High Scalability Resource Management with SLURM
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What is SLURM

- Simple Linux Utility for Resource Management

- Performs resource management within a single cluster
- Typically used with an external scheduler (e.g. Moab or LSF)

- Arbitrates requests by managing queues of pending work
- Allocates access to computer nodes and their interconnect
- Launches parallel jobs and manages them (I/O, signals, time limits, etc.)

- Developed by LLNL with help from HP, Bull, Linux NetworX, and others
Design objectives

- High scalability
  - Thousands of nodes

- Reliable
  - Avoid single point of failure

- Simple to administer

- Open source (GPL)

- Extensible
  - Very flexible plugin mechanism
SLURM architecture overview

- **slurmctld** (backup)
- **slurmctld**
- **slurmd**
- **slurmd**
- **slurmd**
- **slurmd**
- **MySQL**

- **slurmd**
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**Accounting and Configuration Information**

**Control Functions**

**Compute Nodes**
How we achieve high scalability

- High parallelism
  - Dozens of active threads are common in the daemons
  - Independent read and write locks on various data structures
  - Offload as much work as possible from slurmctld (SLURM Control Daemon)
Example of parallel srmctld operations

- Get system configuration information
- Get information about job 1234
- Get information about all of user bob’s jobs
- Get queue configurations

srmctld
THREA D 1
THREA D 2
THREA D 3
THREA D 4
Hierarchical communication

- Slurmd daemons (one per compute node) have hierarchical communications with fault-tolerance and configurable fanout

Most of the communications overhead is pushed down to slurmd daemons.

Synchronizes system noise to minimize impact upon applications.

Slurmd provides fault-tolerance and combines results into one response message, dramatically reducing slurmd’s overhead.
Non-killable processes

- Non-killable processes (typically hung on I/O to global file system) are not uncommon so we try to minimize their impact

- SLURM supports configurable timeout and program to execute when non-killable processes are found so that system administrators can respond quickly to problems

- SLURM will release a resource for reuse by another job once all processes associated with the previous job on that node complete. There is no need to wait for all processes on all nodes to complete
Highly efficient algorithms

- Bitmap operations used for much of the scheduling work
- RPCs use simple binary information rather than XML (which is more flexible, but slower)

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Binary Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes in selected partition AND</td>
<td>11111111111111110000</td>
</tr>
<tr>
<td>Nodes with selected features AND</td>
<td>11111111000000000000</td>
</tr>
<tr>
<td>Nodes with available resources</td>
<td>00111000000011100001</td>
</tr>
<tr>
<td>Select from these nodes--&gt;</td>
<td>00111000000000000000</td>
</tr>
</tbody>
</table>
Hostlist expressions used in configuration file

- Configuration file size is relatively independent of cluster size

```
# slurm.conf
# plugins, timers, log files, etc.
#
NodeName=tux[0-1023] SocketsPerNode=4 CoresPerSocket=4
#
PartitionName=debug Nodes=tux[0-15] MaxTime=30:00
PartitionName=batch Nodes=tux[16-1023] MaxTime=1-00:00:00
```
### Hostlist expressions used in most commands

$ squeue

<table>
<thead>
<tr>
<th>PARTITION</th>
<th>AVAIL</th>
<th>TIMELIMIT</th>
<th>NODES</th>
<th>STATE</th>
<th>NODELIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>debug</td>
<td>up</td>
<td>30:00</td>
<td>16</td>
<td>idle</td>
<td>tux[0-15]</td>
</tr>
<tr>
<td>batch</td>
<td>up</td>
<td>1-00:00:00</td>
<td>32</td>
<td>alloc</td>
<td>tux[16-47]</td>
</tr>
<tr>
<td>batch</td>
<td>up</td>
<td>1-00:00:00</td>
<td>976</td>
<td>idle</td>
<td>tux[48-1023]</td>
</tr>
</tbody>
</table>

$ sinfo

<table>
<thead>
<tr>
<th>JOBID</th>
<th>PARTITION</th>
<th>NAME</th>
<th>USER</th>
<th>ST</th>
<th>TIME</th>
<th>NODES</th>
<th>NODELIST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1234</td>
<td>batch</td>
<td>a.out</td>
<td>bob</td>
<td>R</td>
<td>10:14</td>
<td>16</td>
<td>tux[16-31]</td>
</tr>
<tr>
<td>1238</td>
<td>batch</td>
<td>my.sh</td>
<td>alice</td>
<td>R</td>
<td>8:57</td>
<td>16</td>
<td>tux[32-47]</td>
</tr>
</tbody>
</table>
Results

- SLURM is running on about 35% of the Top500 systems
- Total execution time (resource allocation, launch, I/O processing, resource deallocation)
  - 32 nodes 0.1 second
  - 256 nodes 1.0 seconds
  - 1k nodes 3.7 seconds
  - 2k nodes 19.5 seconds
  - 4k nodes 56.6 seconds
- Virtual machine with 64k nodes has been emulated
Special note on task launch

- Some vendors supply proprietary task launch mechanisms (e.g. IBM BlueGene `mpirun`)

- For compatibility with existing vendor tools and/or infrastructure (rather than for performance reasons), the vendor supplied task launch mechanism can be used with SLURM performing the resource management
  - Current model on IBM BlueGene systems
For more information about SLURM

- Information: https://computing.llnl.gov/linux/slurm/
- Downloads: http://sourceforge.net/projects/slurm/
- Email: jette1@llnl.gov

- SLURM BOF in Hilton (directly across the street)
  - Thursday 20 November 3PM to 5PM
  - Room: Salon D
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