

Intermediate Linux and High Performance Computing on Orchestra

HMS Research Computing

Spring 2016

Class Objectives

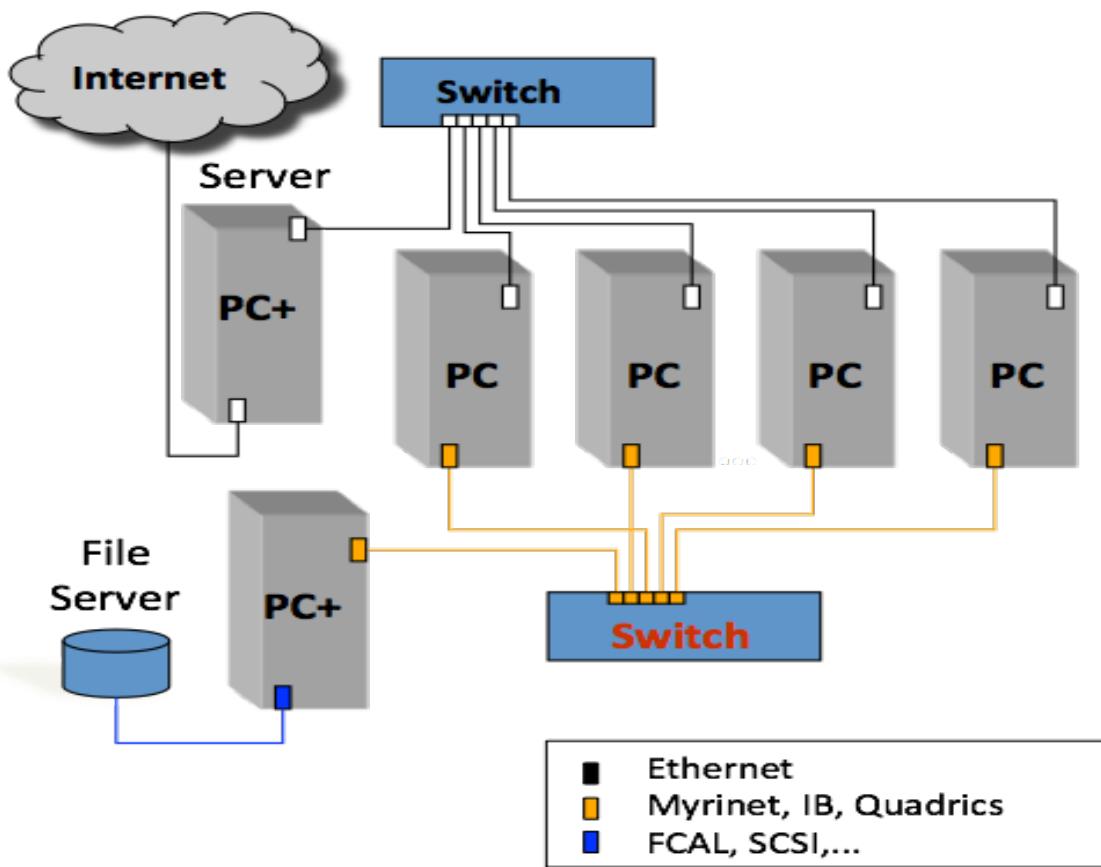
- Quick review of the Orchestra HPC environment
- Learn new Linux and Orchestra tools
- Work with command line output and error
- More advanced ways to run and manage Orchestra jobs
- Introduction to loops and shell scripting

What is Orchestra?

- Wiki page: <https://wiki.med.harvard.edu/Orchestra>
- Tech spec:
 - Over 500 compute nodes
 - Over 6500 cores
 - 10GigE interconnection
 - Over 40TB RAM
- CentOS Linux
- LSF scheduler
- Total 25PB storage



Generic Cluster Architecture

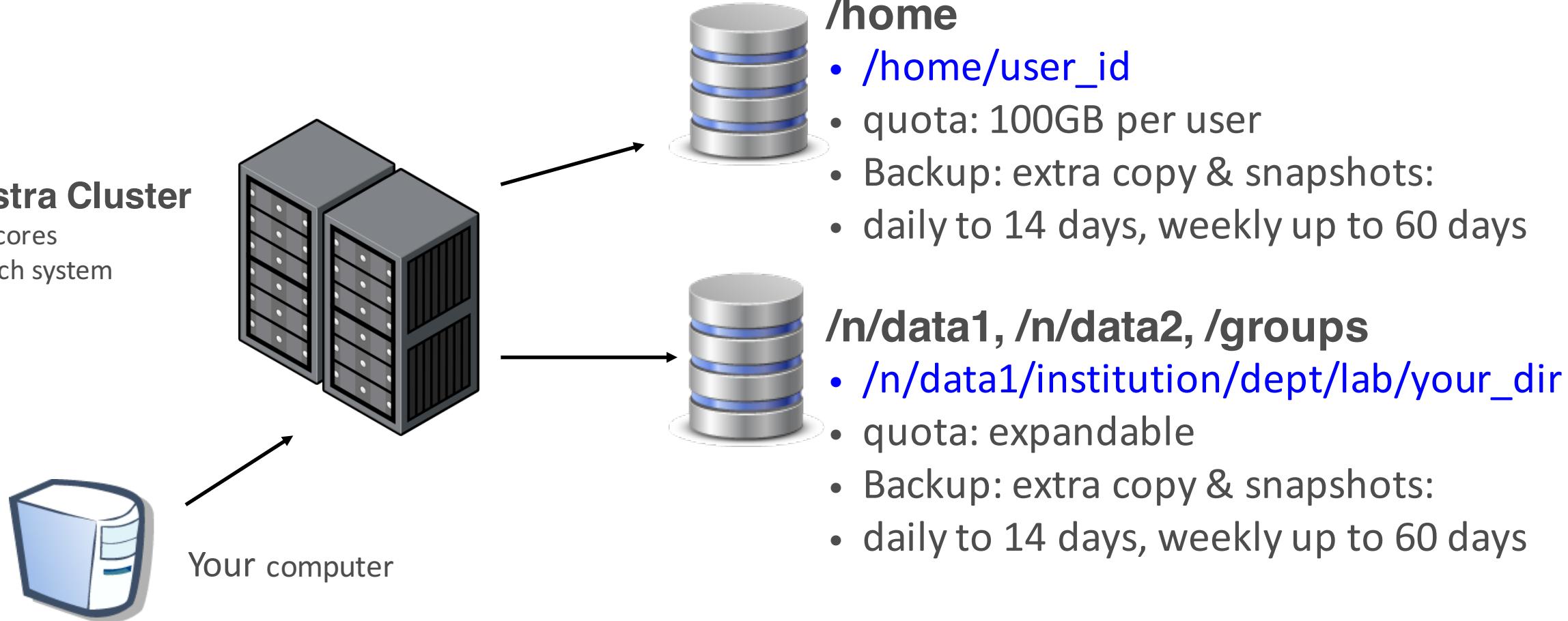


- Login nodes are for data management, job submission, code development, etc.
- Compute nodes are for production runs
- Your storage space is centralized network storage system
- Hundreds users are sharing the resources, so please be nice each other.
- Job scheduler works based on complex algorithms of fair-share, priority management, load balancing, etc.

Orchestra Primary Storage

Orchestra Cluster

- 6500+ cores
- LSF batch system



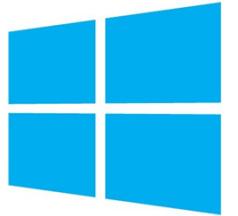
Temporary “Scratch” storage



- **/n/scratch2**
- **For data only needed temporarily during analyses.**
- **Each account can use up to 5 TB.**
 - **Lustre** --> a high-performance parallel file system running on DDN Storage.
 - More than 1 PB of total shared disk space.
 - No backups! Files are automatically deleted after unaccessed for 15 days, to save space.
 - More info at: <https://wiki.med.harvard.edu/Orchestra/LustreScratch>

“No backup” GPFS storage

- **/n/nobackup**
 - **used for large data sets not requiring backups**
 - **limited to only a few labs with large data requirements**
-
- **GPFS** --> a high-performance clustered file developed by IBM.
 - 2 PB of disk space.
 - No backups, but files are not purged on a schedule like “scratch” storage.
 - More info at: <https://wiki.med.harvard.edu/Orchestra/NoBackupGPFS>



Logging Into Orchestra: Windows

- Install PuTTY (google it)
- In box under “Host Name (or IP address)”
orchestra.med.harvard.edu
- To display graphics back to your desktop (X11 Forwarding):
 1. Install Xming (google it) and have it running
 2. In PuTTY, under Connection -> SSH -> X11:
 3. Check “Enable X11 Forwarding” first and THEN log in



Logging Into Orchestra: Mac

- Open a terminal (search “terminal”)

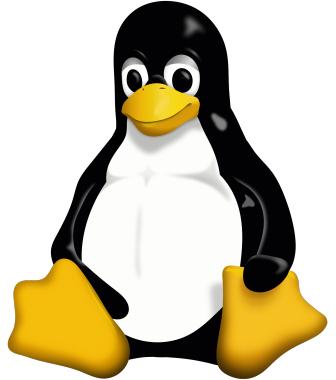
`ssh username@orchestra.med.harvard.edu`

- To display graphics back to your desktop (X11 forwarding)

Install XQuartz (google it) and have it running

`ssh -X username@orchestra.med.harvard.edu`

Logging Into Orchestra: Linux



- Open a terminal (search: “terminal”)

`ssh username@orchestra.med.harvard.edu`

For graphics (X11 Forwarding)

`ssh -X username@orchestra.med.harvard.edu`

Checking Storage Usage

- To check your available storage, run “quota”:

`mfk8@loge:~$ quota`

Reports are updated hourly.

Home directory: everyone gets 100 GB.

Group directories, as applies to your account:

/groups

/n/data1

/n/data2



rsync: better/faster data transfer

- To copy or synchronize data between Orchestra directories
 - `mfk8@node:~$ rsync -av /home/mfk8/data/. /n/data1/dir/groupdata/.`
- To copy from a remote system/desktop to Orchestra For GB+ transfers, use Orchestra's file transfer server: transfer.orchestra.med.harvard.edu
- rsync can resume interrupted transfers!
- Please do not use Orchestra's login servers for heavy I/O jobs like rsync or sftp.

rsync: from desktop -> Orchestra

```
1. bash
andys-mbp:~ alb15$ rsync -av -e ssh testfile alb15@transfer.orchestra.med.harvard.edu:~/building file list ... done
testfile

sent 151 bytes received 42 bytes 386.00 bytes/sec
total size is 26 speedup is 0.13
andys-mbp:~ alb15$
```

Using Software: Environment Modules

- Most “software” on Orchestra is installed as an environment module.
Allows for clean, easy loading, including most dependencies, and switching versions.

```
$ module avail
```

```
$ module avail seq/
```

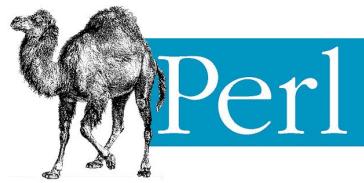
```
$ module avail stats/
```

```
$ module avail seq/bowtie/
```

Loading/Unloading Modules

- Loading modules
`$ module load seq/bowtie/2.0.6`
- Which module version is loaded (if at all)?
`$ which bowtie`
- See all modules loaded
`$ module list`
- Unloading modules
`$ module unload seq/bowtie/2.0.6`
- Dump all modules
`$ module purge`





Python, R, Perl

- Manage your own package libraries: get the version you want, when you want it!
- **Python:** virtual environment allows pip installs

<https://wiki.med.harvard.edu/Orchestra/PersonalPythonPackages>

- **R:** set up a personal R library for cran, bioconductor

<https://wiki.med.harvard.edu/Orchestra/PersonalRPackages>

- **Perl:** local::lib allows cpan, cpanm

<https://wiki.med.harvard.edu/Orchestra/PersonalPerlPackages>

Retrieving backups from daily snapshots

- Snapshots kept for up to 60 days under `/home` and group directories.
- `mfk8@loge:~$ cd .snapshot`
- `mfk8@loge:~$ ls`
 - Orchestra_home_daily_2015-10-02-00
 - Orchestra_home_daily_2015-10-01-02-00
- `mfk8@loge:~$ cd Orchestra_home_daily_2015-10-02-00`
- `mfk8@loge:~$ cp MyRetrievedFile ~`





Linux stuff



Symbolic Links (aka symlinks)

- A special file type similar to a Windows or Mac “shortcut”.
- Symbolic links can resolve across different filesystems.
 - Make a file or directory and then a symlink to it called myshortcut:
 - `mfk8@loge:~$ mkdir work`
 - `mfk8@loge:~$ ln -s work myshortcut`
 - `mfk8@loge:~$ ls -l` (note the “L” file type for symlink)
- Note: a “hard” link (**without the “-s” option**) is different.
 - Always use “`ln -s`” unless you really know what you’re doing!



Text searching with “grep”

```
alb15@loge:~$ grep -i abc /groups/rc-training/linux2/ex1
abc
abc def
ABCDEF
alb15@loge:~$ 
```

The syntax of grep

- “grep” can search files or any text input for patterns line by line
 - Etymology: *g/re/p* (*globally search a regular expression and print*)
- Common options:
 - -i ignore case
 - -r search all files in subdirectories recursively
 - -v show everything *except* the specified pattern
- `mfk8@loge:~$ grep -v 'pattern' myfile.txt`
 - Quotes are needed when patterns include spaces and !@#\$% type characters.

Example with grep: try this!

- cd /groups/rc-training/linux2
- cat ex1
- grep abc ex1
- grep -i abc ex1
- grep -v abc ex1
- grep -iv abc ex1
- grep abcd ex1
- grep “abc def” ex1



Wildcard * Pattern Matching

- Useful for copying/removing/etc all files matching a certain pattern
- Example Case:

To copy “all” files ending in “.fastq”:

```
mfk8@loge:~$ cp *.fastq ./NewFastqFolder
```

Pattern-matching can get much more granular than this, but we don’t want to overwhelm you yet.

Command line search with “find”

```
alb15@loge:~$ find ~/test -name '*.bam'  
/home/alb15/test/2/24h2jk14jh3.bam  
/home/alb15/test/3/34njnjk13.bam  
/home/alb15/test/4/jkljkj23kj4klfdsfs.bam  
/home/alb15/test/1/fdsfsdfdfs.bam  
alb15@loge:~$ █
```



“find” Command Syntax

- Use “find” to search directories based on file attributes:
 - Name: `find /tmp -name 'myfile*.txt'` (match the name of pattern `myfile*.txt`)
 - Owner: `find /tmp -user mfk8` (owned by user `mfk8`)
 - Group: `find /tmp -group mylab` (owned by `mylab` group)
 - Date: `find /tmp -ctime 30` (modified in the past 30 days)
 - (see *manual page for other options*)

Using find: -exec option

- Sometimes it's useful to run a command against the results of “find”.
- Examples:

- `find /tmp -atime 30 -exec rm {} \;` (remove all files older than 30 days)
- `find ~ -atime 30 -exec mv {} ~/archive \;` (move old files to an archive directory)
- `find . -name '*.bam' -exec ln -s {} \;` (create a symlink for each BAM file)

- *The {} symbol is a placeholder for the output of find.*
- *The escaped semi-colon \; is required in this case to finish the command.*

File Permissions

- By default, Orchestra home directories are world-readable!
 - That means all other Orchestra users have read access.
 - Why? This is a standard configuration in Linux/UNIX to allow for file sharing.
 - You can restrict your own file permissions with the “`chmod`” command:
 - `mfk8@loge:~$ chmod o-rwx /home/mfk8`
- By default, Orchestra shared directories are restricted to the group.
 - Group directories are owned by a designated group, e.g. “mylab”
 - File permissions are set as 2770 (no access outside of the owning group)
 - If desired, you can request changes from Research Computing.

Fixing permissions in group directories

- If files are not owned or writable to the group in your lab's shared directory, but should be, you can fix **files you are the owner of.**
 - example group = mylab
 - example directory = /n/data1/hms/sysbio/mylab/mydir
- mfk8@loge:~\$ cd /n/data1/hms/sysbio/mylab
- mfk8@loge:~\$ chgrp -R mylab mydir
- mfk8@loge:~\$ find mydir -type d -exec chmod g+rwxs {} \;
- mfk8@loge:~\$ find mydir -type f -exec chmod g+rw {} \;



What is Standard Output / Error ?

- Standard Output:
 - The “normal” output of Linux commands and applications.
 - **The bsub “–o” option is for creating an output log file**
- Standard error comes from:
 - bad command syntax
 - incorrect file permissions (can’t read / write a file)
 - missing library files or other application errors
 - **The bsub “–e” option is for creating an error log file**
- By default, both are displayed in the terminal screen.

Redirecting Standard Output

- Redirect (`>`)
 - Writes output to a new file instead of writing to the terminal.
 - Will overwrite an existing file completely.
- Append (`>>`)
 - Appends output to the end of a file without overwriting.
- Pipe (`|`)
 - Redirects standard output to a new command.

Examples: redirecting standard output

- Redirect (`>`)
 - `mfk8@loge:~$ grep abc /groups/rc-training/linux2/ex1 > out.txt`
 - `mfk8@loge:~$ cat out.txt`
- Append (`>>`)
 - `mfk8@loge:~$ find /groups/rc-training/linux2 -name 'ex*' >> out.txt`
 - `mfk8@loge:~$ cat out.txt`
- Pipe (`|`)
 - `mfk8@loge:~$ samtools sort in.bam | view -h > out.bam`



Using LSF on Orchestra



“bsub” – submitting a job to Orchestra

```
mfk8@loge:~$ bsub -q queue -W hr:min your_job
```

- Required Options (jobs will not dispatch without these):
 - q [queue]
 - W [runtime in hr:min]

Primary shared Job Queues

- ***priority*** if you have just one or two jobs to run
 - ***mcore*** if you have multi-core jobs to run.
 - ***short*** if your jobs will take less than 12 hours to run.
 - ***interactive*** to get an interactive login for up to 12 hours.
 - ***mpi*** if you have an MPI parallel job
 - ***long*** everything else
-
- **bqueues** displays which queues you have access to
 - <https://wiki.med.harvard.edu/Orchestra/ChoosingAQueue>

Setting a job's Runtime Limit

- **-W in hours:minutes (this option is required!)**
- Runtimes are subject to the maximum time permitted per queue
- If your job exceeds your runtime, your job will be killed ☹
- Running many jobs that finish quickly (less than a few minutes) is suboptimal and may result in job suspension. **Contact RC to learn how to batch jobs!**

Example: setting a 2 hour runtime limit to the short queue:

```
mfk8@loge:~$ bsub -q short -W 02:00 ./myseq.sh
```



Multithreading

- A single CPU can execute multiple processes (threads) concurrently
- `-n` indicates how many cores are requested
- Jobs that are over-efficient (use more cores than reserved) jeopardize the health of a node
- Reserve the same amount of cores in your job and your bsub!
 - The default is 1 core if `-n` is not specified.

CPU Limit: matching # of cores to your job

- CPU limit = number of seconds the cluster works on your job
 - which is calculated by LSF using: **Ncores * Runlimit (-n * -W)**
 - The default is 1 core per job unless you specify more in bsub with: **-n**
- Here's a common error, using "tophat" as an example:

`bsub -q short -W 8:00 tophat -p 8`

tophat requests 8 cores but gets 1 (no **-n** so the default is 1 core).

Result: Job killed in 1 hour.

Should have been: `bsub -q short -W 8:00 -n 8 tophat -p 8`

Monitoring Jobs

- List info about jobs/their status:

mfk8\$loge:~\$ bjobs

-r (running jobs)

-p (pending jobs)

-l (command entered, long form)

- List historical job information

mfk8\$loge:~\$ bhist jobid

Job Suspensions

- Jobs in the “long” queue can be suspended by LSF temporarily to allow jobs from the “short” queue (less than 12h) to run.
- If a job is suspended for >50% of the –W runlimit cumulatively, it will be automatically moved to the “no_suspend” queue where it can’t be suspended anymore.
- **bstop jobid** - manually pause a running job
- **bresume jobid** - manually resume a paused job



Terminating Jobs

- Terminate a job (jobid given at submission)

```
mfk8$loge:~$ bkill jobid
```

- Terminate multiple jobs

```
mfk8$loge:~$ bkill jobid1 jobid2 jobid3
```

- Terminate all of your jobs (be careful!)

```
mfk8$loge:~$ bkill 0
```

bsub exercise: submit a job and change its state

```
1. ssh
alb15@loge:~$ bsub -q short -W 1:00 sleep 3600
Job <6108102> is submitted to queue <short>.
alb15@loge:~$ bjobs
JOBID      USER      STAT  QUEUE      FROM_HOST      EXEC_HOST      JOB_NAME      SUBMIT_TIME
6108102    alb15     PEND  short      loge.orches
alb15@loge:~$ bjobs
JOBID      USER      STAT  QUEUE      FROM_HOST      EXEC_HOST      JOB_NAME      SUBMIT_TIME
6108102    alb15     RUN   short      loge.orches  clarinet002  sleep 3600  Mar  8 13:01
alb15@loge:~$ bstop 6108102
Job <6108102> is being stopped
alb15@loge:~$ bjobs
JOBID      USER      STAT  QUEUE      FROM_HOST      EXEC_HOST      JOB_NAME      SUBMIT_TIME
6108102    alb15     USUSP short      loge.orches  clarinet002  sleep 3600  Mar  8 13:01
alb15@loge:~$ bresume 6108102
Job <6108102> is being resumed
alb15@loge:~$ bjobs
JOBID      USER      STAT  QUEUE      FROM_HOST      EXEC_HOST      JOB_NAME      SUBMIT_TIME
6108102    alb15     RUN   short      loge.orches  clarinet002  sleep 3600  Mar  8 13:01
alb15@loge:~$ bkill 6108102
Job <6108102> is being terminated
alb15@loge:~$ bjobs
No unfinished job found
alb15@loge:~$ 
```



bsub: specify output and error logs

```
1. ssh
alb15@loge:~$ bsub -q short -W 1:00 -o job.output -e job.error "touch /test"
Job <6113404> is submitted to queue <short>.
alb15@loge:~$ cat job.error
touch: cannot touch `/test': Permission denied
alb15@loge:~$ 
```

Other bsub options

<code>-n 4</code>	<i>(number of cores. default =1)</i>
<code>-R "rusage[mem=8000]"</code>	<i>(memory requested in MB)</i>
<code>-I\$</code>	<i>(interactive login shell)</i>
<code>-N</code>	<i>(notify when job completes)</i>
<code>-J jobname</code>	<i>(define a Job Name)</i>
<code>-a openmpi</code>	<i>(type of mpi run)</i>

Reserving Memory

- Most nodes have 90GB memory. Some have more.
- Make a resource request with
 - R “rusage[mem=8000]” (must request memory in MB units)
- Memory multiplies by cores requested, so
 - n 4 -R “rusage[mem=16000]” reserves 64GB memory
- Asking for more memory may cause jobs to pend longer
- TERM_MEMLIMIT errors indicate not enough memory was reserved

Reserving GPUs

Orchestra has < 10 nodes equipped with GPUs. To access them, you must specify the “ngpus” resource with bsub:

- R “rusage[ngpus=1]” (select # of GPUs for the job)
- Orchestra currently has some older “clarinet” nodes with 1 GPU installed, and 1 newer “contrabassoon” node with 8 GPUs installed.
- If you need help verifying your application can work with Orchestra’s CUDA or GPU hardware, please contact RC.

MPI

- Can be an efficient way to run batches of jobs which are not “embarrassingly parallel”
- There is a dedicated queue with same-type compute nodes for optimal performance of MPI (800 cores)
- Matlab, Python, Java, R, C++, Fortran have MPI options
- Orchestra implementation: openMPI-1.8.
- Contact RC if you are considering MPI and want advice!

Interactive Jobs on compute nodes

- The login servers are not designed to handle intensive processes. Using 40% of a CPU results in a process being terminated.
- An “interactive session” on a compute node lasts up to 12 hours:
- `mfk8@loge:~$ bsub -Is -q interactive -n 1 bash`

`-Is` (capital eye, s) tells Orchestra you want an interactive shell

`-q interactive` is required for an interactive job

`-n` is the number of cores requested (20 maximum)

“`bash`” opens a session using the bash UNIX shell

`mfk8@clarinet001:~/$`



Automate commands with a “for” loop

- Repeat one or more commands against a designated list.
- This syntax is for the **bash** shell. Other shells (**tcsh**) are different.
- Examples:
 - `mfk8@clarinet001:~$ for x in 1 2 3 ; do mkdir $x ; done`
 - `mfk8@clarinet001:~$ for x in `cat list` ; do cp $x ~/work ; done`



Using bsub with a “for” loop

- When you need to submit a bunch of separate jobs systematically
 - `mfk8@loge:~$ for i in [input] ; do [your bsub command] ; done"`
 - For example:
 - `mfk8@loge:~$ for i in *.bam; do bsub -q short -W 30 "samtools sort -n $i $i.sorted; done"`

Shell Scripts: The Basics

```
#! /bin/sh      #always at the top. Defines type of shell to run.
```

```
#program with options
```

```
tophat -p 4 -o ./mytophatdir1 hg19 file1_1.fastq file1_2.fastq
```

```
tophat -p 4 -o ./mytophatdir2 hg19 file2_1.fastq file2_2.fastq
```

```
#save as a file such as myshellscript.sh
```

```
#To make the script “executable” by default, update permissions:
```

```
# chmod u+x myshellscript.sh
```

Submitting a Shell Script as a job

1). Traditional Shell script

```
mfk8@loge:~$ bsub -q mcore -W 12:00 -n 4 -e errfile.txt -o outfile.txt  
-N ./myshellscript.sh
```

2). A script with LSF options already embedded (next slide):

```
mfk8@loge:~$ bsub < myshellscript.sh
```



Creating a Shell Script for job submission

Create a txt file (job.txt) with contents defining the job array as below.

[bsub < job.txt](#)

```
#!/bin/sh
#BSUB -q mcore
#BSUB -W 12:00
#BSUB -o %J.out
#BSUB -e %J.err
#BSUB -N
#BSUB -n 4
#BSUB -R "rusage[mem=12000]"
module load seq/tophat/2.1.0 seq/bowtie/2.1.0 seq/samtools/1.2
tophat -p 4 -o ./mytophatdir1 hg19 file1_1.fastq file1_2.fastq
#save as myshellscript2.sh
```



Using Job Arrays in a script

- #BSUB -L /bin/bash
- #BSUB -n 1
- #BSUB -q short
- #BSUB -W 00:10
- #BSUB -J copytest[1-10]
- #BSUB -o copytest.%I.out
- job_index=\$LSB_JOBINDEX
- time cp file\$job_index.zip fileout\$job_index.zip

Job Dependencies

- When you need behavior like "run job B only if job A finishes"
- **bsub –w dependency_expression**
- See bsub manual page for full details. Examples:
 - **bsub –w done (jobid)**
 - **bsub –w exited (jobid)**
 - **bsub –w started (jobid)**

More Exercises

- How many jobs do I have running on Orchestra?
 - mfk8@loge:~\$ bjobs | wc -l
 - (“`wc -l`” command counts # of lines)
- How many jobs in the “RUN” state do I have running on Orchestra?
 - mfk8@loge:~\$ bjobs | grep RUN | wc -l
- How many total jobs are running on Orchestra?
 - mfk8@loge:~\$ bjobs -u all | wc -l



Installing Software: Binary Example

- mfk8@loge:~\$ bsub -Is -q interactive bash
- mfk8@clarinet001:~\$ wget <http://path/to/binary/mysoftware.tar.gz>
- mfk8@clarinet001:~\$ tar -zxvf mysoftware.tar.gz
- mfk8@clarinet001:~\$ ls mysoftware/bin

Installing Software: Source

- mfk8@loge:~\$ bsub -Is -q interactive bash
- mfk8@clarinet001:~\$ module load dev/compiler/gcc-4.8.5
- mfk8@clarinet001:~\$ wget <http://path/to/source/mysoftware.tar.gz>
- mfk8@clarinet001:~\$ tar -zxvf mysoftware.tar.gz
- mfk8@clarinet001:~\$ cd mysoftware
- mfk8@clarinet001:~\$ less README
- mfk8@clarinet001:~\$./configure --prefix=/home/mfk8/software
- mfk8@clarinet001:~\$ make
- mfk8@clarinet001:~\$ make install



Customizing your account's environment

- Command Aliases: create your own commands! Examples:
 - `alias ll='ls -la'`
 - `alias h=history`
- Change your default umask:
 - `umask 0002`
- Alter your default command path. Add a custom “bin” directory:
 - `export PATH=$PATH:/home/user/bin`
- Add any of these commands to your account’s profile (for bash):
 - `~/.bash_profile` (this file is read once upon login)
 - `~/.bashrc` (this file is read at every invocation of your shell)



For more direction:

- <https://wiki.med.harvard.edu/Orchestra/NewUserGuide>
- <http://rc.hms.harvard.edu>
- rchelp@hms.harvard.edu
- Office Hours: Wednesdays 1-3p Gordon Hall 500
- Class survey:
<http://hmsrc.me/inthpc2016-survey2>

