HPC User Environment 2

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Outline

- Review HPC User Environment 1 topics
  - Available HPC resources
  - Accounts and Allocations
  - Cluster architecture
  - Connect to clusters
  - Software management using softenv and module

- Things to be covered in this training
  - Job management
    - More on job queues
    - Submit and monitor your jobs
    - Job scheduling basics
      - Job priority
      - Backfill
  - Compiling and analyze codes on cluster
    - Serial program
    - Parallel program
HPC User Environment 2

Brief Review of Session 1
Inside A Cluster Rack
Inside A Compute Node

- Network Card
- Processor
- Memory
- Storage
- Accelerator (GPU/Xeon Phi)
## Cluster Nomenclature

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster</td>
<td>The top-level organizational unit of an HPC cluster, comprising a set of nodes, a queue, and jobs.</td>
</tr>
<tr>
<td>Node</td>
<td>A single, named host machine in the cluster.</td>
</tr>
<tr>
<td>Core</td>
<td>The basic computation unit of the CPU. For example, a quad-core processor is considered 4 cores.</td>
</tr>
<tr>
<td>Job</td>
<td>A user's request to use a certain amount of resources for a certain amount of time on cluster for his work.</td>
</tr>
</tbody>
</table>
HPC Cluster Architectures

- **Two major architectures**
  - Intel x86_64 clusters
    - Vendor: Dell
    - Operating System: Linux (RHEL 4/5/6)
    - Processor: Intel
Accessing cluster using ssh (Secure Shell)

- **On Unix and Mac**
  - use ssh on a terminal to connect

- **Windows box (ssh client):**
  - Putty, Cygwin
    - [http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html](http://www.chiark.greenend.org.uk/~sgtatham/putty/download.html)

- `ssh username@mike.hpc.lsu.edu`

- **Host name**
  - LONI: `<cluster_name>.loni.org`
    - `<cluster_name>` can be:
      - eric.loni.org
      - qb.loni.org
  - LSU HPC: `<cluster_name>.hpc.lsu.edu`
    - `<cluster_name>` can be:
      - mike.hpc.lsu.edu
      - smic.hpc.lsu.edu
      - philip.hpc.lsu.edu
More on Job Queues
Cluster Environment

- Multiple compute nodes
- Multiple users
- Each user may have multiple jobs running simultaneously
- Multiple users may share the same node
Job submission basics

- Find appropriate queue
- Understand the queuing system and your requirements and proceed to submit jobs
- Monitor jobs during execution
Job Queues

- Nodes are organized into queues. Nodes can be shared.
- Each job queue differs in
  - Number of available nodes
  - Max run time
  - Max running jobs per user
  - Nodes may have special characteristics: GPU/Xeon Phi’s, Large memory, etc.
- Jobs need to specify resource requirements
  - Nodes, time, queue
- It’s called a queue for a reason, but jobs don’t run on a “First Come First Served” policy,
  - This will be detailed in later slides
## Queue Characteristics – LONI clusters

<table>
<thead>
<tr>
<th>Machine</th>
<th>Queue</th>
<th>Max Runtime</th>
<th>ppn</th>
<th>Max running jobs</th>
<th>Max nodes per job</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eric</td>
<td>workq</td>
<td>3 days</td>
<td>8</td>
<td>16</td>
<td>24</td>
<td>Unpreemptable</td>
</tr>
<tr>
<td></td>
<td>checkpoint</td>
<td></td>
<td>8</td>
<td></td>
<td>48</td>
<td>Preemptable</td>
</tr>
<tr>
<td></td>
<td>single</td>
<td>1</td>
<td>32</td>
<td></td>
<td>1</td>
<td>ppn=1/2/4/8</td>
</tr>
<tr>
<td>QB2</td>
<td>workq</td>
<td>3 days</td>
<td>20</td>
<td>128</td>
<td></td>
<td>Unpreemptable</td>
</tr>
<tr>
<td></td>
<td>checkpoint</td>
<td></td>
<td>20</td>
<td></td>
<td>256</td>
<td>Preemptable</td>
</tr>
<tr>
<td></td>
<td>single</td>
<td>7 days</td>
<td>1,2,4,8</td>
<td></td>
<td>1</td>
<td>Single node jobs</td>
</tr>
</tbody>
</table>
Queue Characteristics – LSU Linux clusters

<table>
<thead>
<tr>
<th>Machine</th>
<th>Queue</th>
<th>Max Runtime</th>
<th>ppn</th>
<th>Max running jobs</th>
<th>Max nodes per job</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>SuperMike II</td>
<td>workq</td>
<td>3 days</td>
<td>16</td>
<td></td>
<td>128</td>
<td>Unpreemptable</td>
</tr>
<tr>
<td></td>
<td>checkpoint</td>
<td></td>
<td>16</td>
<td></td>
<td>128</td>
<td>Preemptable</td>
</tr>
<tr>
<td></td>
<td>bigmem</td>
<td>2 days</td>
<td>16</td>
<td>34</td>
<td>1</td>
<td>Big memory</td>
</tr>
<tr>
<td></td>
<td>gpu</td>
<td>3 days</td>
<td>16</td>
<td></td>
<td>16</td>
<td>Job using GPU</td>
</tr>
<tr>
<td></td>
<td>single</td>
<td>3 days</td>
<td>1,2,4,8</td>
<td></td>
<td>1</td>
<td>Single node jobs</td>
</tr>
<tr>
<td>Philip</td>
<td>workq</td>
<td>3 days</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>Unpreemptable</td>
</tr>
<tr>
<td></td>
<td>checkpoint</td>
<td></td>
<td>8</td>
<td></td>
<td>4</td>
<td>Preemptable</td>
</tr>
<tr>
<td></td>
<td>bigmem</td>
<td></td>
<td>8</td>
<td></td>
<td>2</td>
<td>Big memory</td>
</tr>
<tr>
<td></td>
<td>single</td>
<td>14 days</td>
<td>4</td>
<td>50</td>
<td>1</td>
<td>Single processor</td>
</tr>
<tr>
<td>SuperMIC</td>
<td>workq</td>
<td>3 days</td>
<td>20</td>
<td>34</td>
<td>128</td>
<td>Unpreemptable</td>
</tr>
<tr>
<td></td>
<td>checkpoint</td>
<td></td>
<td>20</td>
<td></td>
<td>360</td>
<td>Preemptable</td>
</tr>
</tbody>
</table>
Queue Characteristics

➢ “qstat -q” will give you more info on the queues

[fchen14@mike2 ~]$ qstat -q

server: mike3

<table>
<thead>
<tr>
<th>Queue</th>
<th>Memory</th>
<th>CPU</th>
<th>Time</th>
<th>Walltime</th>
<th>Node</th>
<th>Run</th>
<th>Que</th>
<th>Lm</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>workq</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>128</td>
<td>31</td>
<td>6</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>mwfa</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>8</td>
<td>3</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>bigmem</td>
<td>--</td>
<td>--</td>
<td>48:00:00</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>lasigma</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>28</td>
<td>28</td>
<td>7</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>bigmemtb</td>
<td>--</td>
<td>--</td>
<td>48:00:00</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>priority</td>
<td>--</td>
<td>--</td>
<td>168:00:0</td>
<td>128</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>single</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>1</td>
<td>62</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>gpu</td>
<td>--</td>
<td>--</td>
<td>24:00:00</td>
<td>16</td>
<td>1</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>preempt</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>checkpoint</td>
<td>--</td>
<td>--</td>
<td>72:00:00</td>
<td>128</td>
<td>31</td>
<td>137</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>admin</td>
<td>--</td>
<td>--</td>
<td>24:00:00</td>
<td>--</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
<tr>
<td>scalemp</td>
<td>--</td>
<td>--</td>
<td>24:00:00</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>--</td>
<td>E</td>
<td>R</td>
</tr>
</tbody>
</table>

➢ For a more detailed description use mdiag
Queue Querying – Linux Clusters

- Displays information about active, eligible, blocked, and/or recently completed jobs: `showq` command

```
$ showq
active jobs------------------------
JOBID    USERNAME    STATE   PROCS   REMAINING STARTTIME
236875   ebeigi3    Running 16   1:44:29  Mon Sep 15 20:00:22
236934   mwu3        Running 16   00:03:27 Mon Sep 15 19:04:20
...
eligible jobs----------------------
JOBID    USERNAME    STATE   PROCS   WCLIMIT QUEUETIME
236795   dmarce1    Idle 1456  00:15:00 Mon Sep 15 16:38:45
236753   rsmith     Idle 2000  4:00:00  Mon Sep 15 14:44:52
236862   dlamas1    Idle   576   2:00:00  Mon Sep 15 17:28:57
...
121 eligible jobs
blocked jobs-----------------------
JOBID    USERNAME    STATE   PROCs   WCLIMIT QUEUETIME
232741   myagho1    Idle 2000 1:00:00:00 Mon Sep 8 07:22:12
235545   tanping    Idle   1   2:21:10:00 Fri Sep 12 16:50:49
235546   tanping    Idle   1   2:21:10:00 Fri Sep 12 16:50:50
...
Submit and Monitor Your Jobs

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Two Job Types

- **Interactive job**
  - Set up an interactive environment on compute nodes for users
    - Advantage: can run programs interactively
    - Disadvantage: must be present when the job starts
  - Purpose: testing and debugging, compiling
    - **Do not run on the head node!!!**
    - Try not to run interactive jobs with large core count, which is a waste of resources)

- **Batch job**
  - Executed without user intervention using a job script
    - Advantage: the system takes care of everything
    - Disadvantage: can only execute one sequence of commands which cannot changed after submission
  - Purpose: production run
Submitting Jobs on Linux Clusters

- **Interactive job example:**
  
  ```bash
  qsub -I -X -V \ 
  -l walltime=<hh:mm:ss>,nodes=<num_nodes>:ppn=<num_cores> \ 
  -A <Allocation> \ 
  -q <queue name>
  
  DO NOT directly ssh to compute nodes,
  unless the nodes assigned to you by the job scheduler.
  ```
  
  – Add `-X` to enable X11 forwarding

- **Batch Job example:**
  
  ```bash
  qsub job_script
  ```
PBS Job Script – Serial Job

#!/bin/bash

#PBS -l nodes=1:ppn=1      # Number of nodes and processor
#PBS -l walltime=24:00:00  # Maximum wall time
#PBS -N myjob             # Job name
#PBS -o <file name>       # File name for standard output
#PBS -e <file name>       # File name for standard error
#PBS -q single            # The queue for serial jobs
#PBS -A <loni_allocation> # Allocation name
#PBS -m e                 # Send mail when job ends
#PBS -M <email address>   # Send mail to this address

<shell commands>
<path_to_executable> <options>
<shell commands>
PBS Job Script – Parallel Job

```
#!/bin/bash

#PBS -l nodes=2:ppn=16 #Number of nodes and processors per node
#PBS -l walltime=24:00:00 #Maximum wall time
#PBS -N myjob #Job name
#PBS -o <file name> #File name for standard output
#PBS -e <file name> #File name for standard error
#PBS -q checkpt #Queue name
#PBS -A <allocation_if_needed> #Allocation name
#PBS -m e #Send mail when job ends
#PBS -M <email address> #Send mail to this address

<shell commands>

mpirun -machinefile $PBS_NODEFILE -np 32 <path_to_executable> <options>
<shell commands>
```

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Tells the scheduler how much resource you need.

How will you use the resources?
Job Monitoring - Linux Clusters

- **Check details on your job using** `qstat`  
  
  ```bash
  $ qstat -n -u $USER  : For quick look at nodes assigned to you
  $ qstat -f jobid     : For details on your job
  $ qdel jobid         : To delete job
  ```

- **Check approximate start time using** `showstart`  
  
  ```bash
  $ showstart jobid
  ```

- **Check details of your job using** `checkjob`  
  
  ```bash
  $ checkjob jobid
  ```

- **Check health of your job using** `qshow`  
  
  ```bash
  $ qshow jobid
  ```

- Please pay close attention to the load and the memory consumed by your job!
Using the “top” command

- The top program provides a dynamic real-time view of a running system.

```
top - 19:39:56 up 89 days,  4:13,  1 user,  load average: 0.63, 0.18, 0.06
Tasks: 489 total,   2 running, 487 sleeping,  0 stopped,  0 zombie
Cpu(s):  6.3%us,  0.0%sy,  0.0%ni, 93.7%id,  0.0%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:   65909356k total, 3389616k used, 62519740k free,  151460k buffers
Swap: 207618040k total,  5608k used, 207612432k free,  947716k cached

PTD  USER      PR  NI  VIRT   RES   SHR  S %CPU %MEM    TIME+ COMMAND
39595  fchen14   20   0  266m  257m  592 R  99.9  0.4   0:06.94 a.out
39589  fchen14   20   0 17376  1612  980 R  0.3  0.0   0:00.05 top
38479  fchen14   20   0 108m  2156  1348 S  0.0  0.0   0:00.03 bash
39253  fchen14   20   0 103m  1340  1076 S  0.0  0.0   0:00.00 236297.mike3.SC
39254  fchen14   20   0 103m  1324  1060 S  0.0  0.0   0:00.00 bm_laplace.sh
39264  fchen14   20   0 99836  1908  992 S  0.0  0.0   0:00.00 sshd
39265  fchen14   20   0 108m  3056  1496 S  0.0  0.0   0:00.03 bash
```
PBS Environmental Variables

[fchen14@mike315 ~]$ echo $PBS_

$PBS_ENVIRONMENT   $PBS_MOMPORT   $PBS_NUM_PPN   $PBS_O_MAIL
$PBS_QUEUE         $PBS_WALLTIME  $PBS_GPUFILE  $PBS_NODEFILE
$PBS_O_HOME        $PBS_O_PATH   $PBS_SERVER   $PBS_JOBCOOKIE
$PBS_NODENUM      $PBS_O_HOST   $PBS_O_QUEUE  $PBS_TASKNUM
$PBS_JOBID        $PBS_NP       $PBS_O_LANG   $PBS_O_SHELL
$PBS_VERSION      $PBS_JOBNAME  $PBS_NUM_NODES $PBS_O_LOGNAME
$PBS_O_WORKDIR    $PBS_VNODENUM

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Pay attention to single queue usage

- **Single queue** - Used for jobs that will only execute on a single node, i.e. $\text{nodes}=1: \text{ppn}=1/2/4/8$.

- **Jobs in the single queue should not use:**
  - More than 2GB memory per core for Eric, Philip and SuperMike2 (32G/16).
  - More than 3.2GB memory per core for QB2 (64G/20).

- **If applications require more memory, scale the number of cores (ppn)** to the amount of memory required: i.e. max memory available for jobs in single queue is 8GB for $\text{ppn}=4$ on SuperMike2.

- **Typical type of warning:**
  - **E124 - Exceeded memory allocation.** This Job XXXX appears to be using more memory (GB) than allocated ($9 > 3$).
  - **E123 - Exceeded ppn/core allocation.** This Job XXXX appears to be using more cores than allocated ($6 > 1$). Please allocate the number of cores that the job will use, ($\text{ppn}=6$). This Job has 1 core(s) allocated ($\text{ppn}=1$).
More things to be noticed

- Eric is old and will be retired in the near future LONI users are encouraged to migrate their codes to QB-2 as soon as possible.
- The purpose of bigmem queue on QB-2 is for jobs costing big (larger than 64 GB) memory not for jobs using more number of cores.
- GPU is available to workq or checkpt queues on QB2.
- Xeon Phi is available to workq or checkpt queues on SuperMIC.
- There is no single queue on SuperMIC.
- Users are encouraged to use accelerators (GPU/Xeon Phi) whenever possible. Application for allocation involving with usage of accelerators will be easier to be approved.
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Job Scheduling Basics
Back to Cluster Architecture

- As a user, you interact with the scheduler and/or resource manager whenever you submit a job, or query on the status of your jobs or the whole cluster, or seek to manage your jobs.
- Resource managers give access to compute resource
  - Takes in a resource request (job) on login node
  - Finds appropriate resource and assigns you a priority number
  - Positions your job in a queue based on the priority assigned.
  - Starts running jobs until it cannot run more jobs with what is available.
Job Scheduler

- HPC & LONI Linux clusters use TORQUE, an open source version of the Portable Batch System (PBS) together with the MOAB Scheduler, to manage user jobs.

- Resource Manager - Torque
  - Manages a queue of jobs for a cluster of resources
  - Launches job to a simple FIFO job queue

- Workload Manager - Moab
  - A scheduler that integrates with one or more Resource Managers to schedule jobs across domains of resources (servers, storage, applications)
  - Prioritizes jobs
  - Provides status of running and queued jobs, etc.

- The batch queuing system determines
  - The order jobs are executed
  - On which node(s) jobs are executed
Job management philosophy

- **Working Philosophy**
  - Prioritize workload into a queue for jobs
  - *Backfill* idle nodes to maximize utilization
    - Will be detailed later...

![Diagram showing job management philosophy](image)
# Job Priorities

- Jobs with a higher job priority are scheduled ahead of jobs with a lower priority.

- Job priorities have contributions from the following:
  - credential priority
  - fairshare priority
  - resource priority
  - service priority

- Priority determination for each queued job, use
  
  ```
  $ mdiag -p
  ```

  ```
  diagnosing job priority information (partition: ALL)
  
<table>
<thead>
<tr>
<th>Job</th>
<th>PRIORITY*</th>
<th>Cred( User:Class)</th>
<th>FS( User: WCA)</th>
<th>Serv(QTime:XFctr)</th>
<th>Res( Proc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights --------</td>
<td>100( 10: 10)</td>
<td>100( 10: 50)</td>
<td>2( 2: 20)</td>
<td>30( 10)</td>
<td></td>
</tr>
<tr>
<td>236172</td>
<td>246376</td>
<td>40.6(100.0: 0.0)</td>
<td>8.6( 19.6: 0.3)</td>
<td>4.0(1480.: 99.7)</td>
<td>46.8(2048.)</td>
</tr>
<tr>
<td>235440</td>
<td>242365</td>
<td>41.3(100.0: 0.0)</td>
<td>4.6(  8.2: 0.6)</td>
<td>6.6(3959.: 6.5)</td>
<td>47.5(512.0)</td>
</tr>
<tr>
<td>235441</td>
<td>242365</td>
<td>41.3(100.0: 0.0)</td>
<td>4.6(  8.2: 0.6)</td>
<td>6.6(3959.: 6.5)</td>
<td>47.5(512.0)</td>
</tr>
<tr>
<td>235442</td>
<td>242361</td>
<td>41.3(100.0: 0.0)</td>
<td>4.6(  8.2: 0.6)</td>
<td>6.6(3958.: 6.5)</td>
<td>47.5(512.0)</td>
</tr>
<tr>
<td>236396</td>
<td>241821</td>
<td>41.4(100.0: 0.0)</td>
<td>8.8( 19.6: 0.3)</td>
<td>2.2(664.0: 67.4)</td>
<td>47.6(1456.)</td>
</tr>
</tbody>
</table>
  ```

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Priority components

- **Credential priority** = credweight * (userweight * job.user.priority)
  
  \[ = 100 \times (10 \times 100) = 100000 \]

  It is a constant for all users.

- **Fairshare priority** = fsweight * min (fscap, (fsuserweight*DeltaUserFSUsage))
  
  \[ = 100 \times (10 \times \text{DeltaUserFSUsage}) \]

  If you have not submitted jobs in the past 7 days, \( \text{DeltaUserFSUsage} = 20000 \)

- **Service priority** = serviceweight * (queuetimeweight * QUEUETIME + xfactorweight * XFACTOR)
  
  \[ = 2 \times (2 \times \text{QUEUETIME} + 20 \times \text{XFACTOR}), \]

  where \( \text{XFACTOR} = 1 + \frac{\text{QUEUETIME}}{\text{WALLTIMELIMIT}} \).

- **Resource priority** = resweight * min (rescap, (procweight * TotalProcessorsRequested))
  
  \[ = 30 \times \text{min}(3840, (10 \times \text{TotalProcessorsRequested})) \]

- See [http://www.hpc.lsu.edu/docs/pbs.php](http://www.hpc.lsu.edu/docs/pbs.php), click “Job priority”.
How to get higher priority?

- Do not submit too many jobs within one week.
- Submit your job early to accumulate the queue time.
- More on resource priority:
  - Request more compute nodes.
  - Request a smaller walltime limit.
  - see next few slides...
How to maximize the usage of a cluster?

- Fill in high-priority (large) jobs
- Backfill low-priority (small) jobs
An Overview of Backfilling (1)

- Backfill is a scheduling optimization that allows a scheduler to make better use of available resources by running jobs out of order.
- Enabling backfill allows the scheduler to start other, lower-priority jobs so long as they do not delay the highest priority job.

If the FIRSTFIT algorithm is applied, the following steps are taken:

- The list of feasible backfill jobs is filtered, selecting only those that will actually fit in the current backfill window.
- The first job is started.
- While backfill jobs and idle resources remain, repeat step 1.
An Overview of Backfilling (2)

- Although by default the start time of the highest priority job is protected by a reservation, there is nothing to prevent the third priority job from starting early and possibly delaying the start of the second priority job.

- Command to show current backfill windows:
  - `showbf`
    
    - Shows what resources are available for immediate use.
    - This command can be used by any user to find out how many processors are available for immediate use on the system. It is anticipated that users will use this information to submit jobs that meet these criteria and thus obtain quick job turnaround times.
  
  - Example:

    
    ```
    [fchen14@eric2 ~]$ showbf -c workq
    Partition   Tasks  Nodes  Duration  StartOffset        StartDate
    ----------  -----  -----  ---------  --------------  -------------
    ALL         40     5       18:50:35  00:00:00        11:16:49_09/04
    ALL          8     1       INFINITY  00:00:00        11:16:49_09/04
    ```
How Much Time Should I Ask for?

- **It should be**
  - Long enough for your job to complete
  - As short as possible to increase the chance of backfilling
Frequently Asked Questions

- I submitted job A before job B. Why job B started earlier than job A?
- There are free nodes available, why my job is still waiting and not running?
- Why my job is not get accelerated when running on cluster?
  - Is your job utilizing the parallel resource on the cluster?
  - Does you job have lots of I/O tasks?
  - See next section...
HPC User Environment 2

Compile and Analyze Codes on Cluster
## Compilers

### Serial compilers

<table>
<thead>
<tr>
<th>Language</th>
<th>Linux cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intel</td>
<td>PGI</td>
</tr>
<tr>
<td>Fortran</td>
<td>ifort</td>
</tr>
<tr>
<td>C</td>
<td>icc</td>
</tr>
<tr>
<td>C++</td>
<td>icpc</td>
</tr>
</tbody>
</table>

### Parallel compilers

<table>
<thead>
<tr>
<th>Language</th>
<th>Linux clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fortran</td>
<td>mpif77, mpif90</td>
</tr>
<tr>
<td>C</td>
<td>mpicc</td>
</tr>
<tr>
<td>C++</td>
<td>mpiCC</td>
</tr>
</tbody>
</table>
Example compiling serial code

- icc hello_cpu_elapsed.c
- gfortran test_hello2.f90

- List symbols for executables:
  nm - list symbols from object files
- Example:
  [fchen14@mike2 hello]$ nm ./a.out | grep intel
  000000000060eb60 B __intel_cpu_indicator

  [fchen14@mike2 hello]$ nm ./a.out | grep gfortran
  U _gfortran_set_args@@GFORTTRAN_1.0
CPU time vs Elapsed time

- **CPU time (or process time):**
  - The amount of time for which a central processing unit (CPU) was used for processing instructions of a computer program or operating system, as opposed to, for example, waiting for input/output (I/O) operations or entering low-power (idle) mode.

- **Elapsed real time (or simply real time, or wall clock time)**
  - The time taken from the start of a computer program until the end as measured by an ordinary clock. Elapsed real time includes I/O time and all other types of waits incurred by the program.

- **If a program uses parallel processing, total CPU time for that program would be more than its elapsed real time.**
  - \( \frac{\text{Total CPU time}}{\text{Number of CPUs}} \) would be same as elapsed real time if work load is evenly distributed on each CPU and no wait is involved for I/O or other resources.
Compiling and Analyzing C serial program

#include <stdio.h>
#include <time.h>

int main(char *argc, char **argv) {
    double s=0.0;
    // fundamental arithmetic type representing clock tick counts.
    clock_t start, end;
    int i;
    start = clock();
    for (i=0;i<1000000000;i++)
        s+=i*2.0; // doing some floating point operations
    end = clock();
    double time_elapsed_in_seconds = (end - start)/(double)CLOCKS_PER_SEC;
    printf("cputime_in_sec: %e\n", time_elapsed_in_seconds);
    start = clock();
    system ("sleep 5"); // just sleep, does this accumulate CPU time?
    end = clock();
    time_elapsed_in_seconds = (end - start)/(double)CLOCKS_PER_SEC;
    printf("cputime_in_sec: %e\n", time_elapsed_in_seconds);
    return 0;
}
Watch the actual cpu time using “time”

[fchen14@mike429 serial]$ gcc hello_cpu_elapsed.c
[fchen14@mike429 serial]$ time ./a.out
cputime_in_sec: 2.740000e+00
cputime_in_sec: 0.000000e+00

real 0m7.782s
user 0m2.750s
sys 0m0.005s
Some additional info about “time”

- Use the Linux command `time` to evaluate the actual time usage
  - time a simple command or give resource usage
- Real refers to actual elapsed time (wall clock time)
  - Time from start to finish of the call. This is all elapsed time including time used by other processes and time the process spends blocked (for example if it is waiting for I/O to complete).
- User and Sys refer to CPU time used only by the process.
  - User is the amount of CPU time spent in user-mode code (outside the kernel) within the process.
  - Sys is the amount of CPU time spent in the kernel within the process.
- Purpose of this example:
  - real < user: The process is CPU bound and takes advantage of parallel execution on multiple cores/CPUs.
  - real ≈ user: The process is CPU bound and takes no advantage of parallel execution.
  - real > user: The process is I/O bound. Execution on multiple cores would be of little to no advantage.
Two parallel schemes

- **Shared Memory system**
  - A single multicore compute node
  - Open Multi-processing (OpenMP)

- **Distributed Memory system**
  - Multiple compute nodes
  - Message Passing Interface (MPI)

**MPI**: Distributed Memory System

**OpenMP**: Shared Memory System

Typically less memory overhead/duplication. Communication often implicit, through cache coherency and runtime.
Example compiling threaded OpenMP code

- Compiling OpenMP code often requires the `openmp` compiler flags, it varies with different compiler
- Environment Variable `OMP_NUM_THREADS` sets the number of threads
- Examples:
  - `gcc -fopenmp hello_openmp.c`
  - `ifort -openmp hello_openmp.f90`

<table>
<thead>
<tr>
<th>Compiler</th>
<th>Compiler Options</th>
<th>Default behavior for # of threads (OMP_NUM_THREADS not set)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNU (gcc, g++, gfortran)</td>
<td>-fopenmp</td>
<td>as many threads as available cores</td>
</tr>
<tr>
<td>Intel (icc ifort)</td>
<td>-openmp</td>
<td>as many threads as available cores</td>
</tr>
<tr>
<td>Portland Group (pgcc,pgCC,pgf77,pgf90)</td>
<td>-mp</td>
<td>one thread</td>
</tr>
</tbody>
</table>
Sample OpenMP C code

```c
#include <omp.h>
#include <stdio.h>
#include <stdlib.h>

int main (int argc, char *argv[]) {
    int nthreads, tid;

    /* Fork a team of threads with their own copies of variables */
    #pragma omp parallel private(nthreads, tid)
    {
        /* Obtain thread number */
        tid = omp_get_thread_num();
        printf("Hello World from thread = %d\n", tid);
        /* Only master thread does this */
        if (tid == 0) {
            nthreads = omp_get_num_threads();
            printf("Number of threads = %d\n", nthreads);
        }
    } /* All threads join master thread and disband */
```
program hello

integer nthreads, tid, omp_get_num_threads, omp_get_thread_num
! fork a team of threads giving them their own copies of variables
!$omp parallel private(nthreads, tid)
! obtain thread number
 tid = omp_get_thread_num()
print *, 'hello world from thread = ', tid
! only master thread does this
if (tid .eq. 0) then
    nthreads = omp_get_num_threads()
    print *, 'number of threads = ', nthreads
end if
! all threads join master thread and disband
!$omp end parallel
end
Analyzing a parallel (OpenMP) program

What will be the CPU time and elapsed time for the following code segment:

See (on SuperMike II):
/home/fchen14/userenv/src/openmp/hello_openmp_cpu_elapse.c

```c
// fundamental arithmetic type representing clock tick counts.
clock_t start, end;
struct timeval r_start, r_end;
int i;
gettimeofday(&r_start, NULL);
start = clock();
#pragma omp parallel for // spawn the openmp threads
for (i=0;i<N;i++) a = i*2.0; // doing some floating point operations
end = clock();
gettimeofday(&r_end, NULL);
double cputime_elapsed_in_seconds = (end - start)/(double)CLOCKS_PER_SEC;
double realtime_elapsed_in_seconds = ((r_end.tv_sec * 1000000 + 
r_end.tv_usec) - (r_start.tv_sec * 1000000 + 
r_start.tv_usec))/1000000.0;
```
# Available MPI libraries on LONI & HPC

<table>
<thead>
<tr>
<th>Cluster Resource</th>
<th>Name</th>
<th>Mvapich</th>
<th>Mvapich2</th>
<th>OpenMPI</th>
<th>MPICH</th>
<th>Default serial compiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONI</td>
<td>Eric</td>
<td>0.98, 1.1</td>
<td>1.4, 1.6, 1.8.1</td>
<td>1.3.4</td>
<td>X</td>
<td>Intel 11.1</td>
</tr>
<tr>
<td>QB2</td>
<td>X</td>
<td>2.0</td>
<td>1.8.1</td>
<td>3.0.3</td>
<td></td>
<td>Intel 14.0.2</td>
</tr>
<tr>
<td>LSU</td>
<td>SuperMikell</td>
<td>X</td>
<td>1.9, 2.0.1</td>
<td>1.6.2, 1.6.3, 1.6.5</td>
<td>3.0.2</td>
<td>Intel 13.0.0</td>
</tr>
<tr>
<td>Philip</td>
<td>X</td>
<td>X</td>
<td>1.4.3, 1.6.1</td>
<td>1.2.7, 1.3.2, 1.4.1</td>
<td></td>
<td>Intel 11.1</td>
</tr>
<tr>
<td>SuperMIC</td>
<td>X</td>
<td>2.0</td>
<td>1.8.1</td>
<td>3.0.3, 3.1.1</td>
<td></td>
<td>Intel 14.0.2</td>
</tr>
</tbody>
</table>
## MPI Compilers (1)

<table>
<thead>
<tr>
<th>Language</th>
<th>Linux clusters</th>
<th>AIX clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fortran</td>
<td>mpif77, mpif90</td>
<td>mpxlf, mpxlf90</td>
</tr>
<tr>
<td>C</td>
<td>mpicc</td>
<td>mpcc</td>
</tr>
<tr>
<td>C++</td>
<td>mpiCC</td>
<td>mpCC</td>
</tr>
</tbody>
</table>

`mpif90 hello.f90`

`mpicc hello.c`

`mpicxx hello.cpp`
MPI Compilers (2)

- **These MPI compilers are actually wrappers**
  - They still use the compilers we've seen on the previous slide
    - Intel, PGI or GNU
  - They take care of everything we need to build MPI codes
    - Head files, libraries etc.
  - What they actually do can be revealed by the `-show` option

- **It’s extremely important that you compile and run your code with the same version of MPI!**
  - Use the default version if possible
Compiling a MPI C program

- **Compiling Hello world in C version:**
  ```c
  mpicc hello_mpi.c
  
  #include <mpi.h>
  #include <stdio.h>
  
  int main(int argc, char** argv) {
    int name_len, world_size, world_rank;
    char processor_name[MPI_MAX_PROCESSOR_NAME];
    
    //Initialize the MPI environment
    MPI_Init(NULL, NULL);
    
    // Get the number and rank of processes
    MPI_Comm_size(MPI_COMM_WORLD, &world_size);
    MPI_Comm_rank(MPI_COMM_WORLD, &world_rank);
    
    // Get the name of the processor
    MPI_Get_processor_name(processor_name, &name_len);
    
    // Print off a hello world message
    printf("Iam from processor %s, rank %d out of %d processors
", processor_name, world_rank, world_size);
    
    // Finalize the MPI environment.
    MPI_Finalize();
  }
  ```
Compiling a MPI Fortran program

- Compiling Hello world in Fortran:
  ```fortran
  mpif90 hella_mpi.f90
  program hello_mpi
    include 'mpif.h'
    use mpi
    character 10 name
    ! Initialize the MPI library:
    call MPI_Init(ierr)
    ! Get size and rank
    call MPI_Comm_Size(MPI_COMM_WORLD, numtasks, ierr)
    call MPI_Comm_Rank(MPI_COMM_WORLD, rank, ierr)
    ! print date
    if (nrank == 0) then
      write( , )'System date'
      call system('date')
    endif
    call MPI_Barrier(MPI_COMM_WORLD, ierr)
    ! print rank
    call MPI_Get_Processor_Name(name, len, ierr)
    write( , )'I am ', nrank, ', of', numtasks, 'on ', name
    ! Tell the MPI library to release all resources it is using:
    call MPI_Finalize(ierr)
  end program hello_mpi
  ```
Notes for compiling a MPI program (1)

- Always verify what compiler/library is being used:

```bash
$ mpicc -show
icc -I/usr/local/packages/openmpi/1.6.2/Intel-13.0.0/include -L/usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib -lmpi -ldl -lm -Wl,--export-dynamic -lrt -lnsl -libverbs -libumad -lpthread -lutil

$ mpif90 -show
ifort -I/usr/local/packages/openmpi/1.6.2/Intel-13.0.0/include -I/usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib -L/usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib -lmpi_f90 -lmpi_f77 -lmpi -ldl -lm -Wl,--export-dynamic -lrt -lnsl -libverbs -libumad -lpthread -lutil
```
Notes for compiling a MPI program (2)

- Always verify what library is being used: Before and after:

  $ ldd a.out # ldd - print shared library dependencies

  linux-vdso.so.1 => (0x00007fff907ff000)
  libmpi_f90.so.1 => /usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib/libmpi_f90.so.1 (0x00002b9ae577e000)
  libmpi_f77.so.1 => /usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib/libmpi_f77.so.1 (0x00002b9ae5982000)
  libmpi.so.1 => /usr/local/packages/openmpi/1.6.2/Intel-13.0.0/lib/libmpi.so.1 (0x00002b9ae5bb9000)

  ...  
  libpthread.so.0 => /lib64/libpthread.so.0 (0x00000003b2180000)

  ...  
  libifport.so.5 => /usr/local/compilers/Intel/compiler_xe_2013.0.079/compiler/lib/intel64/libifport.so.5 (0x00002b9ae61ee000)
  libifcore.so.5 => /usr/local/compilers/Intel/compiler_xe_2013.0.079/compiler/lib/intel64/libifcore.so.5 (0x00002b9ae641d000)
Running and Analyzing MPI program

- Make sure you are running your jobs on the correct nodes
- Important if you want to run less processes than ppn
- Understand the usage of $PBS_NODEFILE

```
[fchen14@mike2 ~]$ qsub -I -X -l nodes=2:ppn=16 -l walltime=01:00:00 -q gpu
...
[fchen14@mike429 ~]$ echo $PBS_NODEFILE
/var/spool/torque/aux//236660.mike3
[fchen14@mike429 ~]$ cat $PBS_NODEFILE
mike429
  ...
  # 16 repeats of mike429
mike429
mike430
  ...
  # 16 repeats of mike430
mike430
[fchen14@mike429 hybrid]$ cat $PBS_NODEFILE| uniq > hosts
[fchen14@mike429 hybrid]$ cat hosts
mike429
mike430
```
Running and Analyzing MPI program

[fchen14@mike315 mpi]$ mpicc hello_mpi.c
[fchen14@mike315 mpi]$ mpirun -np 32 -hostfile $PBSNODEFILE ./a.out

Iam from processor mike315, rank 1 out of 32 processors
Iam from processor mike315, rank 6 out of 32 processors
Iam from processor mike315, rank 9 out of 32 processors
Iam from processor mike315, rank 12 out of 32 processors
Iam from processor mike315, rank 0 out of 32 processors
Iam from processor mike315, rank 2 out of 32 processors
Iam from processor mike315, rank 3 out of 32 processors
Iam from processor mike315, rank 7 out of 32 processors
Iam from processor mike315, rank 10 out of 32 processors
Iam from processor mike315, rank 5 out of 32 processors
Iam from processor mike315, rank 13 out of 32 processors
Iam from processor mike315, rank 4 out of 32 processors
Iam from processor mike315, rank 8 out of 32 processors
Iam from processor mike334, rank 17 out of 32 processors
Iam from processor mike315, rank 11 out of 32 processors
Iam from processor mike315, rank 14 out of 32 processors
Iam from processor mike315, rank 15 out of 32 processors
Iam from processor mike334, rank 18 out of 32 processors
Compiling hybrid (MPI+OpenMP) program

- **See** /home/fchen14/userenv/src/hybrid/hello_hybrid.c for complete source
- **Use command:**
  - $ mpicc -openmp hello_hybrid.c

```c
#pragma omp parallel default(shared) private(itd, np)
{
    gtd = omp_get_num_threads(); // get total num of threads in a process
    itd = omp_get_thread_num();   // get thread id
    gid = nrank*gtd + itd;        // global id
    printf("Gid %d from thd %d out of %d from process %d out of %d on %s\n",
            gid, itd, gtd, nrank, numprocs, processor_name);
    if (nrank==0 && itd==0)
    {
        // system("pstree -ap -u $USER");
        system("for f in `cat $PBS_NODEFILE|uniq`; do ssh $f pstree -ap -u $USER; done;"));
        system("sleep 10");
    }
}
```
Analyzing a hybrid program

```
[fchen14@mike315 hybrid]$ export OMP_NUM_THREADS=4
[fchen14@mike315 hybrid]$ mpirun -np 2 -x OMP_NUM_THREADS ./a.out
Gid 0 from thread 0 out of 4 from process 0 out of 2 on mike315
Gid 2 from thread 2 out of 4 from process 0 out of 2 on mike315
Gid 1 from thread 1 out of 4 from process 0 out of 2 on mike315
Gid 3 from thread 3 out of 4 from process 0 out of 2 on mike315
Gid 4 from thread 0 out of 4 from process 1 out of 2 on mike315
Gid 6 from thread 2 out of 4 from process 1 out of 2 on mike315
Gid 7 from thread 3 out of 4 from process 1 out of 2 on mike315
Gid 5 from thread 1 out of 4 from process 1 out of 2 on mike315
bash,108067
    |-mpirun,110651 -np 2 -x OMP_NUM_THREADS ./a.out
    |
    |   |-a.out,110652
    |   |
    |   |   |-sh,110666 -c ...
    |   |
    |   |   `-ssh,110670 mike315 pstree -ap -u fchen14
    |   |
    |   |   `-{a.out},110654
    |   |
    |   |   `-{a.out},110656
    |   |
    |   |   `-{a.out},110662
    |   |
    |   |   `-{a.out},110663
    |   |
    |   |   `-{a.out},110664
    |   |
    |   |   `-{a.out},110665
    |
```
Exercise

- Submit a small job to run “sleep 180” and “print PBS variables”
  - Create a script to submit a 5 min job and print from within the job script PBS variables $PBS_NODEFILE, $PBS_WORKDIR. Also run “sleep 180” to give you a few minutes to verify status.
  - Once the job is running, find out the Mother Superior node and other slave nodes assigned to your job using qstat.
  - Log into MS node and verify that your job is running and find your temporary output file
  - Modify your script to print hello from each of your assigned nodes

- Run a shell script using mpirun to print process id of shell
Future Trainings

- **Next week training:** *Introduction to Latex*
  - Wednesdays 9:00am, June 29, Frey Computing Service Center 101

- **Programming/Parallel Programming workshops**
  - Usually in summer

- **Keep an eye on our webpage:** www.hpc.lsu.edu