence a -l m_mem_free request comes with implicit m_mem_free_n<node> requests depending of the binding the scheduler determines.

1.7.6 Checkpointing Jobs

Checkpointing delivers the possibility to save the complete state of a job and to restart from this point of time if the job was halted or interrupted. Univa Grid Engine supports two kinds of Checkpointing jobs: the user-level and the kernel-level Checkpointing.

1.7.6.1 User-Level Checkpointing

User-Level Checkpointing jobs have to do their own checkpointing by writing restart files at certain times or algorithmic steps. Applications without an integrated user-level checkpointing can use a checkpointing library like the Condor project.

1.7.6.2 Kernel-Level Checkpointing

Kernel-Level Checkpointing must be provided by the executing operating systems. The checkpointing job itself does not need to do any checkpointing. This is done by the OS entirely.

1.7.6.3 Checkpointing Environments

To execute and run checkpointing jobs environments, similar to parallel jobs, are necessary to control how, when and how often checkpointing should be done.

TABLE: Handle Checkpointing Environments with `qconf`

Parameter	Description
-ackpt	add a checkpointing environment
-dckpt *<ckpt_env>*	delete the given checkpointing environment
-mckpt *<ckpt_env>*	modify the given checkpointing environment
-sckpt *<ckpt_env>*	show the given checkpointing environment

A checkpointing environment is made up of the following parameters:

TABLE: Handle Checkpointing Environments Parameters

Parameter	Description
ckpt_name	The name of the checkpointing environment.
interface	The type of the checkpointing which should be used. Valid types:
	hibernator: The Hibernator kernel-level checkpointing is interfaced.
	cpr: The SGI kernel-level checkpointing is used.
	cray-ckpt: The Cray kernel-level checkpointing is used.
	transparent: Univa Grid Engine assumes that the job submitted within this environment uses a checkpointing library such as the mentioned Condor.
	userdefined: Univa Grid Engine assumes that the job submitted within this environment uses a its private checkpointing method.
	application-level: Uses all interface commands configured in the checkpointing object. In case of one of the kernel level checkpointing interfaces the restart_command is not used.
ckpt_command	Command which will be executed by Univa Grid Engine to initiate a checkpoint.
migr_command	Command which will be executed by Univa Grid Engine during a migration of a checkpointing job from one host to another.
restart_command	Command which will be executed by Univa Grid Engine if a previously checkpointed job is restarted.
clean_command	Command which will be executed by Univa Grid Engine after a checkpointing job is completed.

<table>
<tr><td>ckpt_dir</td><td>Directory where checkpoints are stored.</td></tr>
<tr><td>ckpt_signal</td><td>A UNIX signal which is sent by Univa Grid Engine to the job when a checkpoint is initiated.</td></tr>
<tr><td>when</td><td>Point of time when checkpoints are expected to be generated. Valid values for this parameter are composed by the letters s, m, x and r and any combinations thereof without any separating character in between:
<table>
<tr><td>s</td><td>The job is checkpointed, aborted and if possible migrated if the corresponding execution daemon is shut down on the job's machine.</td></tr>
<tr><td>m</td><td>Checkpoints are generated periodically at the min_cpu_interval interval defined by the queue in which a job executes.</td></tr>
<tr><td>x</td><td>A job is checkpointed, aborted and if possible, migrated as soon as the job is suspended (manually as well as automatically).</td></tr>
<tr><td>r</td><td>A job is rescheduled (not checkpointed) when the job host goes into an unknown state and the time interval reschedule_unknown defined in the global/local cluster configuration is exceeded.</td></tr>
</table></td></tr>
</table>

1.7.6.4 Submitting a Checkpointing Job

```
# qsub -ckpt <cpkt_env> -c <when_options> job
```

The *-c* option is not mandatory. It can be used to override the *when* parameters stated in the checkpointing environment.

1.7.6.5 Example of a Checkpointing Script

The environment variable **RESTARTED** is set for checkpointing jobs that are restarted. This variable can be used to skip e.g. preparation steps.

```
#!/bin/sh
#$ -S /bin/sh

# Check if job was restarted/migrated
if [ $RESTARTED = 0 ]; then
  # Job is started first time. Not restarted.
  prepare_chkpt_env
  start_job
else
  # Job was restarted.
  restart_job
fi
```

1.7.7 Immediate Jobs

Univa Grid Engine tries to start such jobs *immediately* or not at all. If, in case of array jobs, not all tasks can be scheduled immediately, none will be started.

To indicate an immediate job, the *-now* option has to be declared with the parameter *yes*.

Example:

```
# qsub -now yes immediate_job.sh
```

The *-now* option is available for **qsub**, **qsh**, **qlogin** and **qrsh**.

In case of qsub *no* is the default value for the *-now* option, in case of qsh, qlogin and qrsh vice versa.

1.7.8 Reservations

With the concept of Advance Reservations (AR) it is possible to reserve specific resources for a job, an user or a group in the cluster for future use. If the AR is possible (resources are available) and granted it is assigned an ID.

1.7.8.1 Configuring Advance Reservations

To be able to create advance reservations the user has to be member of the *arusers* list. This list is created during the Univa Grid Engine installation.

Use qconf to a user to the *arusers* list.

```
# qconf -au username arsusers
```

1.7.8.2 Creating Advance Reservations

qrsub is the command used to create advance reservations and to submit them to the Univa Grid Engine system.

```
# qrsub -a <start_time> -e <end_time>
```

The start and end times are in *[[CC]YY]MMDDhhmm[.SS]* format. If no start time is given, Univa Grid Engine assumes the current time as the start time. It is also possible to set a *duration* instead of an end time.

```
# qrsub -a <start_time> -d <duration>
```

The duration is in hhmm[.SS] format. **Examples:** The following example reserves an slot in the queue *all.q* in host *host1* starting at 04-27 23:59 for 1 hour.

```
# qrsub -q all.q -l h=host2 -a 04272359 -d 1:0:0
```

Many of the options available for qrsub are the same as for qsub.

1.7.8.3 Monitoring Advance Reservations

qrstat is the command to list and show all advance reservations known by the Univa Grid Engine system. To list all configured advance reservations type:

```
# qrstat
```

To list a special advance reservation type:

```
# qrstat <ar_id>
```

Every submitted AR has an own ID and a special state.

TABLE: Possible Advance Reservation States

State	Description
w	Waiting - Granted but start time not yet reached
r	Running - Start time reached
d	Deleted - Deleted manually
W	Warning - AR became invalid but start time is not yet reached
E	Error - AR became invalid and start time is reached

Examples:

```
# qrstat
ar-id   name       owner        state start at            end at              duration
------------------------------------------------------------------------------------
    1              user1        w     04/27/2011 23:59:00 04/28/2011 00:59:00 01:00:00

# qrstat -ar 1
id                            1
name
owner                         user1
state                         w
start_time                    04/27/2011 23:59:00
end_time                      04/28/2011 00:59:00
duration                      01:00:00
submission_time               04/27/2011 15:00:11
group                         users
account                       sge
resource_list                 hostname=host1
granted_slots_list            all.q@host1=1
```

1.7.8.4 Deleting Advance Reservations

'*qrdel* is the command to delete an advance reservation. The command requires at least the ID or the name of the AR.

Example:

```
# qrdel 1
```

A job which refers to an advance reservation which is in deletion will also be removed. The AR will not be removed until all referring jobs are finished!

1.7.8.5 Using Advance Reservations

Advance Reservations can be used via the **-ar <ar_id>** parameter which is available for *qsub*, *qalter*, *qrsh*, *qsh* and *qlogin*.

Example:

```
# qsub -ar 1 reservation_job.sh
```

1.8 Submission, Monitoring and Control via an API

1.8.1 The Distributed Resource Management Application API (DRMAA)

The Distributed Resource Management Application API is the industry-leading open standard of the Open Grid Forum (www.ogf.org) DRMAA working group (www.drmaa.org) for accessing DRMS. The goal of the API is to provide an external interface to applications for basic tasks, like job submission, job monitoring and job control. Since this standard is adapted by most DRMS vendors it offers a very high investment protection, when developing a DRM aware software application, because it can be easily transferred to another DRM. Univa Grid Engine supports all DRMAA concepts, which allows for the movement of existing DRMAA applications from different DRM vendors.

1.8.2 Basic DRMAA Concepts

DRMAA version 1.0 specifies a set of functions and concepts. Each DRMAA application must contain an initialization and disengagement function which must be called at the beginning and at the end respectively. In order to do something useful a new DRMAA session must be created or one existing must be re-opened. When re-opening a DRMAA session, the job IDs of the session can be reused in order to obtain the job status and gain job control. In order to submit jobs, a standard job template must be allocated and filled out according to needs with the job name and the corresponding parameters. This job template than can then be submitted with a job submission routine. There are two job submission routines specified: One for individual jobs and one for array jobs. A job can be monitored and controlled (e.g. holding, releasing, suspending, resuming) once the job is complete and the exit status can be checked. Additionally DRMAA specifies a set of error codes. In order to exploit additional functionality, which is only available in Univa Grid Engine, the standard will allow this with either the native specification functionality or with job categories.

1.8.3 Supported DRMAA Versions and Language Bindings

Univa Grid Engine supports currently the DRMAA v1.0 standard and is shipped with a fully featured DRMAA C binding v1.0 and a DRMAA Java binding v1.0. The standards can be downloaded at www.drmaa.org.

1.8.4 When to Use DRMAA

Writing applications with DRMAA has several advantages: High job submission throughput with Univa Grid Engine, the defined workflow is independent from underlying DRM, it is much

easier to use in programming languages like C or Java, and it is a widely known and adapted standard backed by an experienced community.

1.8.5 Examples

1.8.5.1 Building a DRMAA Application with C

1.8.5.1.1 Compiling, Linking and Running the C Code DRMAA Example

In order to compile a DRMAA application, the `drmaa.h` must include the file and the DRMAA library must be available. The `drmaa.h` file can be found in the `$SGE_ROOT/include` directory and the libraries are installed in `$SGE_ROOT/lib/$ARCH`.

In the following example the root installation directory (`$SGE_ROOT`) is `/opt/uge800` and the architecture is `lx-amd64`.

```
> gcc -I/opt/uge800/include -L/opt/uge800/lib/lx-amd64 -ldrmaa -o yourdrmaaapp youdrmaaapp.c
```

In order to run `yourdrmaaapp` the Univa Grid Engine environment must be present and the path to the shared DRMAA library must be set.

```
> export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/opt/uge800/lib/lx-amd64
> ./yourdrmaaapp
```

1.8.5.1.2 Job Submission, Waiting and Getting the Exit Status of the Job

In the following example a job session is initially opened with `drmaa_init()`. The return code of the all calls indicate the success of a function (`DRMAA_ERRNO_SUCCESS`) or if an error has occurred. In the case of an error, the error string with the corresponding message is returned. In order to submit a job, a job template must be allocated with `drmaa_allocate_job_template()` and the `DRMAA_REMOTE_COMMAND` parameters must be set. After a successful job submission with `drmaa_run_job()` the application waits until the job is scheduled and eventually finished. Then the exit code of the job is accessed and printed before the job session is closed by `drmaa_exit`.

```
000 #include <stdio.h>
001 #include "drmaa.h"
002
003 int main(int argc, char **argv) {
004
005    /* err contains the return code of the called functions */
006    int err = 0;
007
008    /* allocate a string with the DRMAA string buffer length */
009    char errorstr[DRMAA_ERROR_STRING_BUFFER];
010
011    /* allocate a buffer for the job name */
012    char jobid[DRMAA_JOBNAME_BUFFER];
013
014    /* pointer to a job template */
015    drmaa_job_template_t *job_template = NULL;
016
```

```
017    /* DRMAA status of a job */
018    int status = 0;
019
020    /* if job exited normally */
021    int exited = 0;
022
023    /* exit code of the job */
024    int exitstatus = 0;
025
026    /* create a new DRMAA session */
027    err = drmaa_init(NULL, errorstr, DRMAA_ERROR_STRING_BUFFER);
028
029    /* test if the DRMAA session could be opened  */
030    if (err != DRMAA_ERRNO_SUCCESS) {
031       printf("Unable to create a new DRMAA session: %s\n", errorstr);
032       return err;
033    }
034
035    /* allocate a job template */
036    err = drmaa_allocate_job_template(&job_template, errorstr,
037                                      DRMAA_ERROR_STRING_BUFFER);
038
039    /* test if the DRMAA job template could be allocated */
040    if (err != DRMAA_ERRNO_SUCCESS) {
041       printf("Unable to allocate a new job template: %s\n", errorstr);
042       /* close the DRMAA session and exit */
043       err = drmaa_exit(errorstr, DRMAA_ERROR_STRING_BUFFER);
044       if (err != DRMAA_ERRNO_SUCCESS) {
045          printf("Unable to close DRMAA session: %s\n", errorstr);
046       }
047       return err;
048    }
049
050    /* specify the job */
051    err = drmaa_set_attribute(job_template, DRMAA_REMOTE_COMMAND, "./job.sh",
052                              errorstr, DRMAA_ERROR_STRING_BUFFER);
053
054    if (err != DRMAA_ERRNO_SUCCESS) {
055       printf("Unable to set the remote command name: %s\n", errorstr);
056       /* close the DRMAA session and exit */
057       err = drmaa_exit(errorstr, DRMAA_ERROR_STRING_BUFFER);
058       if (err != DRMAA_ERRNO_SUCCESS) {
059          printf("Unable to close DRMAA session: %s\n", errorstr);
060       }
061       return err;
062    }
063
064    /* submit the job */
065    err = drmaa_run_job(jobid, DRMAA_JOBNAME_BUFFER, job_template, errorstr,
066                        DRMAA_ERROR_STRING_BUFFER);
067
068    /* wait for the job */
069    err = drmaa_wait(jobid, NULL, 0, &status, DRMAA_TIMEOUT_WAIT_FOREVER,
070                     NULL, errorstr, DRMAA_ERROR_STRING_BUFFER);
071
072    if (err != DRMAA_ERRNO_SUCCESS) {
073       printf("Unable to wait for the job: %s\n", errorstr);
074       /* close the DRMAA session and exit */
075       err = drmaa_exit(errorstr, DRMAA_ERROR_STRING_BUFFER);
```

```
076         if (err != DRMAA_ERRNO_SUCCESS) {
077            printf("Unable to close DRMAA session: %s\n", errorstr);
078         }
079         return err;
080      }
081
082      /* print the exit status of the job if terminated normally (and don't
083       * check a function error) */
084      drmaa_wifexited(&exited, status, NULL, 0);
085
086      if (exited == 1) {
087         drmaa_wexitstatus(&exitstatus, status, NULL, 0);
088         printf("Exit status of the submitted job: %d\n", exitstatus);
089      }
090
091      /* free the job template */
092      err = drmaa_delete_job_template(job_template, errorstr, DRMAA_ERROR_STRING_BUFFER);
093
094      if (err != DRMAA_ERRNO_SUCCESS) {
095         printf("Unable to delete the job template: %s\n", errorstr);
096         /* close the DRMAA session and exit */
097         err = drmaa_exit(errorstr, DRMAA_ERROR_STRING_BUFFER);
098         if (err != DRMAA_ERRNO_SUCCESS) {
099            printf("Unable to close DRMAA session: %s\n", errorstr);
100         }
101         return err;
102      }
103
104      /* close the DRMAA session and exit */
105      err = drmaa_exit(errorstr, DRMAA_ERROR_STRING_BUFFER);
106      if (err != DRMAA_ERRNO_SUCCESS) {
107         printf("Unable to close DRMAA session: %s\n", errorstr);
108         return err;
109      }
110
111      return 0;
112   }
```

1.8.5.2 Building a DRMAA Application with Java

When writing a Java DRMAA application it must be taken into account that the Java DRMAA library internally is based on the C DRMAA implementation. The implication is that Java DRMAA is fast, but this native code dependency must be handled properly. The DRMAA application must be run on a submission host with an enabled Univa Grid Engine environment.

1.8.5.2.1 Compiling and Running the Java Code DRMAA Example

In order to compile a Java DRMAA application the Java `CLASSPATH` variable must point to `$SGE_ROOT/lib/drmaa.jar`. Alternatively the `-cp` or `-classpath` parameter can be passed to the Java compiler at the time of compilation.

```
> javac -cp $SGE_ROOT/lib/drmaa.jar Sample.java
```

To run the application the native code library (`libdrmaa.so`) must be available in the `LD_LIBRARY_PATH` environment variable.

In this example `$SGE_ROOT` is expected to be `/opt/uge800`.

```
> export LD_LIBRARY_PATH=LD_LIBRARY_PATH:/opt/uge800/lib/linux

> java -cp $SGE_ROOT/lib/drmaa.jar:./ Sample
```

1.8.5.2.2 Job Submission, Waiting and Getting the Exit Status of the Job

The following example has the same behavior as the C example in the section above. First a DRMAA job session is created through a factory method (line 19-22). A new session is opened with the `init()` call (line 23). After a job template is allocated (line 26) and the remote command parameter (line 29) and the job argument (line 32) is set accordingly, the wait method does not terminate as long the job runs (line 39). Finally the exit status of the job is checked (line 41-47), the job template is freed (line 50) and the session is closed (line 53).

```
000 import java.util.Collections;
001 import org.ggf.drmaa.*;
002
003 public class Sample {
004
005    public static void main(String[] args) {
006
007       Sample sample = new Sample();
008
009       try {
010          sample.example1();
011       } catch (DrmaaException exception) {
012          /* something went wrong */
013          System.out.println("DRMAA Error: " + exception.getMessage());
014       }
015    }
016
017    public void example1() throws DrmaaException {
018       /* get the class, which is needed for creating a session */
019       SessionFactory factory = SessionFactory.getFactory();
020
021       /* create a new session */
022       Session s = factory.getSession();
023       s.init(null);
024
025       /* create a new job template */
026       JobTemplate jobTemplate = s.createJobTemplate();
027
028       /* set "sample.sh" as job script */
029       jobTemplate.setRemoteCommand("/path/to/your/job.sh");
030
031       /* set an additional argument */
032       jobTemplate.setArgs(Collections.singletonList("myarg"));
033
034       /* submit the job */
035       String jobid = s.runJob(jobTemplate);
036       System.out.println("The job ID is: " + jobid);
037
038       /* wait for the job */
039       JobInfo status = s.wait(jobid, Session.TIMEOUT_WAIT_FOREVER);
040
```

```
041         /* check if job exited (and was not aborted) */
042         if (status.hasExited() == true) {
043            System.out.println("The exit code of the job was: "
044                               + status.getExitStatus());
045         } else {
046            System.out.println("The job didn't finished normally.");
047         }
048
049         /* delete the job template */
050         s.deleteJobTemplate(jobTemplate);
051
052         /* close DRMAA session */
053         s.exit();
054      }
055
056   }
```

1.8.6 Further Information

Java **DRMAA** related information can be found in the **doc** directory (HTML format). Further information about **DRMAA** specific attributes can be found in the **DRMAA** related **man** pages:

drmaa_allocate_job_template, drmaa_get_next_attr_value, drmaa_misc, drmaa_synchronize, drmaa_attributes, drmaa_get_next_job_id, drmaa_release_attr_names, drmaa_version, drmaa_control, drmaa_get_num_attr_names, drmaa_release_attr_values, drmaa_wait, drmaa_delete_job_template, drmaa_get_num_attr_values, drmaa_release_job_ids, drmaa_wcoredump, drmaa_exit, drmaa_get_num_job_ids, drmaa_run_bulk_jobs, drmaa_wexitstatus, drmaa_get_attribute, drmaa_get_vector_attribute, drmaa_run_job, drmaa_wifaborted, drmaa_get_attribute_names, drmaa_get_vector_attribute_names, drmaa_session, drmaa_wifexited, drmaa_get_contact,drmaa_init, drmaa_set_attribute, drmaa_wifsignaled, drmaa_get_DRMAA_implementation, drmaa_jobcontrol, drmaa_set_vector_attribute, drmaa_wtermsig, drmaa_get_DRM_system, drmaa_job_ps, drmaa_strerror, jsv_script_interface, drmaa_get_next_attr_name, drmaa_jobtemplate, drmaa_submit

1.9 Advanced Concepts

Besides the rich set of basic functionality discussed in the previous sections, Univa Grid Engine offers several more sophisticated concepts at time of job submission and during job execution. This chapter describes such functionality, which becomes important for more advanced users.

1.9.1 Job Dependencies

In many cases the jobs, which are submitted with Univa Grid Engine are not self-contained. Those jobs are usually arranged in a kind of workflow with more or less complex job dependencies. Such workflows can be mapped to Univa Grid Engine with the submission parameter `hold_jid <jobid list>`. The `<jobid list>` contains one or a comma separated list of ids of existing jobs of which the submitted job is waiting for before it can be scheduled. In order get the job IDs, submit the jobs with a name (`-N <name>`) and use the

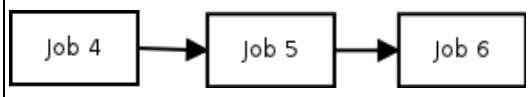
name as ID. Alternatively the **qsub** parameter `-terse` can be used, which transforms the command line result of **qsub** so that only the job id is returned. This makes it very simple to use within scripts.

1.9.1.1 Examples

In the following examples, basic workflow control patterns (see www.workflowpatterns.com) are mapped into a Univa Grid Engine job workflow.

1.9.1.1.1 Sequence Pattern

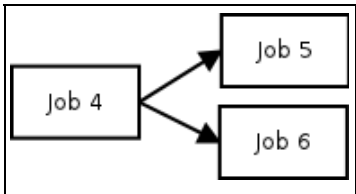
The most simple workflow pattern is the sequence pattern. It is used when a bunch of job must be executed in a pre-defined order. With Univa Grid Engine it is possible to submit all jobs at once but the order is still guaranteed.




```
qsub -b y /bin/sleep 60
Your job 4 ("sleep") has been submitted

qsub -b y -hold_jid 4 /bin/sleep 60
Your job 5 ("sleep") has been submitted

qsub -b y -hold_jid 5 /bin/sleep 60
Your job 6 ("sleep") has been submitted

> qstat
job-ID  prior   name       user         state submit/start
-----------------------------------------------------------
      4 0.55500 sleep      daniel       r      03/01/2011 1
      5 0.00000 sleep      daniel       hqw    03/01/2011 15
      6 0.00000 sleep      daniel       hqw    03/01/2011 15
```

1.9.1.1.2 Parallel Split/Fork Pattern

The fork pattern is used when a job sequence involves tasks that are executed in parallel. In this case two or more jobs depend on just one job, meaning they are scheduled after the job is complete. In Univa Grid Engine, this is mapped through setting the hold job ID value of multiple jobs to the same job.



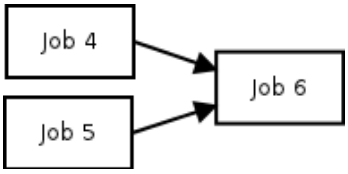

```
qsub -terse -b y /bin/sleep 60
4

qsub -b y -hold_jid 4 /bin/sleep 60
Your job 5 ("sleep") has been submitted

qsub -b y -hold_jid 4 /bin/sleep 60
Your job 6 ("sleep") has been submitted

> qstat
job-ID  prior   name       user         state submit/start at     queue
---------------------------------------------------------------------
        4 0.55500 sleep      daniel       r     03/01/2011 16:00:50 all
        5 0.00000 sleep      daniel       hqw   03/01/2011 16:00:58
```

```
        6 0.00000 sleep      daniel       hqw   03/01/2011 16:01:00

> qstat
job-ID  prior   name       user         state submit/start at     queue
---------------------------------------------------------------------------
        5 0.00000 sleep      daniel       r   03/01/2011 16:00:58
        6 0.00000 sleep      daniel       r   03/01/2011 16:01:00
```

In this example job 5 and 6 depending from job 4.
After job 4 finishes both jobs are scheduled within the same time.

1.9.1.1.3 Synchronization Pattern

With the synchronization pattern, a job starts (is scheduled) when all dependencies are fulfilled, i.e. that all of the waiting jobs have completed. It is usually used after parallel sections induced by the parallel split/fork pattern or when a job is one which finalizes the work of multiple jobs (post processing).




```
qsub -b y /bin/sleep 60
Your job 4 ("sleep") has been submitted

qsub -b y /bin/sleep 120
Your job 5 ("sleep") has been submitted

qsub -b y -hold_jid 4,5 /bin/sleep 60
Your job 6 ("sleep") has been submitted

> qstat
job-ID  prior   name       user         state submit/start at     queue
---------------------------------------------------------------------------
      4 0.55500 sleep      daniel       r      03/01/2011 16:24:50 all.
      5 0.00000 sleep      daniel       r      03/01/2011 16:24:54 all.
      6 0.00000 sleep      daniel       hqw   03/01/2011 16:24:57

> qstat
job-ID  prior   name       user         state submit/start at     queue
---------------------------------------------------------------------------
      5 0.00000 sleep      daniel       r      03/01/2011 16:24:54 all.
      6 0.00000 sleep      daniel       hqw   03/01/2011 16:24:57
```

In this example the job 6 depends on two previously submitted jobs.
The hold state of the job is removed not before job 4 and job 5 ended.

1.9.2 Using Environment Variables

During job execution a number of environment variables are set from Univa Grid Engine and are available for the executing script/binary. These variables contain information about Univa Grid Engine specific settings, job submission related information and other details. Additionally the user can specify at time of submission using the `-v` and `-V` parameter self-defined environment variables. While `-v` expects a list of `variable=value` pairs, which are passed-through from job submission to the jobs environment, the `-V` parameter transfers **all** environment variables from the job submission context into the jobs execution context.

```
qrsh -v answer=42 myscript.csh
```

In `myscript.csh` `$answer` has the value 42.

```
setenv answer 42
qrsh -V myscript.csh
```

In `myscript.csh` `$answer` has the value 42.

In the following tables all Univa Grid Engine environment variables available during job execution are listed:

TABLE: Standard Job Environment Variables

Variable Name	Semantic
SGE_ARCH	The architecture of the host on which the job is running.
SGE_BINARY_PATH	The absolute path to the Univa Grid Engine binaries.
SGE_JOB_SPOOL_DIR	The directory where the Univa Grid Engine shepherd stores information about the job.
SGE_JSV_TIMEOUT	Timeout value (in seconds), when the client JSV will be restarted.
SGE_STDERR_PATH	The absolute path to the standard error file, in which Univa Grid Engine writes errors about job execution.
SGE_STDOUT_PATH	The absolute path to the standard output file, in which Univa Grid Engine writes the output of the job.
SGE_STDIN_PATH	The absolute path to file, the job uses as standard input.
ENVIRONMENT	Univa Grid Engine fills in `BATCH` to identify it as an Univa Grid Engine job submitted with qsub.
HOME	Path to the home directory of the user.
HOSTNAME	Name of the host on which the job is running.
JOB_ID	ID of the Univa Grid Engine job.
JOB_NAME	Name of the Univa Grid Engine job.
JOB_SCRIPT	Name of the script, which is currently executed.
LOGNAME	Login name of the user running the job on the execution host.
PATH	The default search path of the job.
QUEUE	The name of the queue in which the job is running.
REQUEST	The name of the job specified with the -N option.
RESTARTED	Indicates if the job was restarted (`1`) or if it is the first run (`0`).
SHELL	The login shell of the user running the job on the execution host.
TMPDIR	The absolute path to the temporary directory on the execution host.

TMP	The absolute path to the temporary directory on the execution host.
TZ	The timezone set from the execution daemon.
USER	The login name of the user running the job.

TABLE: Job Submission Related Job Environment Variables

Variable Name	Semantic
SGE_O_HOME	The home directory on the submission host.
SGE_O_HOST	The name of the host, on which the job is submitted.
SGE_O_LOGNAME	The login name of the job submitter.
SGE_O_MAIL	The mail directory of the job submitter.
SGE_O_PATH	The search path variable of the job submitter.
SGE_O_SHELL	The shell of the job submitter.
SGE_O_TZ	The time zone of the job submitter.
SGE_O_WORKDIR	The working directory path of the job submitter.

TABLE: Parallel Jobs Related Job Environment Variables

NHOSTS	The number of hosts on which this parallel job is executed.
NQUEUES	The number of queues on which this parallel job is executed.
NSLOTS	The number of slots this parallel job uses (1 for serial jobs).
PE	Only available for parallel jobs: The name of the parallel environment in which the job runs.
PE_HOSTFILE	Only available for parallel jobs: The absolute path to the pe_hostfile.

TABLE: Checkpointing Jobs Related Job Environment Variables

SGE_CKPT_ENV	Checkpointing jobs only: Selected checkpointing environment.
SGE_CKPT_DIR	Checkpointing jobs only: Path of the checkpointing interface.

TABLE: Array Jobs Related Job Environment Variables

SGE_TASK_ID	The task number of the array job task the job represents. If the job is not an array task, the variable contains `undefined`.
SGE_TASK_FIRST	The task number of the first array job task. If the job is not an array task, the variable contains `undefined`.
SGE_TASK_LAST	The task number of the last array job task. If the job is not an array task, the variable contains `undefined`.
SGE_TASK_STEPSIZE	Contains the step size of the array job. If the job is not an array task, the variable contains `undefined`.

1.9.3 Using the Job Context

Sometimes it is necessary that a job makes its internal state visible to `qstat`. This can be done with the job execution context. Job context variables can be initially set on job submission time with the `-ac name=value` parameter and altered/added and deleted during run-time with `qalter -ac` or `-dc` switch.

In the following example a job script makes the internal job state visible to the `qstat` client.

The `context_example.sh` job script looks like the following:

```
00   #!/bin/sh
01
02   sleep 15
03
04   $SGE_BINARY_PATH/qalter -ac STATE=staging $JOB_ID
05
06   sleep 15
07
08   $SGE_BINARY_PATH/qalter -ac STATE=running $JOB_ID
09
10   sleep 15
11
12   $SGE_BINARY_PATH/qalter -ac STATE=finalizing $JOB_ID
```

Now the job with the context `STATE=submitted` is submitted and the context is filtered with the `grep` command every 15 seconds.

```
> qsub -ac STATE=submitted context_example.sh
Your job 4 ("context_example.sh") has been submitted
> qstat -j 4 | grep context
context:                    STATE=submitted
> sleep 15
> qstat -j 4 | grep context
context:                    STATE=staging
> sleep 15
> qstat -j 4 | grep context
context:                    STATE=running
> sleep 15
> qstat -j 4 | grep context
context:                    STATE=finalizing
```

1.9.4 Transferring Data

A common way to transfer input and output data to and from the user application is to use a distributed or network file system like NFS. While this is easy to handle for the user applications, the performance can be a bottleneck, especially when the data is accessed multiple times sequentially. Hence Univa Grid Engine provides interfaces and environment variables for delegated file staging in order to support the user with hookpoints for accessing and transferring data in different ways. In the following section these approaches for transferring user data as well as their advantages and drawbacks are discussed.

1.9.4.1 Transferring Data within the Job Script

While the job script is transferred from the submission host to the execution host, the data the job is working on remains unknown and therefore unreflected by the `qsub` command. If the necessary input and output files are only available through a slow network file system on the execution host, they can be staged in and out from the job itself to the local host. In order to do so, Univa Grid Engine creates a local temporary directory for each job and deletes it automatically after the job ends. The absolute path to this local directory is as `$TMPDIR` environment variable available during job run-time. In the following example an I/O intensive job copies the input data set from the NFS exported home directory of the user to the local directory and the results back to the home directory.

```
#!/bin/sh
...
# copy the data from the exported home directory to the temporary directory
cp ~/files/largedataset.csv $TMPDIR/largedataset.csv
# do data processing
...
# copy results back to user home directory
cp $TMPDIR/results ~/results
```

1.9.4.2 Using Delegated File Staging in DRMAA Applications

The Univa Grid Engine DRMAA implementation comes with built-in support for file staging. The administrator must configure appropriate **prolog** and **epilog** scripts, which are executed before the DRMAA jobs starts and after the DRMAA job ends. Theses scripts can be configured in the global configuration (`qconf -mconf`), in the host configuration (`qconf -mconf hostname`), and in the queue configuration (`qconf -mq queuename`). The script that is executed depends on the scripts which are configured. The host configuration overrides the global configuration and the queue configuration dominates the host configuration.

In order to make the job and epilog script job obvious, a set of variables is defined by Univa Grid Engine. These variables can be used in the configuration line, where the path to the pro- and epilog is defined.

Delegated File Staging Variables

Variable	Semantic
$fs_stdin_file_staging	Indicates if file staging for stdin is turn on (1) or off (0).
$fs_stdout_file_staging	Indicates if file staging for stdout is turn on (1) or off (0).
$fs_stderr_file_staging	Indicates if file staging for stderr is turn on (1) or off (0).
$fs_stdin_host	Name of host where the data originates.
$fs_stdout_host	Name of the host where the data goes.
$fs_stderr_host	Name of the host where the error file goes.
$fs_stdin_path	The absolute path to the input file on the input host.
$fs_stdout_path	The absolute path to the output file on the output host.

$fs_stderr_path	The absolute path to the error file on the output host.
$fs_stdin_tmp_path	The absolute path to the temporary input file.
$fs_stdout_tmp_path	The absolute path to the temporary output file.
$fs_stderr_tmp_path	The absolute path to the temporary error file.

1.9.4.2.1 Example: Copy the DRMAA Job Output File

In the following example an epilog script is parametrized in a way that the DRMAA job output file is copied after the job ends to an user defined host and directory.

```
qconf -mconf
...
epilog /path/to/epilog.sh $fs_stdout_file_staging $fs_stdout_host $fs_stdout_path $fs_stdout_tm
...
```

The `epilog.sh` script looks like the following:

```
000 #!/bin/sh
001
002 doFileStaging=$1
003 outputHost=$2
004 outputHostPath=$3
005 tmpJobPath=$4
006
007 if [ "x$doFileStaging" = "x1" ]; then
008
009    # transfer file from execution host to host specified in DRMAA file
010    echo "Copy file $tmpJobPath to host $outputHost to $outputHostPath"
011    scp $tmpJobPath $outputHost:$outputHostPath
012
013 fi
```

Finally the DRMAA delegated file staging must be turned on:

```
qconf -mconf
 ...
 delegated_file_staging true
```

After this is configured by the Univa Grid Engine administrator everything is the prepared from the Univa Grid Engine side. The DRMAA application now has to determine where to copy the information of the output file in the job template. The following code example shows how to accomplish this with Java DRMAA.

```
/* enable transfer output file to host "yourhostname" in file "/tmp/JOBOUTPUT" */
jobTemplate.setOutputPath("yourhostname:/tmp/JOBOUTPUT");
/* disable transfer input file, enable transfer output file, disable transfer error file *
FileTransferMode mode = new FileTransferMode(false, true, false);
jobTemplate.setTransferFiles(mode);
```

Go back to the Univa Grid Engine Documentation main page.