Scalable I/O-Aware Job Scheduling for Burst Buffer Enabled HPC Clusters

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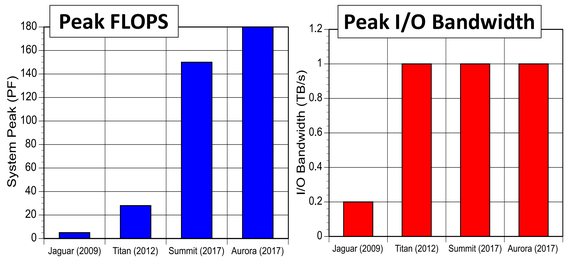
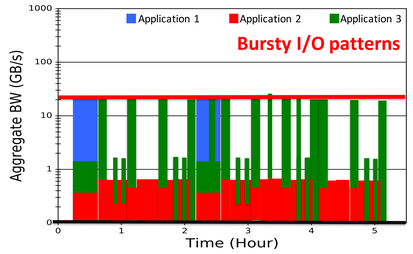
Motivation

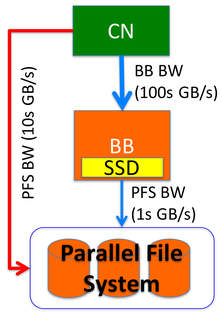


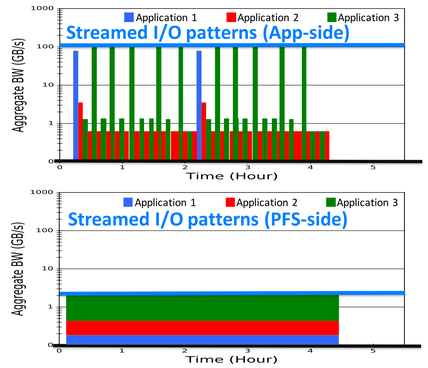
From a talk of Lucy Nowell, DoE Program Director (DoE Workflow Workshop, Rockville, MD, April 20-21, 2015)

- The FLOPS vs. I/O imbalance can cause I/O contention
- Burst buffers (BB) and smart staging postpone contention
- Parallel file systems (PFSes) remain the main bottleneck



Based on: Liu, N, Cope, J, Carns, P, Carothers, C, Ross, R, Grider, G, Crume, A, Maltzahn, C . "On the Role of Burst Buffers in Leadership-class Storage Systems" MSST/SNAPI 2012





- Without BBs, the bursty I/O goes straight to the PFS
- With BBs, the application sees much higher I/O BWs
- With BBs, the I/O to the PFS is a constant stream
- PFS is now provisioned for avg. I/O load (not max load)

We propose a novel, I/O-aware batch scheduling algorithm that can manage I/O contention at the PFS level [1]

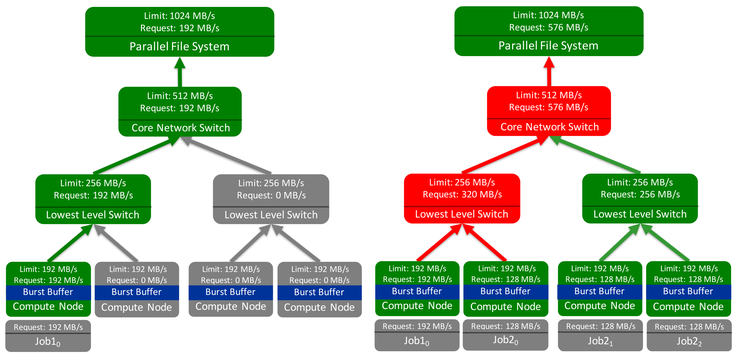
Making the Scheduler I/O-aware

- I/O-aware means using I/O as a key constraint when scheduling jobs
  - Jobs are delayed if they would cause contention in the I/O subsystem
- I/O-aware schedulers keep track of I/O allocations and predict potential I/O contention using both the I/O subsystem and I/O contention models

Flux framework's global system view and resource description language enable the use of I/IO subsystem and contention models in a scheduler

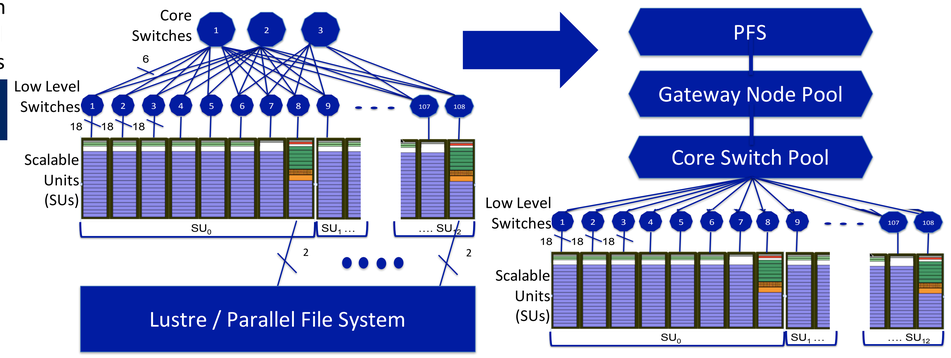
I/O-aware Scheduling Scenarios

- Job 1, by itself, can be scheduled on the system
- Job 2 requests too much BW and can cause contention with Job 1
  - Job 2 is delayed until more BW is available (i.e., when Job 1 completes)



Modeling the I/O Subsystem

From a complex resource graph... To a simple resource tree



- Modeled system:
  - A 1944 node/12 SU cluster
  - I/O routed round-robin across core switches and gateway nodes
- Key simplifications:
  - Merge core switches and gateway nodes
  - Leverage BBs to model I/O as a constant stream rather than variable bursts

Modeling the I/O Contention

- Two scenarios are modeled:
  - All jobs get their requested BW and extra BW remains
  - Smaller I/O requests are satisfied, larger requests contend for BW; no extra BW remains
- Contention occurs in case two and is modeling using an *Interference Factor* defined in [2]

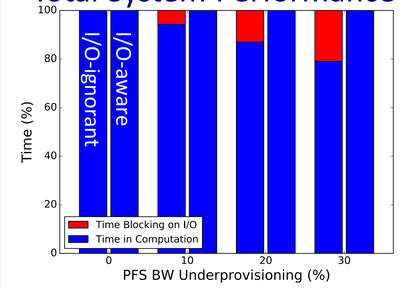
Test Configuration

- 2,500 jobs sampled from LLNL's workloads
  - Constant job I/O rate of 18 MB/s
- 3,888 node system model from LLNL's CTS-1
- I/O-aware/ignorant versions of EASY backfilling
  - Emulated using the Flux framework emulator
- Four levels of PFS provisioning
  - 0% (70GB/s), 10% (63 GB/s), 20% (56 GB/s), and 30% (49 GB/s)
  - Simulates a small PFS or a reservation of BW for external sources of I/O

Critical Questions

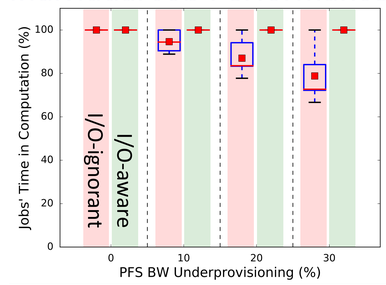
- Does I/O-aware scheduling:
  - Impact percentage of time that nodes spend in computation?
  - Impact the variability of each individual job's performance?
  - Affect the time to make a scheduling decision?
- What is the trade-off between system efficiency and turnaround time?

Total System Performance



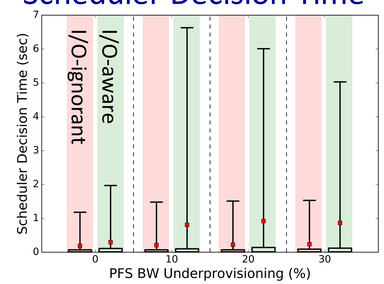
I/O-aware scheduling keeps allocated nodes in computation 100% of the time

Individual Job Performance



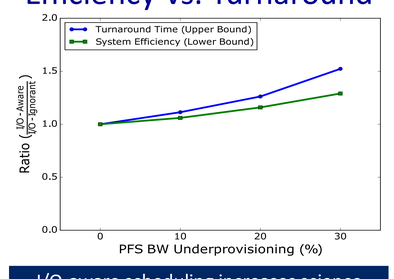
I/O-aware scheduling eliminates variability in job performance due to I/O contention

Scheduler Decision Time



I/O-aware scheduling is still viable for online batch job scheduling

Efficiency vs. Turnaround



I/O-aware scheduling increases science (>1.29x) in exchange for increasing turnaround time (<1.52x)

References: [1] S. Herbein, D. H. Ahn, D. Lipari, T. R. Scogland, M. Stearman, M. Grondona, J. Garlick, B. Springmeyer, and M. Taufer, "Scalable I/O-Aware Job Scheduling for Burst Buffer Enabled HPC Clusters," in Proc. of the 25th International Symposium on High-Performance Parallel and Distributed Computing (HPDC), 2016.
[2] M. Dorier, G. Antoniu, R. Ross, D. Kimpe, and S. Ibrahim. *CALCioM: Mitigating I/O Interference in HPC Systems Through Cross-Application Coordination*. In Proc. of the 2014 IEEE 28th International Parallel and Distributed Processing Symposium (IPDPS), May 2014.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. National Science Foundation CCF-1318445/1318417.

LLNL-POST-690319