Increasing HPC Resiliency Leads to Greater Productivity

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Our HPC Environment

	Shark HPC	Nautilus HPC
Compute nodes	80	336
CPU cores per node	24	24
Total cores	1920	8064
Memory per node	384GB	64GB, 128GB, 192GB
Job scheduler	LSF[1]	Torque/Moab[2]
Filesystem	1.6 PB GPFS	800TB GPFS
Primary workload	Next generation sequencing.	Basic science (biostatistics, radiation physics, etc).

- ~200 applications installed.
- ~125 active users between the two clusters.
- ~3 FTE.
- Utilization typically around 70% or higher.

Node Availability

- Memory over-subscription of compute nodes a major problem on Nautilus.
    - Jobs using (***a lot***) more memory than expected.
    - Users unable to provide reasonable estimates for memory utilization.
    - Users instructed to request a number of CPUs commiserate with the amount of memory they needed:
        - A job that needed 40% of the memory should request 40% of the CPUs on a node.
        - In theory this would prevent over-subscription.
        - In practice this was marginally successful and a difficult concept to convey to the user community.

Node Availability

- Memory over-subscription resulted in node crashes.
  - *Node crash event* – one or more nodes crashing.

Metric	Amount
Node crash events	1.4 per day
Scope of event	3 nodes (almost 1% of the cluster)
Largest event	55 nodes (16% of the cluster)
** Metrics are for Nautilus.*	

- In extreme cases a large number of node failures would have an adverse impact on the shared filesystem which would in turn impact the entire cluster.

Lost Time and Productivity

- Each event resulted in:
  - Lost compute jobs
    - For the offending user.
    - For other users sharing the node.
  - Lost CPU capacity while the nodes were offline.
  - Lost time for the systems administrators
    - Identify the offending jobs.
    - Notify the affected users.
    - Reboot the nodes.
    - These issues often resulted in Help Desk tickets from the user community.
    - Typically ~2 hours per day was devoted to this problem, including weekends.
- ***Not sustainable in many respects!***

Single Threaded versus Multithreaded

- Over-subscription of CPUs on Nautilus was a secondary problem.
  - Users unaware of their software being multithreaded.
  - Software using more cores than reserved by the scheduler.
  - Too many multithreaded jobs being assigned to the same node(s).
    - Caused jobs to run much slower than expected.
    - Jobs exceeded their run time and were terminated.
    - Users submitted tickets asking for help.
    - Users required to resubmit jobs.
- ***More lost time and lost productivity.***

Solution: Job Scheduler to the Rescue!

- Shark HPC was designed to avoid memory over-subscription via LSF configuration:

LSF Config File	Parameter
`lsb.conf`	`LSB_MEMLIMIT_ENFORCE=y`
`lsb.queues`	`MEMLIMIT = 1 377856` `RES_REQ = "rusage[mem=8192] span[hosts=1]"`

- Job scheduler will terminate a job that exceeds the amount of memory it has requested.
- Jobs that do not specify a memory value will be assigned the soft limit.
- Soft and hard limits are set with the `MEMLIMIT` option above.
- Hard limit chosen to be 369GB (369 * 1024MB = 377856MB).
  - Allows operating system and GPFS pagepool to occupy 15GB.
- All jobs will reserve at least 8GB (`rusage[mem=8192]`).

Solution: Job Scheduler to the Rescue!

- Required lines in the LSF Job submission:

LSF parameter	Description
`#BSUB -M 8192`	Memory limit
`#BSUB -R rusage[mem=8192]`	Memory reservation

- Memory limit parameter is the memory hard limit.
- Memory reservation is the amount that has been reserved and can not be scheduled/reserved by other jobs.

- This prevented the memory over-subscription problem from ever occurring on Shark!

Solution: Job Scheduler to the Rescue!

- Porting the changes to Nautilus and expanding the scope:

Moab parameter	Description
`SERVERSUBMITFILTER /opt/moab/etc/jobFilter.pl`	Used to confirm that required submission parameters are present.
`RESOURCELIMITPOLICY JOBMEM:ALWAYS,ALWAYS:NOTIFY,CANCEL`	Notify the user when job memory exceeds soft limit. Cancel job when it exceeds hard limit.
`RESOURCELIMITPOLICY PROC:ALWAYS,ALWAYS:NOTIFY,CANCEL`	Notify the user when job CPU core utilization exceeds soft limit. Cancel job when it exceeds hard limit.
`RESOURCELIMITPOLICY WALLTIME:ALWAYS,ALWAYS:NOTIFY,CANCEL`	Notify the user when job walltime exceeds soft limit. Cancel job when it exceeds hard limit.

- If soft and hard limits are not specified in the scheduler configuration, then those limits become the hard limit as specified by the job submission.

Solution: Job Scheduler to the Rescue!

- Required lines in the Moab job submission:

LSF parameter	Description
`#PBS -l nodes=1:ppn=1`	Node and CPU hard limit
`#PBS -l walltime=1:00:00`	Run time hard limit
`#PBS -l mem=1gb`	Memory hard limit

- Memory limit parameter is the memory hard limit.

- This prevented the memory over-subscription problem from ever occurring on Nautilus!

Solution: Job Scheduler to the Rescue!

- The `JOBMEM` policy will only work with the Moab `MAXMEM` job submission parameter.
- `SERVERSUBMITFILTER` script rewrites the user's submit script:

```
#PBS -l mem=1gb
```

becomes

```
#PBS -W x=MAXMEM:1gb
```

Or adds this if `mem` is absent

```
#PBS -W x=MAXMEM:1mb
```

NOTE: Must submit jobs with `msub` (not `qsub`) to use `SERVERSUBMITFILTER`.

Results!

- 525 days of uptime on Shark.
- 90% of Shark compute nodes NEVER rebooted.
- 360 days of uptime on Nautilus.
- 70% of Nautilus compute nodes NEVER rebooted.

- In the first year of operation for Nautilus:
- 850,000 jobs submitted.
- 12,157 jobs exceeded their memory hard limit and were terminated.
- 2,187 jobs exceeded their CPU cores hard limit and were terminated.
- 0 compute nodes rebooted due to over-subscription.

Self Diagnosis

- Examples of error messages sent to the user:

Scheduler	Error
Moab	`job 3546 exceeded MEM usage hard limit (6135 > 5120).`
LSF	`TERM_MEMLIMIT: job killed after reaching LSF memory usage limit.`

Error Messages

Job has exceeded its walltime (in seconds):

```
Job 3558 exceeded WALLTIME usage hard limit (68 > 66).
```

Job has exceeded its maximum memory allowed (in MB):

```
job 3546 exceeded MEM usage hard limit (6135 > 5120).
```

Job has exceeded its maximum number of CPU cores allowed:

```
job 3526 exceeded PROC usage hard limit (278 > 110).
```

In order to receive these error messages **you must enable email notification** in your job submission script with the following line:

```
#PBS –M MyEmailAddress
```

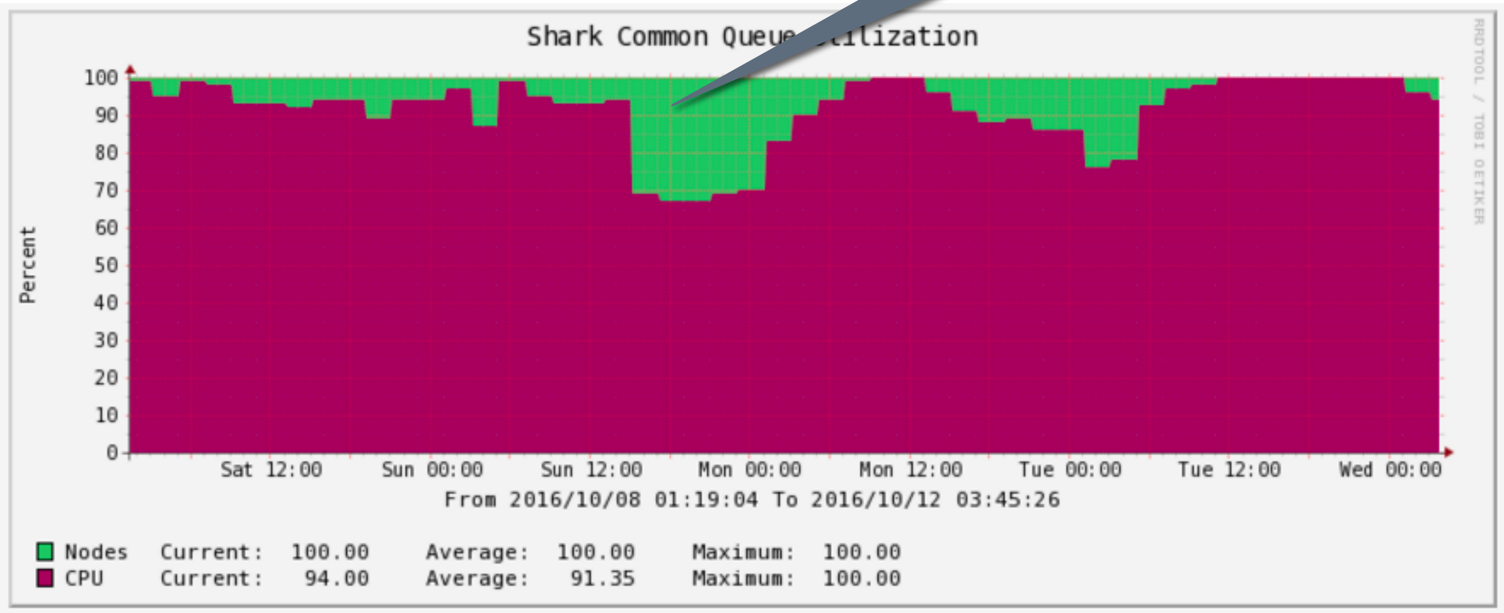
Optionally, if you want to receive email when the job aborts, begins, and ends, add this line:

```
#PBS –m abe
```

Unintended Consequences

- Users tend to deliberately over-estimate their memory and CPU core requirements, resulting in under utilization of the cluster.

70% CPU util.
100% Node util.



Hardening the Resources

- Other items that can be precursors to node crashes:

Item	Threshold
Storage block and inode usage	> 90%
Remote storage unmounted	Y/N
Memory available	< 2GB
Swap available	< 15GB
sshd is running	Y/N

- Monitored with LSF External Load Information Manager (ELIM) script on Shark, and with LBNL Node Health Check (NHC) from Lawrence Berkeley National Laboratory [3] on Nautilus.
- Nodes are automatically marked as “offline” if any of the above conditions are met.

Hardening the Resources

- Deploy a RAMDisk for applications with poor I/O patterns:

Execute from /etc/rc.local:

```
mount -t tmpfs -o size=15g tmpfs /mnt/tmpfs
```

- Clean up RAMDisk with tmpwatch:

/etc/cron.daily/tmpwatch

```
flags=-umc
/usr/sbin/tmpwatch "$flags" 11d /mnt/tmpfs
```

- The size of the RAMDisk and the interval of the tmpwatch clean up is dependent on the requirements and duration of the jobs using the RAMDisk.

Hardening the Resources

- Use tmpwatch to clean up `/var`.

/etc/cron.daily/tmpwatch

```
flags=-umc
/usr/sbin/tmpwatch "$flags" 10d /var/spool/torque/undelivered
/usr/sbin/tmpwatch "$flags" 60d /var/spool/torque/mom_priv/jobs
/usr/sbin/tmpwatch "$flags" 60d /var/spool/torque/spool
```

- The interval for `undelivered` was chosen somewhat arbitrarily.
- The interval for `jobs` and `spool` was chosen to exceed the longest possible run time of a job on the cluster.

Accomplishments!

- Nearly 100% uptime on compute nodes is possible.
- Users able to self-diagnose their job failures because the cluster tells them why jobs were terminated.
- Training of users regarding memory reservation via the job scheduler is much easier.
- Nodes are marked offline when a node error condition occurs, and automatically recover when the error condition is resolved.
- Compute job efficiency is more often discussed now than compute node availability.
- Compute nodes are cleaned up (tmpwatch) automatically.
- Recovered 10 hours per week for FTE to work on other things.
- ***Increased productivity for HPC staff and customers.***

Accomplishments!

- Since June 1, 2016 (176 days as of 11/07/16):
  - Nautilus 100% cluster uptime
    - 89% of nodes never rebooted.
    - 96% of nodes up over 145 days.
  - Shark 100% cluster uptime
    - 95% of nodes never rebooted.

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