Lustre Performance Investigations on Theta

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Overview

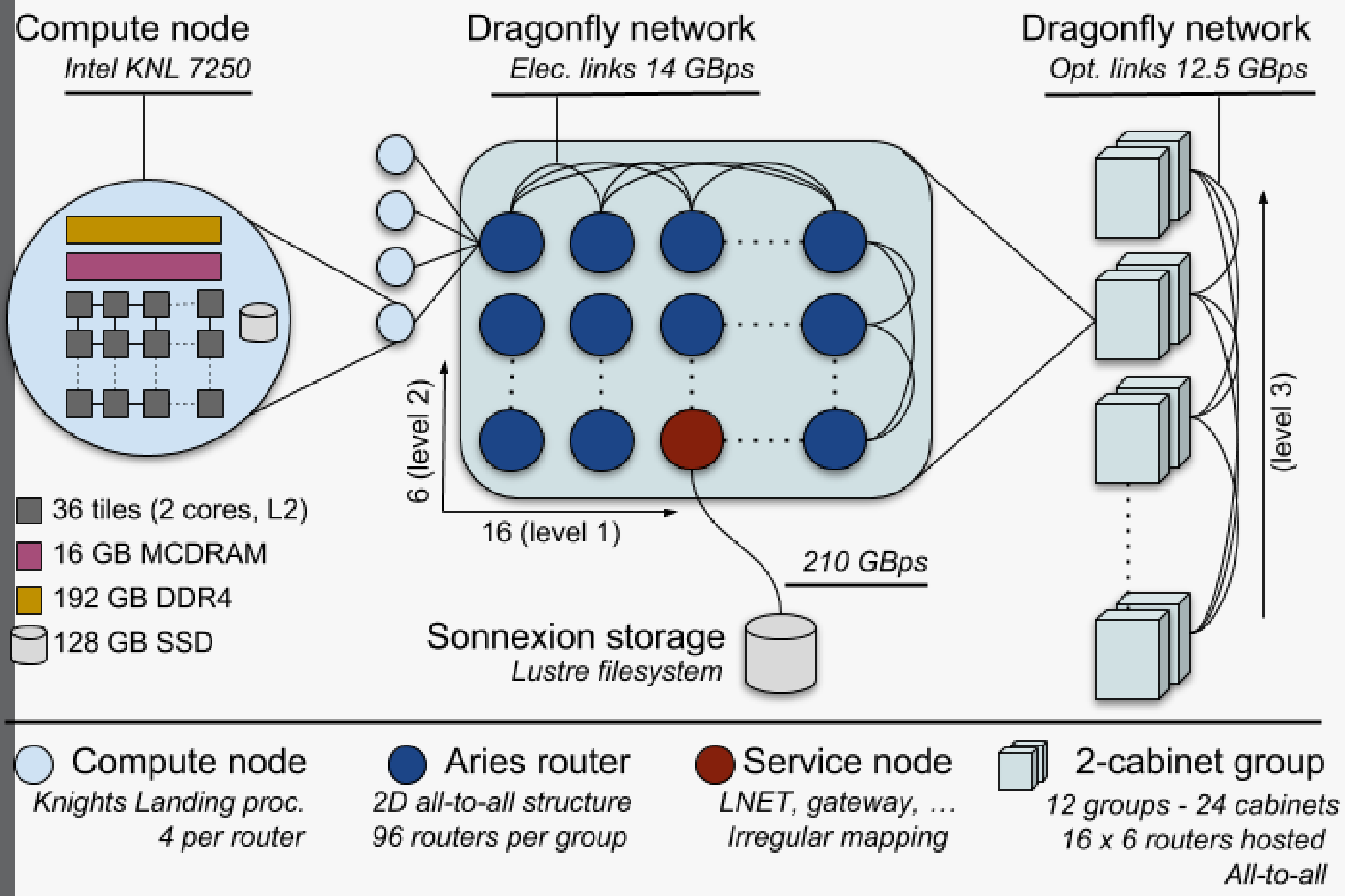
- Theta Lustre Overview
- Performance Characterizations using Cray MPI-IO within IOR
- HDF5 ECP Work - Custom Collective IO VFD
- Operations Metrics

Theta Overview

Argonne Leadership Computing Facility

2004	Blue Gene/L at LLNL: 90-600 TF system #1 on Top 500 for 3.5 years
2005	Argonne accepts 1 rack (1024 nodes) of Blue Gene/L (5.6 TF)
2006	Argonne Leadership Computing Facility (ALCF) created
2008	ALCF accepts 40 racks (160k cores) of Blue Gene/P (557 TF)
2009	ALCF approved for 10 petaflop system to be delivered in 2012
2012	48 racks of Mira Blue Gene/Q (10 PF) in production at ALCF
2014	Development partnership for Theta and Aurora begins
2016	ALCF accepts Theta (10 PF) Cray XC40 with Xeon Phi (KNL)
2021	Aurora (>1 EF) will be delivered

Theta System Overview



Architecture: Cray XC40
Processor: 1.3 GHz Intel Xeon Phi 7230 SKU
Cores/node: 64
Racks: 24
Nodes: 4,392
Memory/node: 192 GB DDR4 SDRAM
High bandwidth memory/node: 16 GB MCDRAM
SSD/node: 128 GB
Aries interconnect with Dragonfly configuration
Total cores: 281,088
Total MCDRAM: 70 TB
Total DDR4: 843 TB
Total SSD: 562 TB
10 PB Lustre file system
Peak performance of 11.69 petaflops

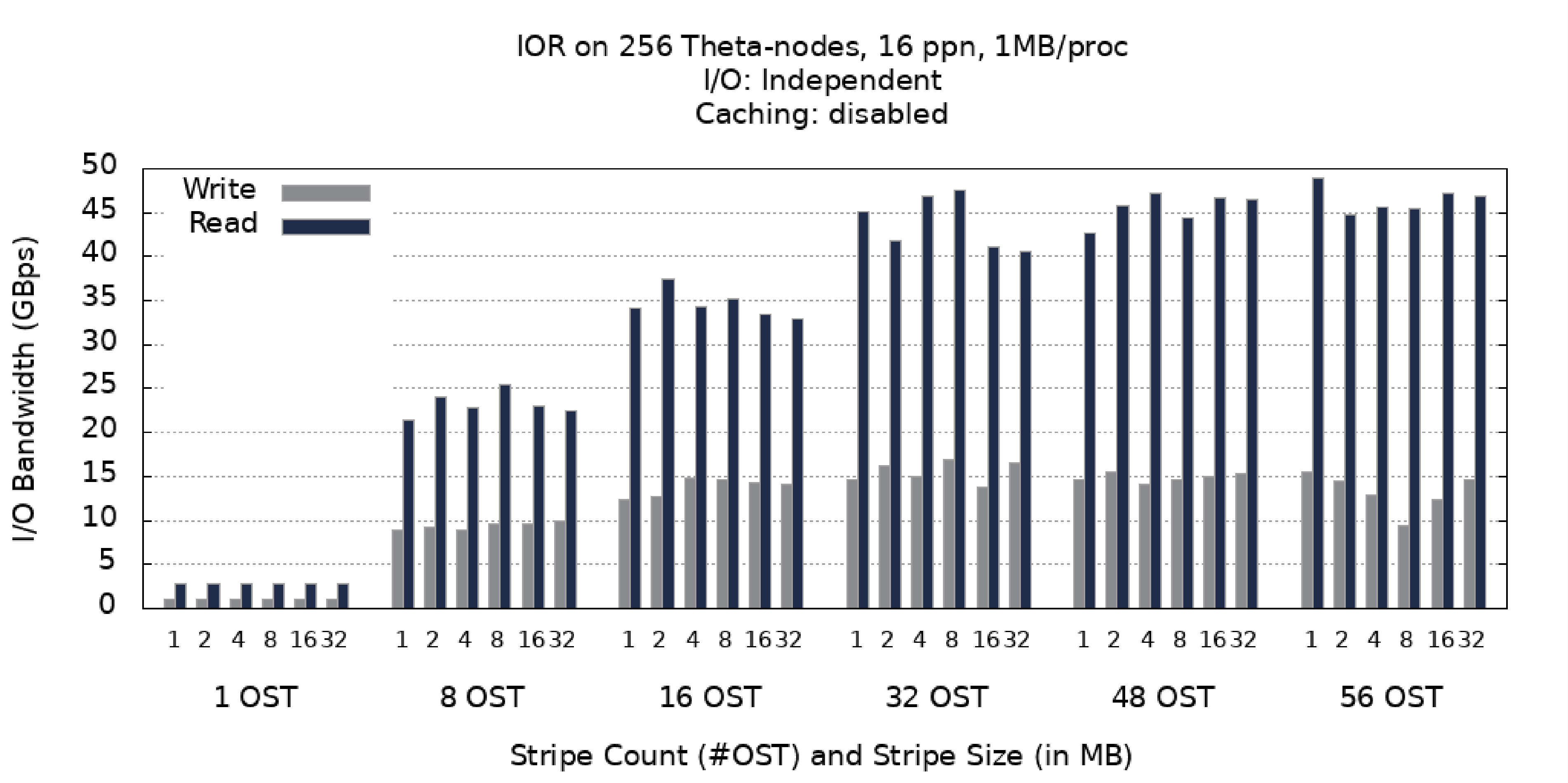
LUSTRE Specifications on Theta

- lfs 2.7.2.26
- Sonexion Storage
  - 4 cabinets
  - 10 PB usable RAID storage
  - Total Lustre Performance Write BW 172 GB/s Read BW 240 GB/s
    - 56 OSS (1 OST per OSS)
      - Peak Performance of 1 OST is 6 GB/s
    - Lustre client cache effects only for much higher BW
      - OSS cache disabled by Sonexion - Cray has seen issues with RAID array bitmap being pushed out of memory due to OSS cache consuming memory on the OSS nodes

Performance Characterizations using MPI-IO within IOR

- Lustre as a component of MPI-IO performance
  - Collective vs Independent, cache effects, shared files vs fpp
- HPC-IOR version
  - Enhanced for MPIIO –e fsync support (MPI_File_sync)
  - https://xgitlab.cels.anl.gov/ExaHDF5/HPC-IOR
- All results show MAX Bandwidth (best times) for each experiment

Shared File Stripe Size vs Count Affect on Performance (Independent I/O - No Lustre Client Cache Effects)



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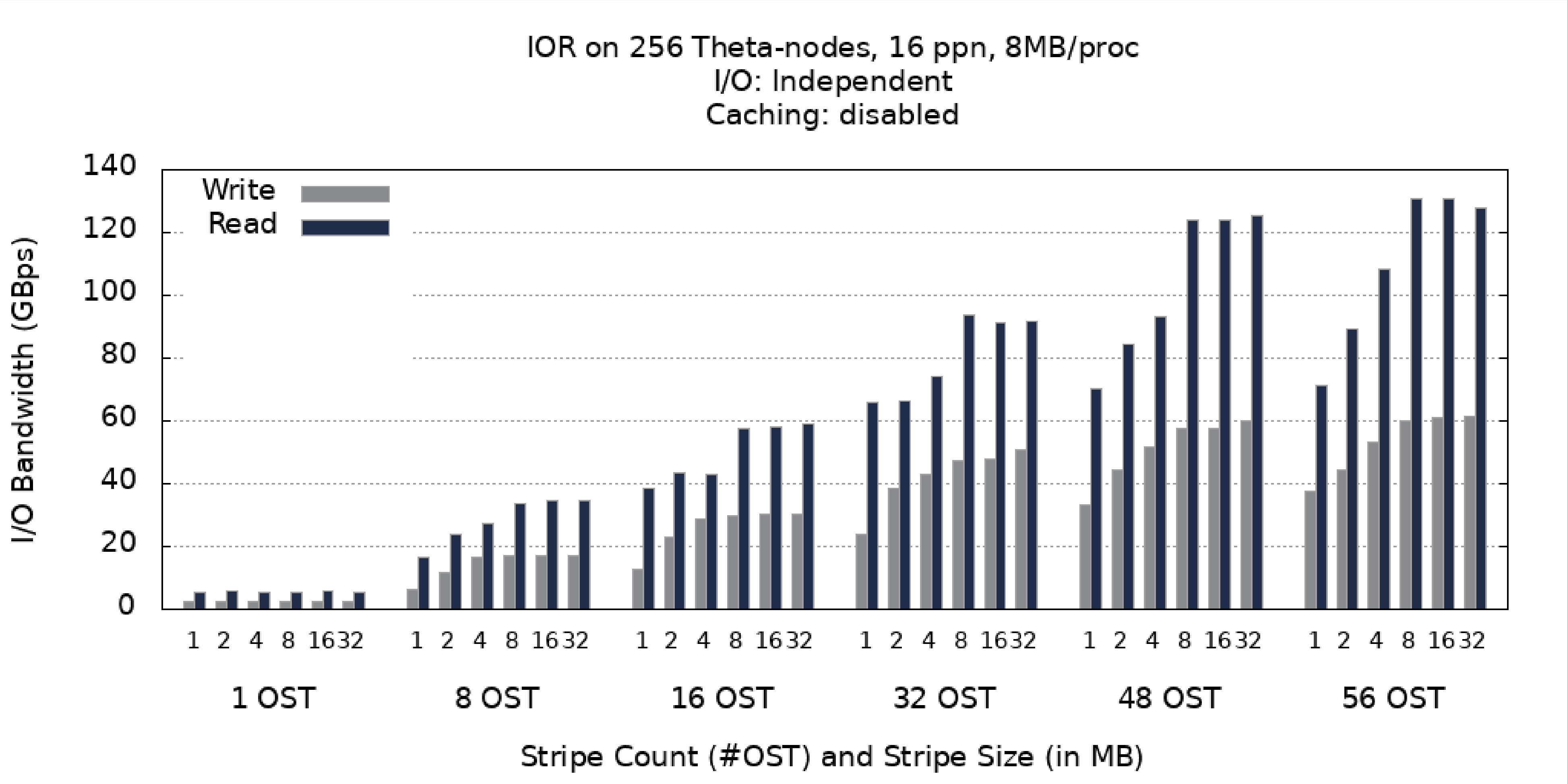
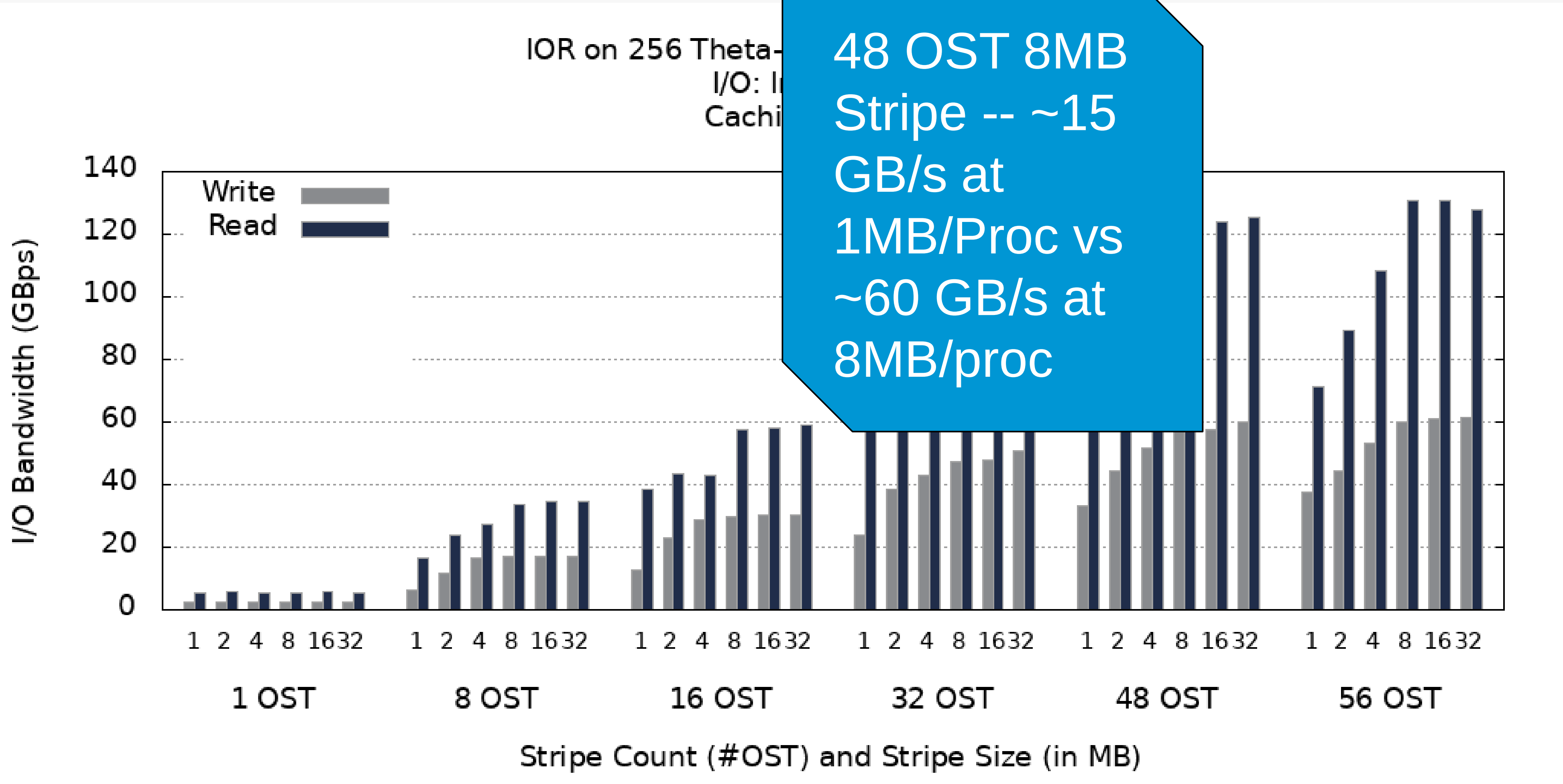
Shared File Stripe Size vs Count Affect on Performance (Independent I/O - No Lustre Client Cache Effects)

8MB/proc

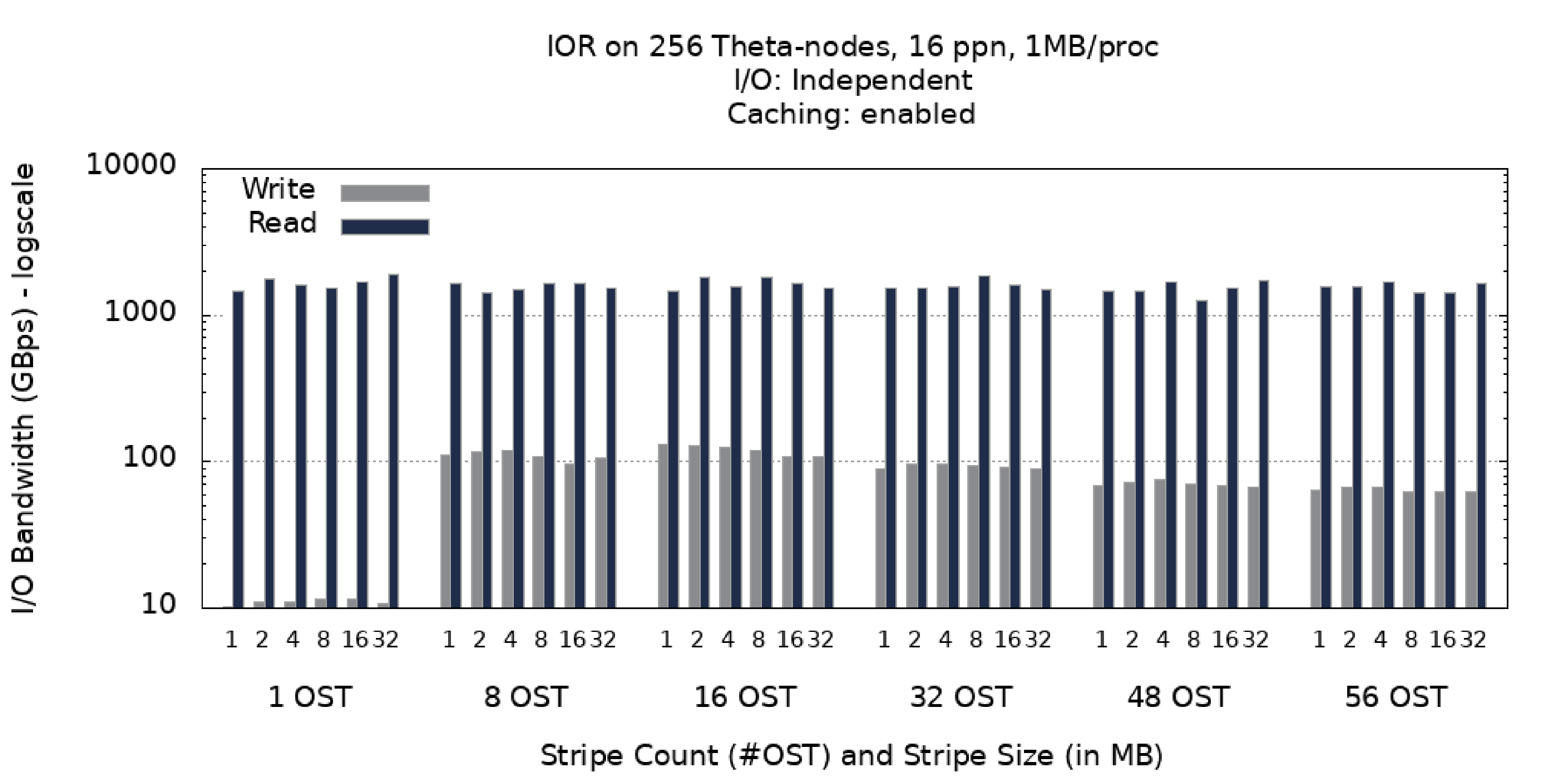


Shared File Stripe Size vs Count Affect on Performance (Independent I/O - No Lustre Client Cache Effects) 8MB/proc



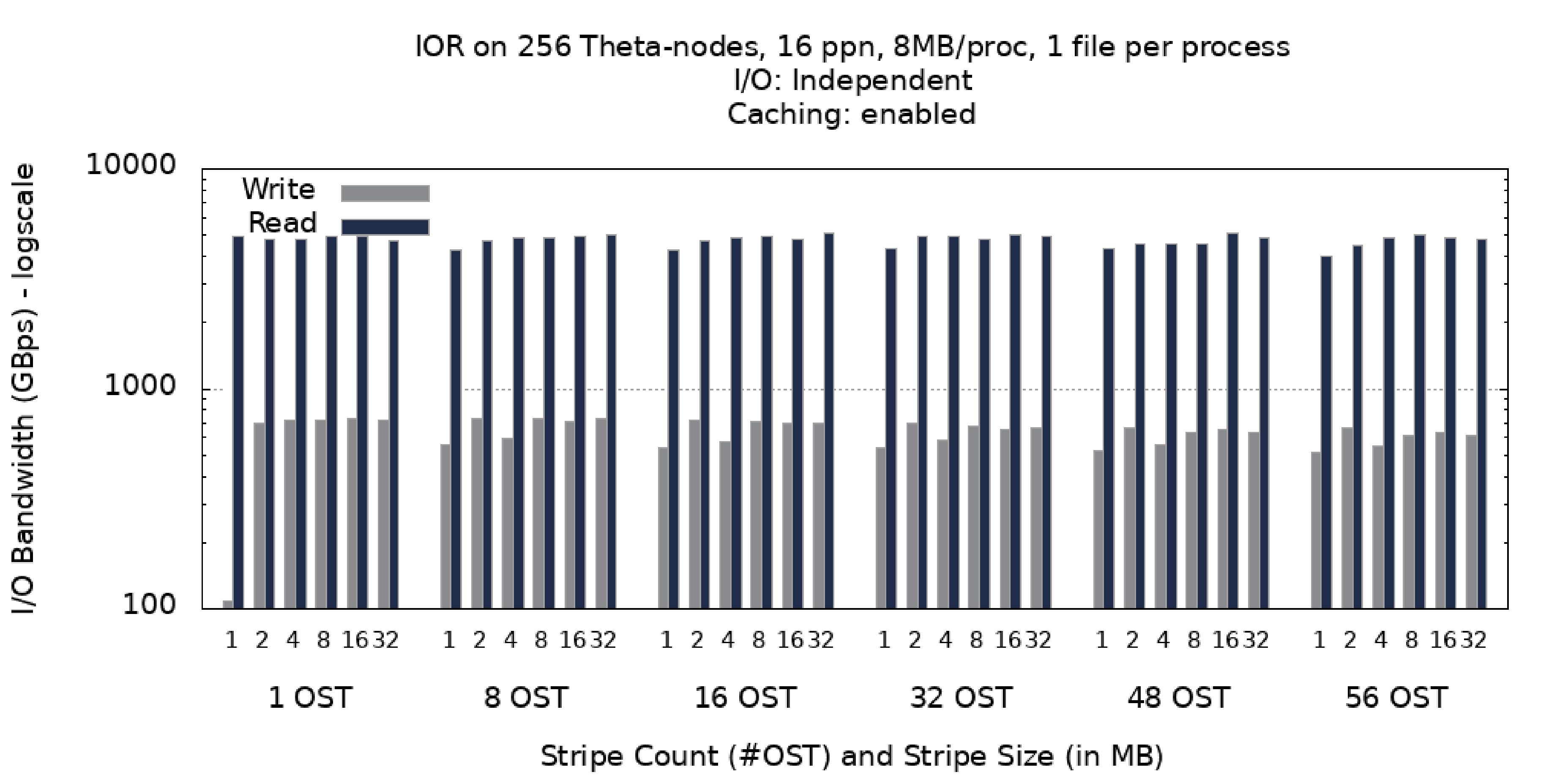
48 OST 8MB Stripe -- ~15 GB/s at 1MB/Proc vs ~60 GB/s at 8MB/proc

Shared File Stripe Size vs Count Affect on Performance (Independent I/O – with Lustre Client Cache Effects)

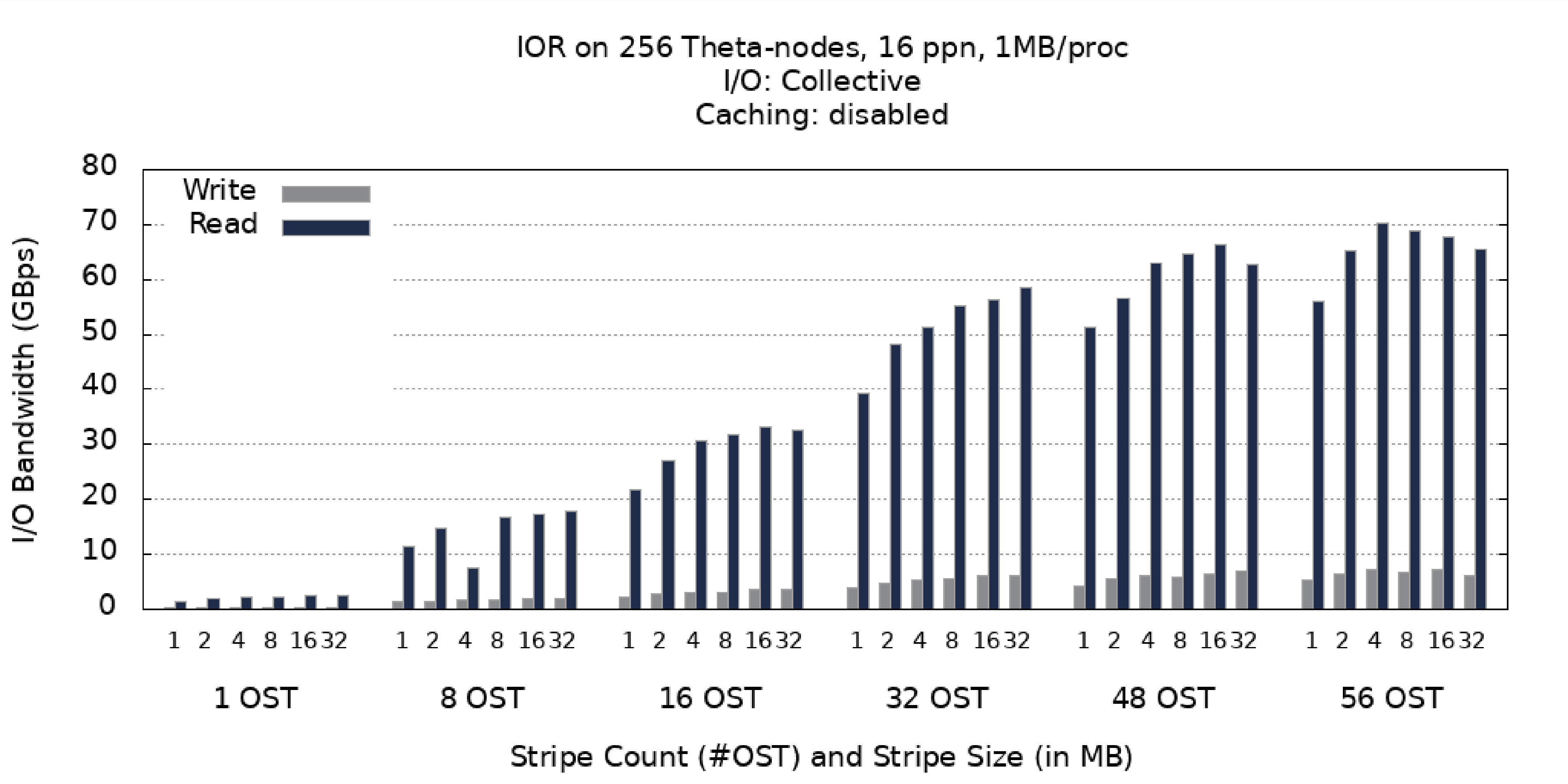


File Per Process - Stripe Size vs Count Affect on Performance (Independent I/O – with Lustre Caching)

8MB/proc



Shared File Stripe Size vs Count Affect on Performance (Collective I/O - No Lustre Client Cache Effects)



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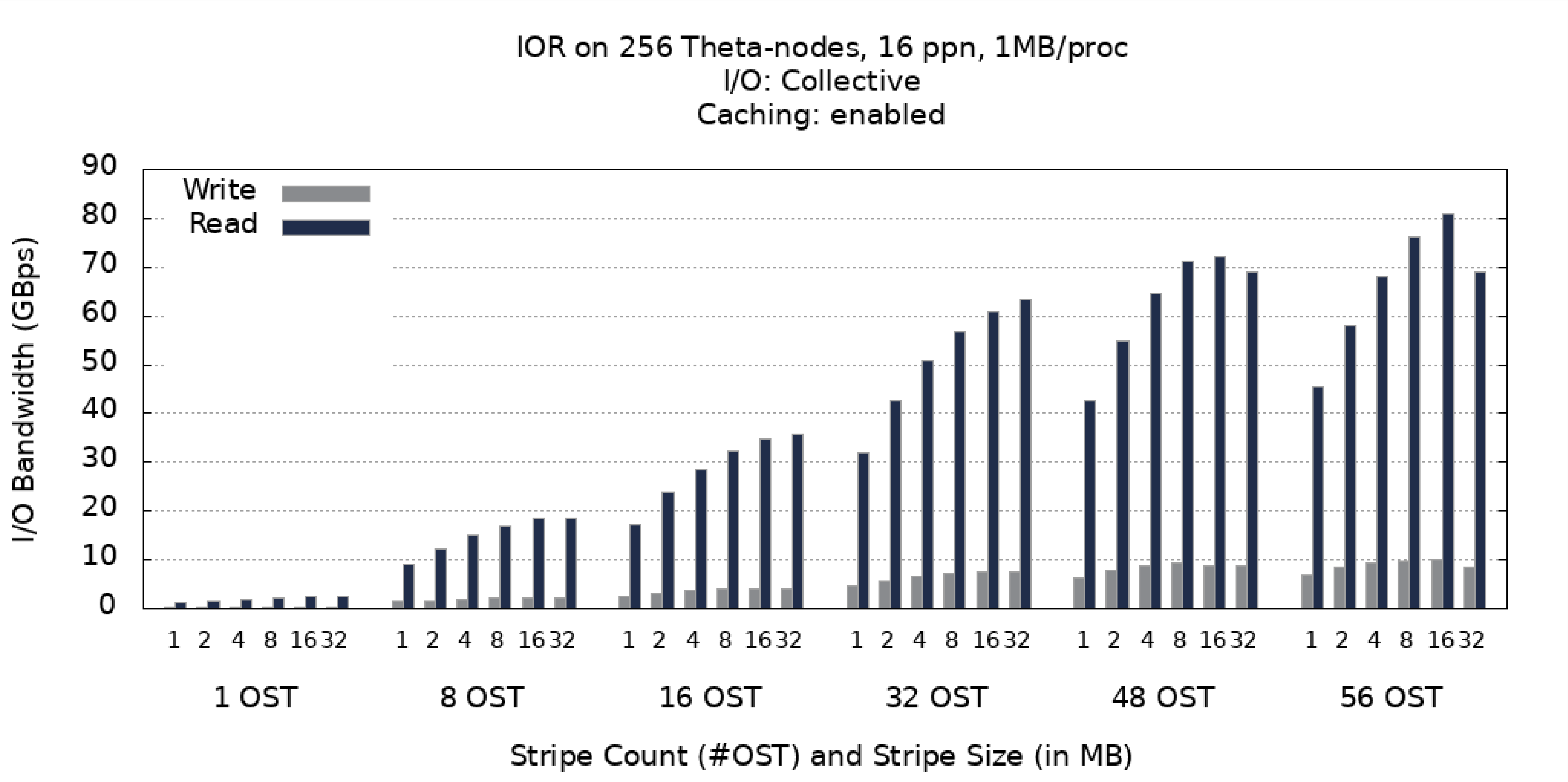
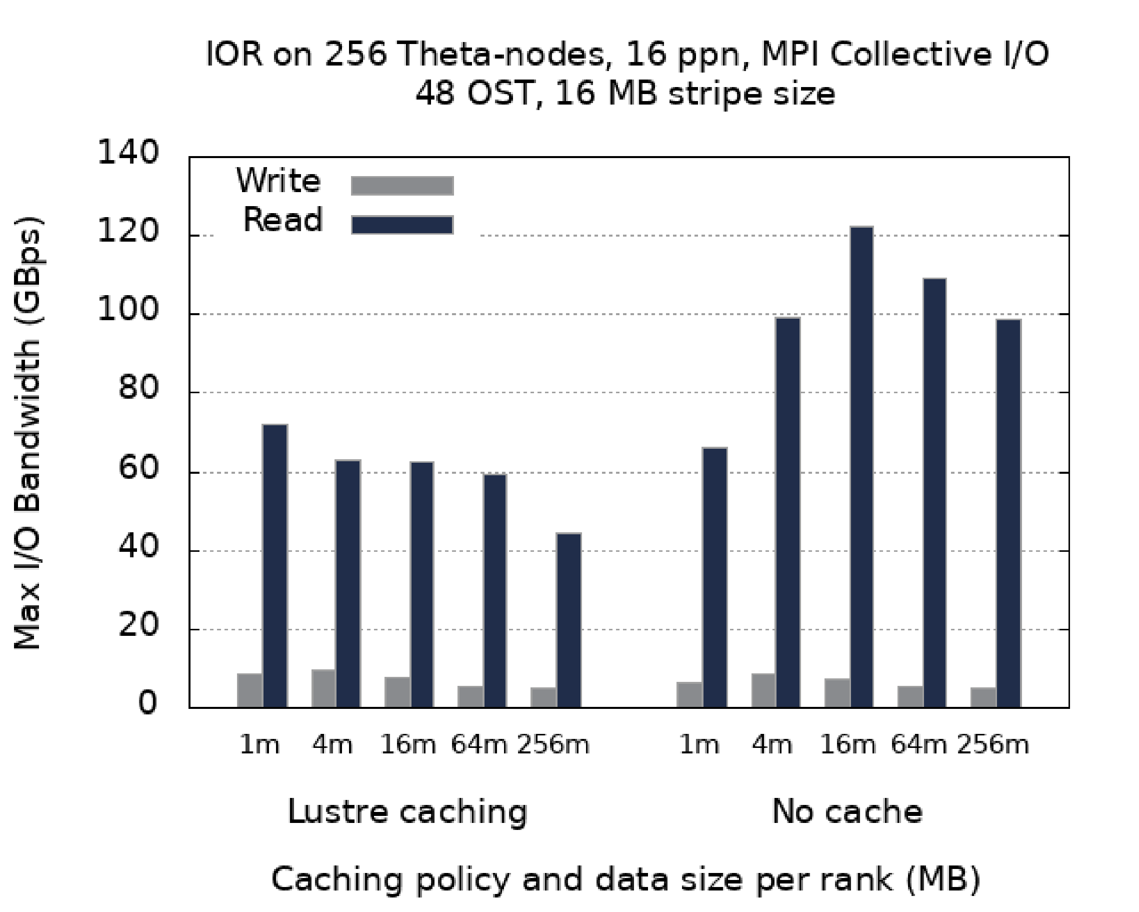
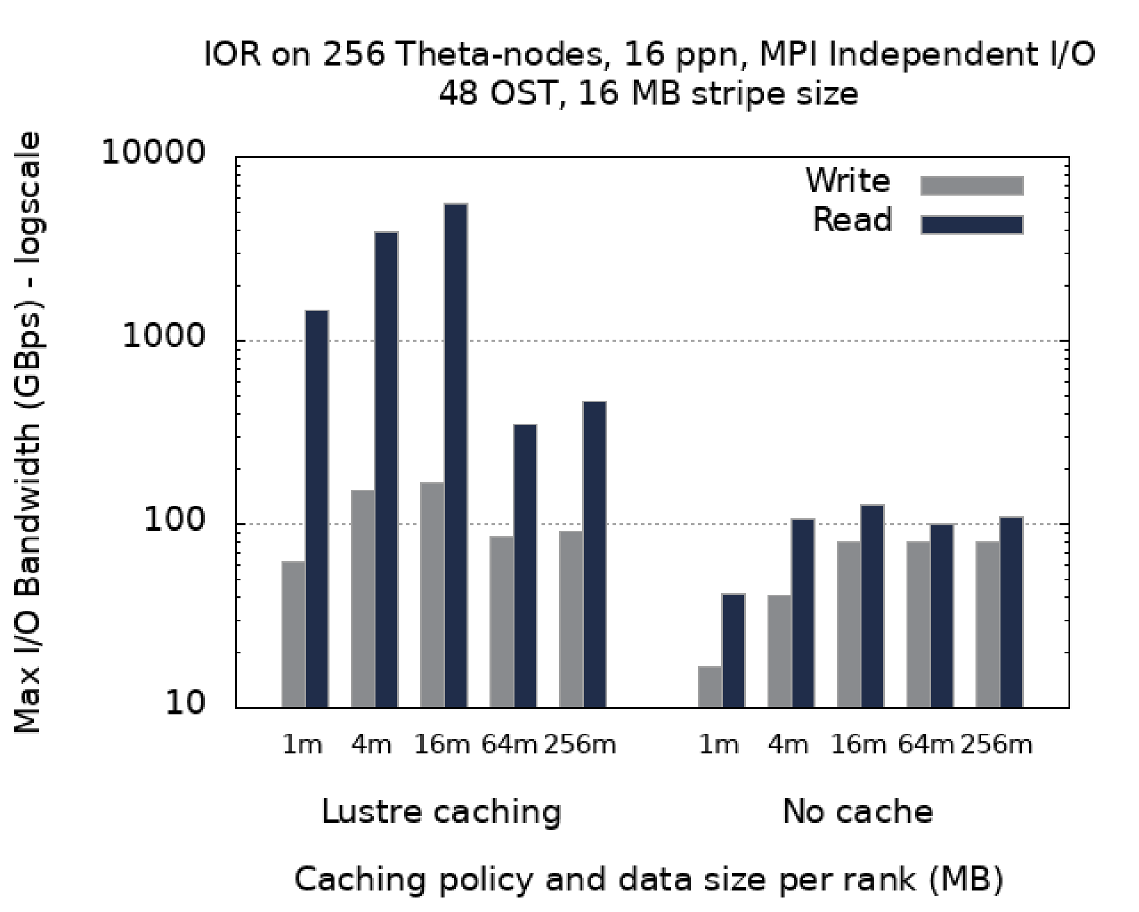
Shared File Stripe Size vs Count Affect on Performance (Collective I/O – with Lustre Client Cache Effects)



Impact of data size on Lustre Cache Performance for 48 OST / 16 MB Stripe – Collective vs Independent IO



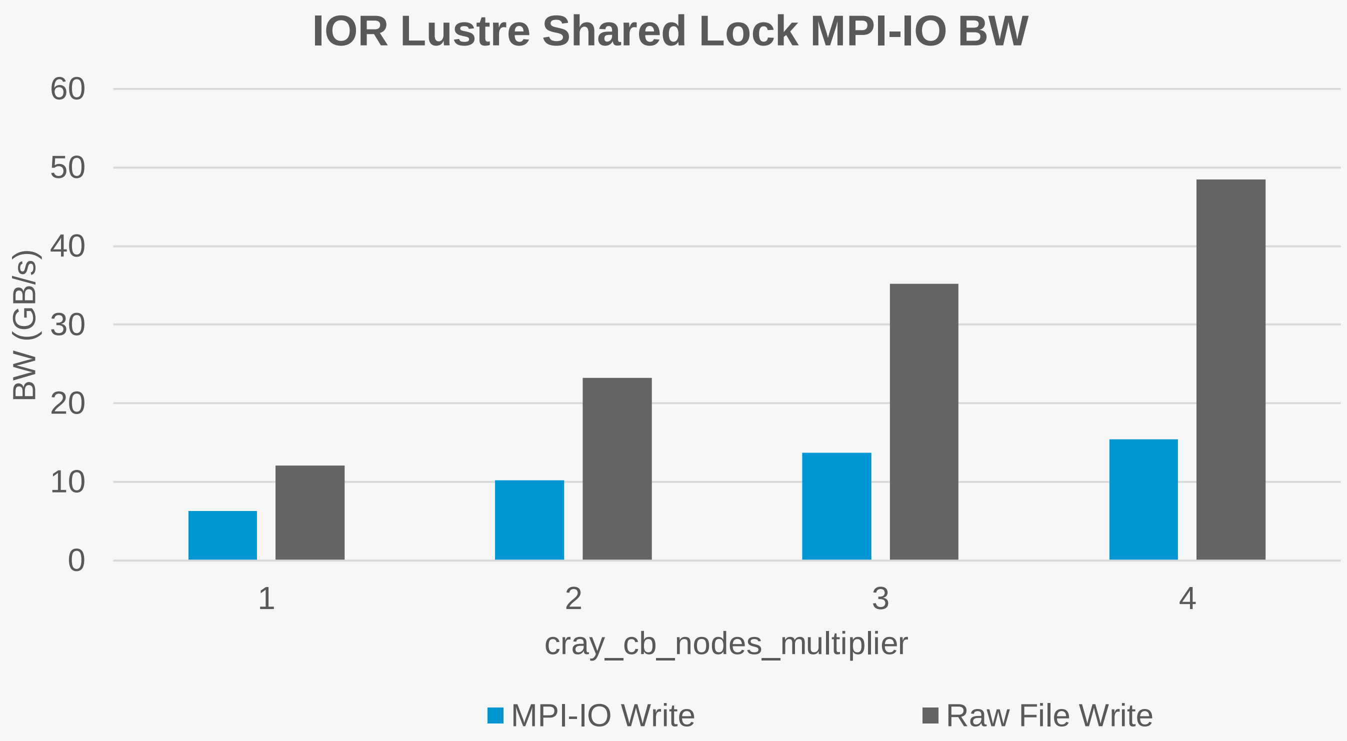


Mitigation of Extent lock contention within Cray MPI-IO

- Each rank (client) needs its own lock when accessing striped data for a given file on an OST
  - If more than one rank concurrently accesses same file on OST, causes extent lock contention, cancels out performance improvement
  - Concurrent access improves storage bandwidth
- Cray MPI-IO has a current limited mitigation for this (cray_cb_write_lock_mode=1 – shared lock locking mode)
  - A single lock is shared by all MPI ranks that are writing the file.
  - Lock ahead locking mode (cray_cb_write_lock_mode=2) not yet supported by Sonexion
  - Following slide run with: MPICH_MPIIO_HINTS=*:cray_cb_write_lock_mode=1:cray_cb_nodes_multiplier=<N>:romio_no_indep_rw=true

IOR MPI-IO Collective Shared Lock Performance Tests

IOR on 256 nodes 16 ppn 48 OSTs 1MB Stripe 1 MB Transfer size



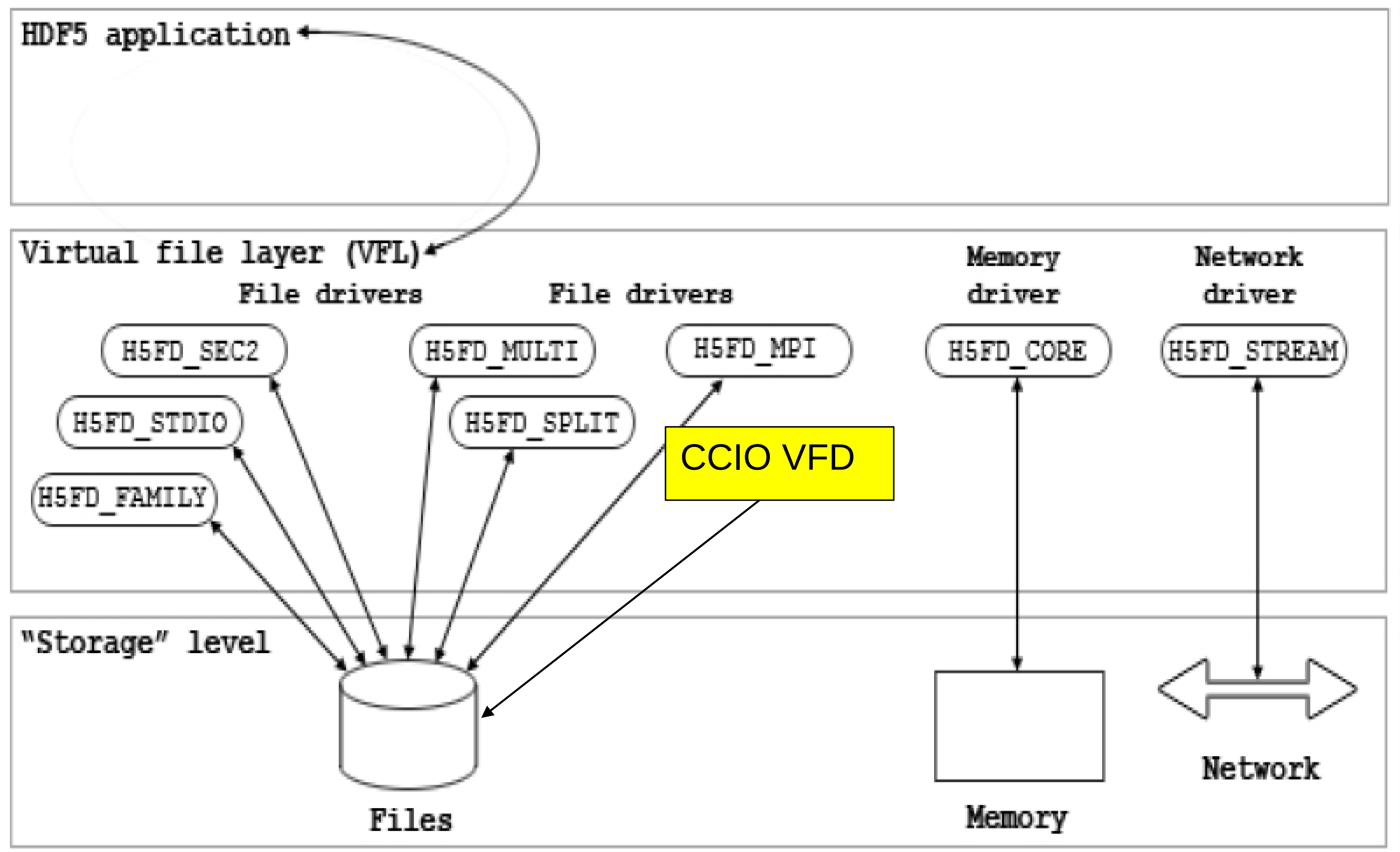
'Raw File Write' times taken from MPICH_MPIIO_TIMERS=1 trace

Raw File write linearly better - MPI-IO 1.5x faster at 4

HDF5 ECP Work – Custom Collective IO Virtual File Driver

- Lustre as a component of HDF5 performance
- CCIO VFD vs MPI VFD

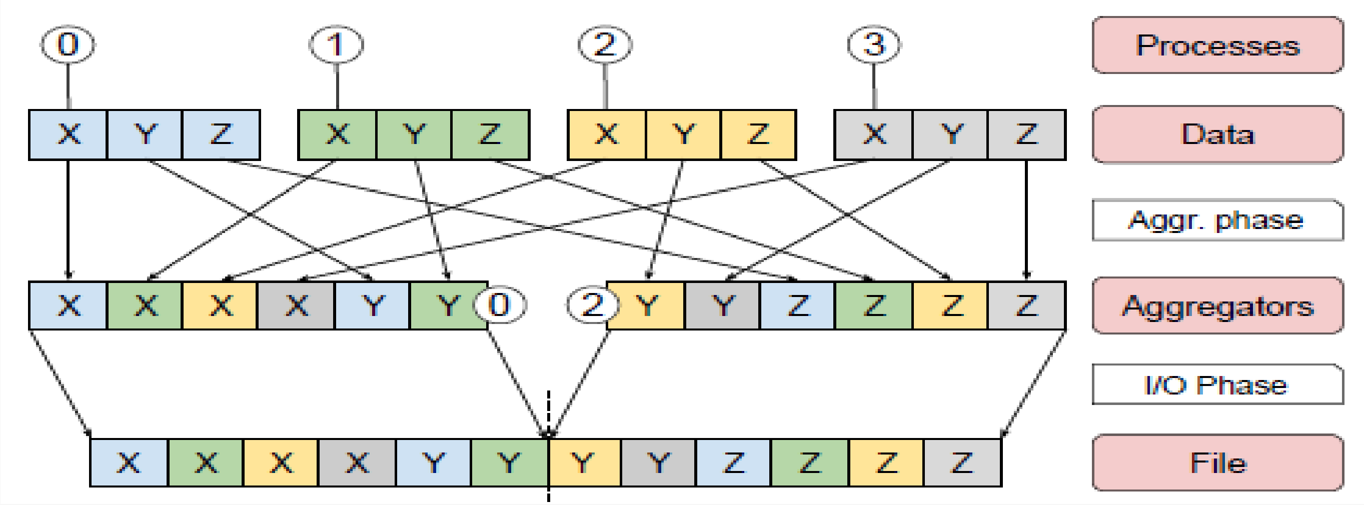
HDF5 Virtual File Layer



Parallel HDF5 CCIO VFD

- Custom Collective IO Virtual File Driver
  - Many HDF5 data access patterns get better performance with collective vs independent (large scale, discontiguous data)
  - Clone of most commonly used H5FD_MPI VFD to support customized collective IO file algorithms outside of MPI
- Highly instrumented for detailed performance profililng
- Current performance enhancements over MPI VFD
  - Avoids performance overhead of construction/deconstruction of MPI_Datatype
    - MPI constructs MPI_Datatype from dataset selection, MPI-IO implementation then needs to deconstruct to get offset/len pairs
    - For highly discontiguous data this can be expensive
  - Implementation of one-sided collective aggregation algorithm – detailed in following slides
- Many targets for future optimization

Standard Two-Phase Collective MPI-IO



- Standard two-phase algorithm as exists in MPICH MPI-IO (ROMIO)
  - Actually has a 3rd (0th) initial collective meta-data planning phase where aggregators determine what data goes where and when
    - Involves send/recv and/or collectives (eg MPI_Alltoall)
  - Data movement for aggregation phase done with send-recv or collectives (MPI_Alltoallv)
    - Done in 'rounds' defined by collective buffer size * number of aggregators

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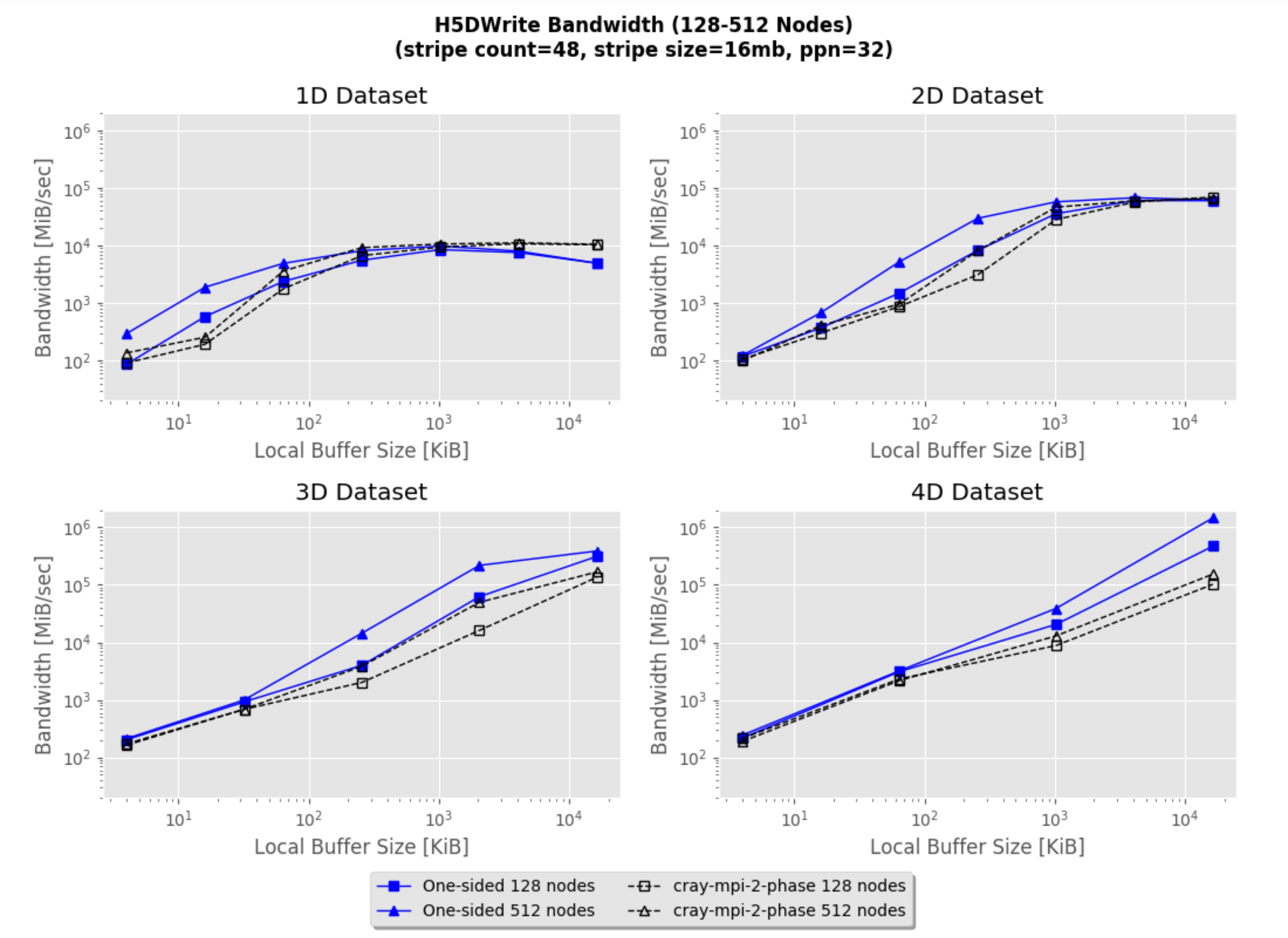
One-Sided Two-Phase Collective MPI-IO

- Currently implemented in MPICH-MPI-IO (ROMIO) with support for lustre (write only)
  - No collective meta-data planning phase
  - Data movement phase does RMA (MPI_Put) from computes into aggregator collective buffers
    - Dependent on architecture RMA implementation for performance
  - Aggregator memory footprint for standard algorithm can be significant at scale
    - Applications can run out of memory
    - Can be detrimental to lustre client cache-effects
  - Various performance improvement - depending on IO pattern and architecture can see 10x speedup or no speedup
  - Vendors evaluating it

Parallel HDF5 Exerciser

- Performance profiling c code exercising most intensive HDF5 functions in common user scenarios for both meta-data and raw data
- Created by ExaHDF5 ECP team
- Includes concepts from other HDF5 Performance benchmarks (IOR, VPIC-IO, FLASH-IO) and expands on them
- Highly customizable via many run-time options
  - Independent/Colletive IO for raw and meta-data, contiguous/chunked storage, multi-dimensions , discontiguous buffers/strides
  - Can craft many complex data access patterns
  - Can run at small and large scale
- Working on getting various HDF5 data access patterns from applications into the HDF5 Exerciser to reproduce and solve performance issues

HDF5 Exerciser One-Sided CCIO VFD vs Cray MPI-IO VFD



EXASCALE COMPUTING PROJECT

ExaHDF5

At 1-d smaller messages benefit because of relative increase in overhead for the collective meta-data planning phase, for larger message sizes degradation from 4mb to 16mb may be some sort of synchronization issue – each agg does 86 rounds of 16mb writes, syncing (MPI_Barrier) with each round

3+ dimensional datasets benefit the most from one-sided aggregation

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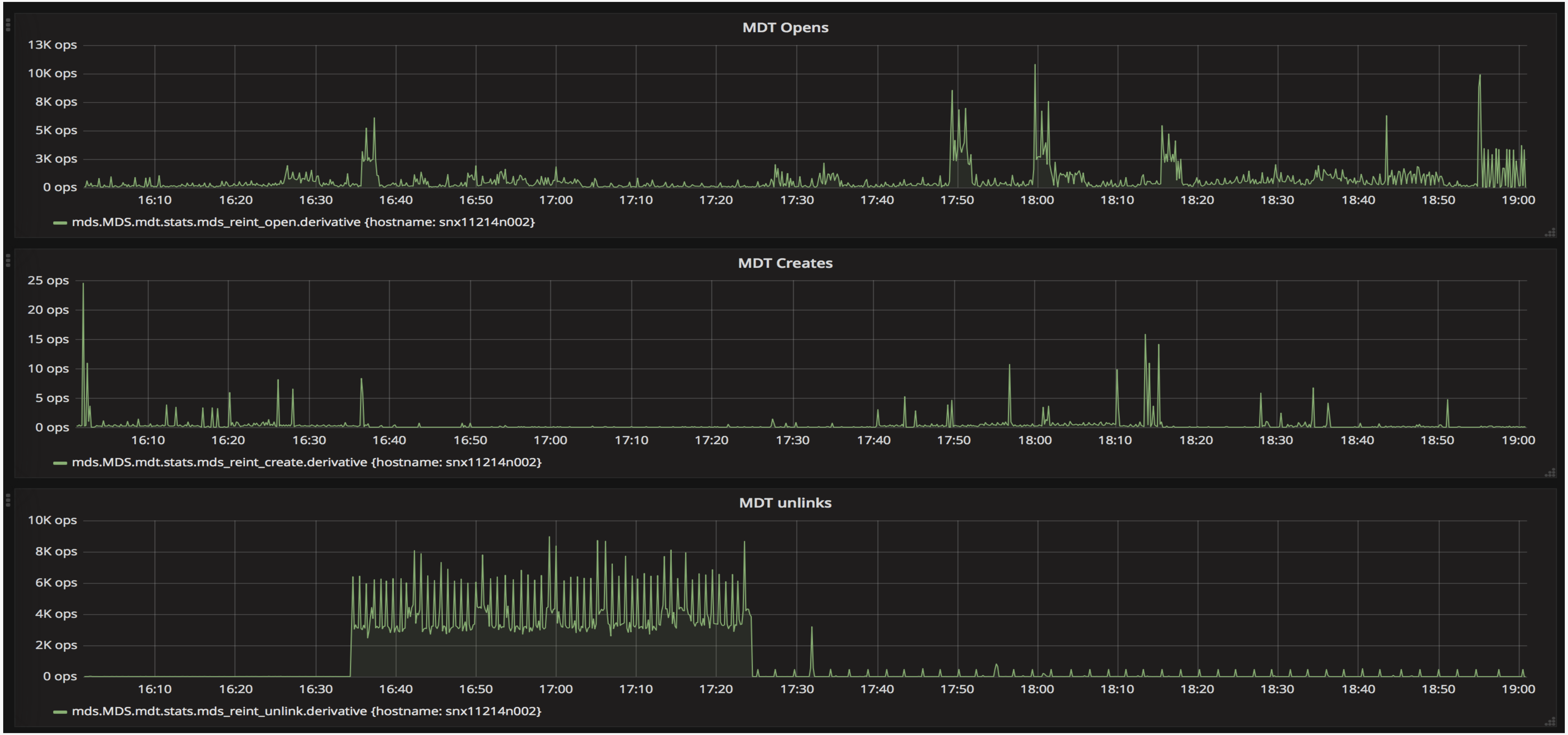
Operations Metrics

- A few examples of the types of Lustre metrics being collected on Theta
- Working on direct correlation to IO performance on job basis
  - Currently indirect correlation we will show in later slides

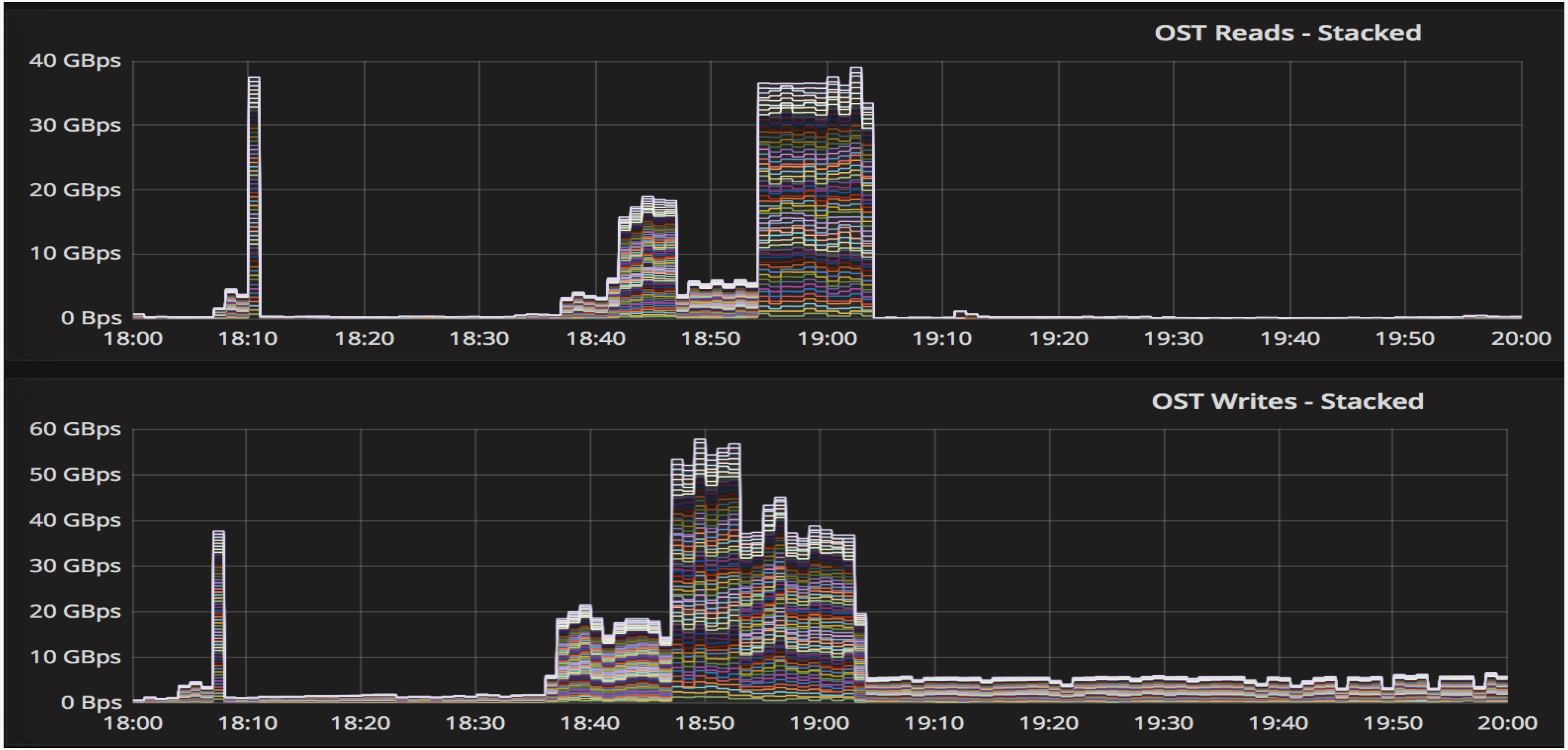
Lustre Metrics

- Operations team records the majority of Lustre stats but focus on monitoring a subset of them
- MDS
  - Monitor all typical metadata operations, e.g. opens, creates, unlinks, renames, (get|set)(x)attr
- OSS
  - Monitor reads/writes grouped by OST and OSS
  - Monitor number of files and space
- Eventually be able to directly tie back to job id and direct correlation with user achieved performance

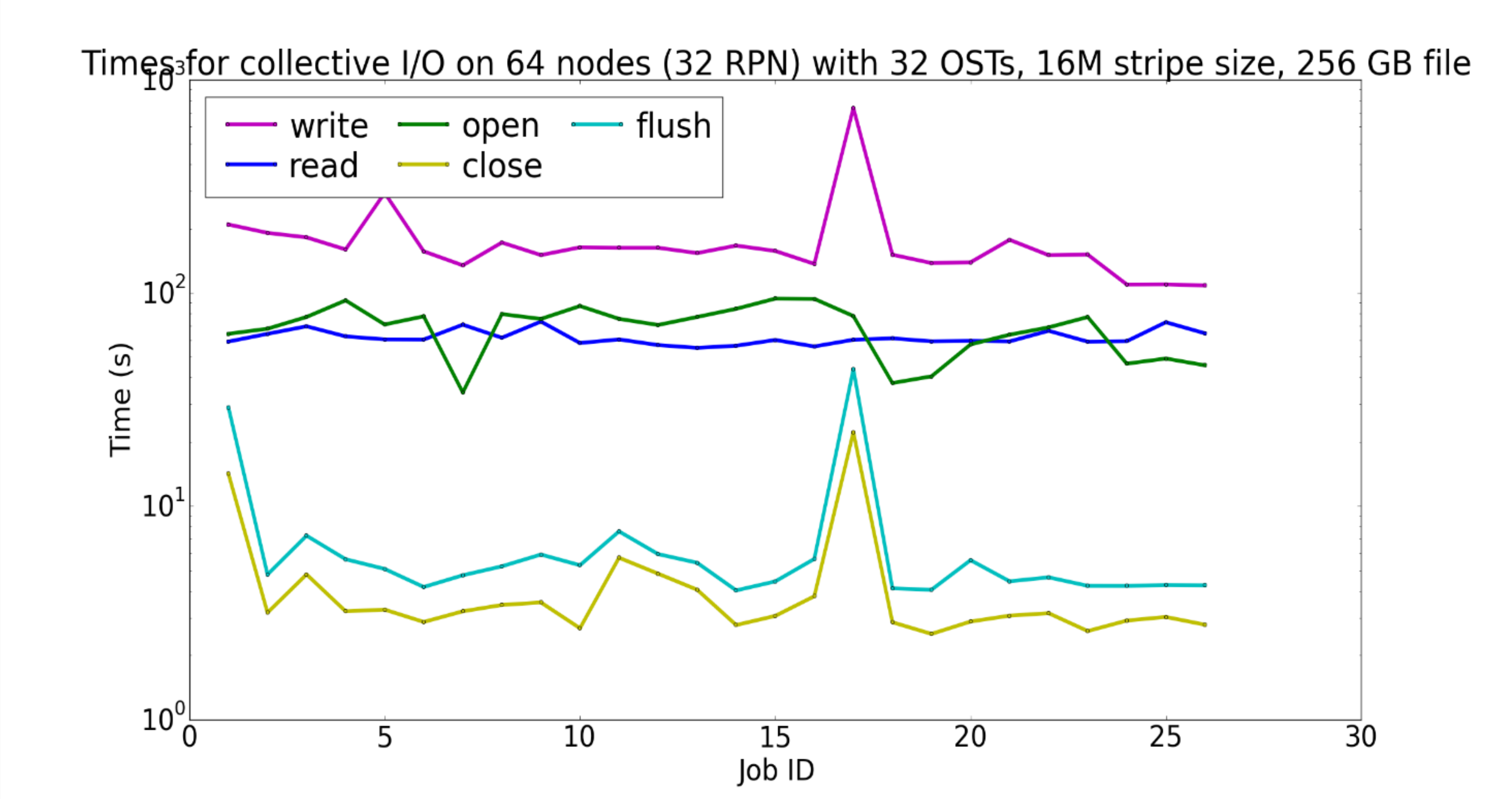
MDT Metrics Dashboard



OST metrics during IOR large data test 18:36 to 19:05



HDF5 Exerciser metrics for 26 jobs on Cori KNL



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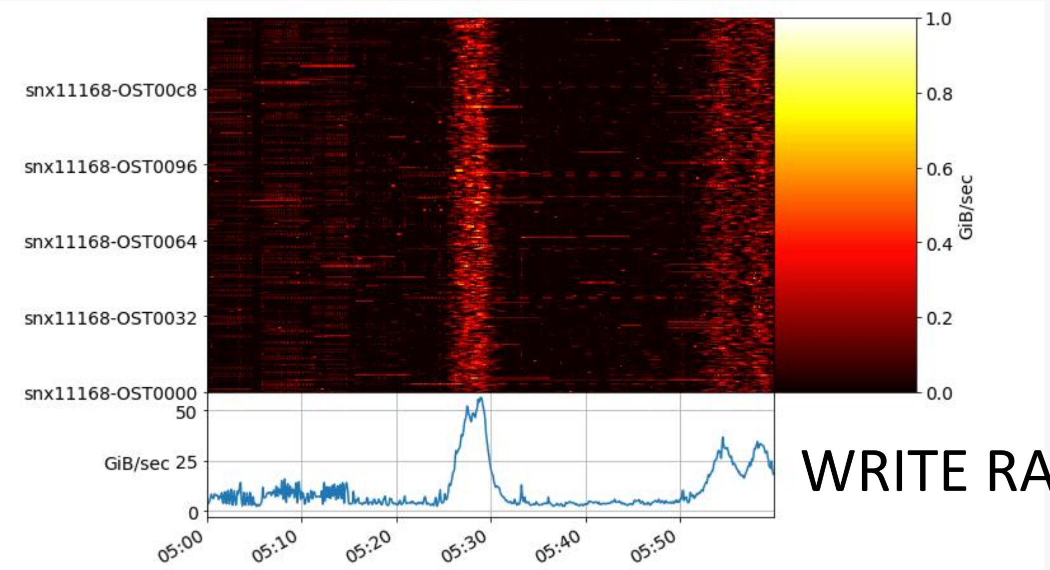
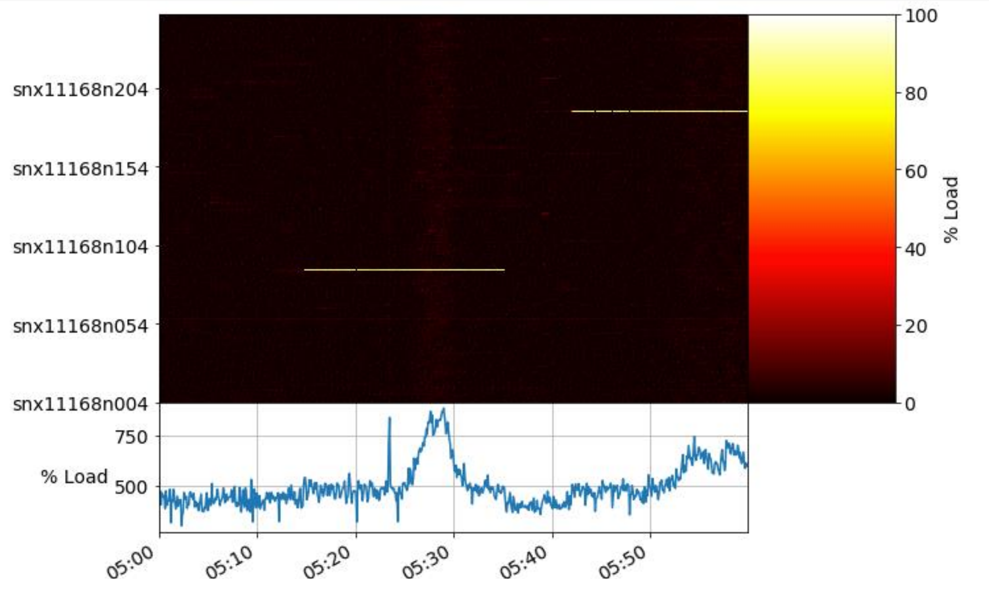
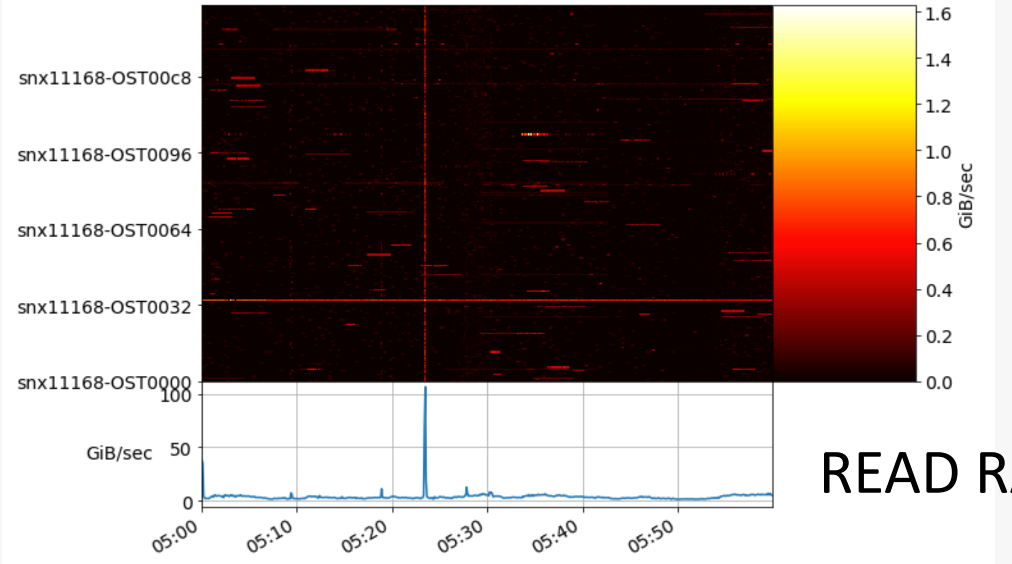
OST, OSS, MDS Statistics via NERSC pytokio API



WRITE RATE

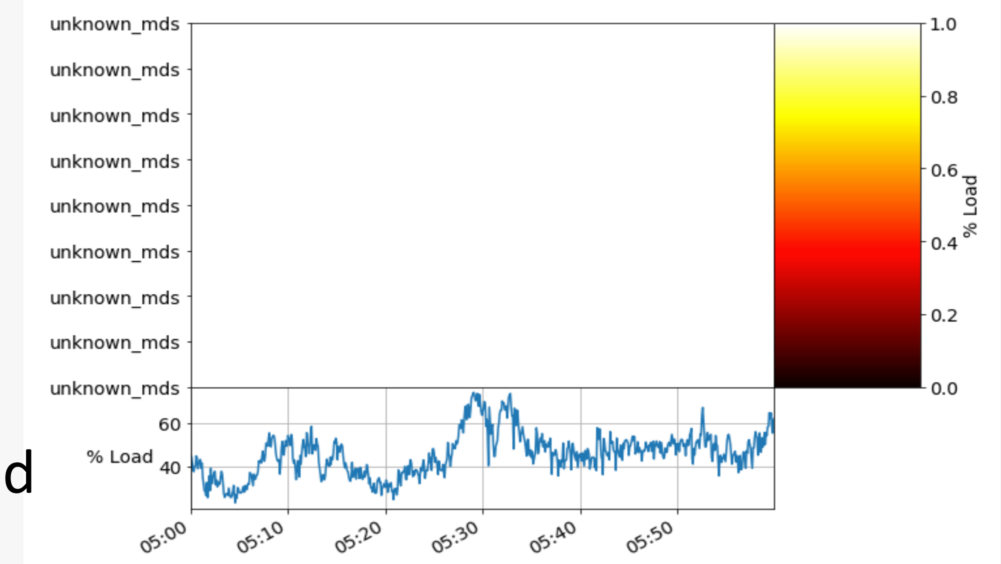
OSS Load





READ RATE

MDS Load



Acknowledgements

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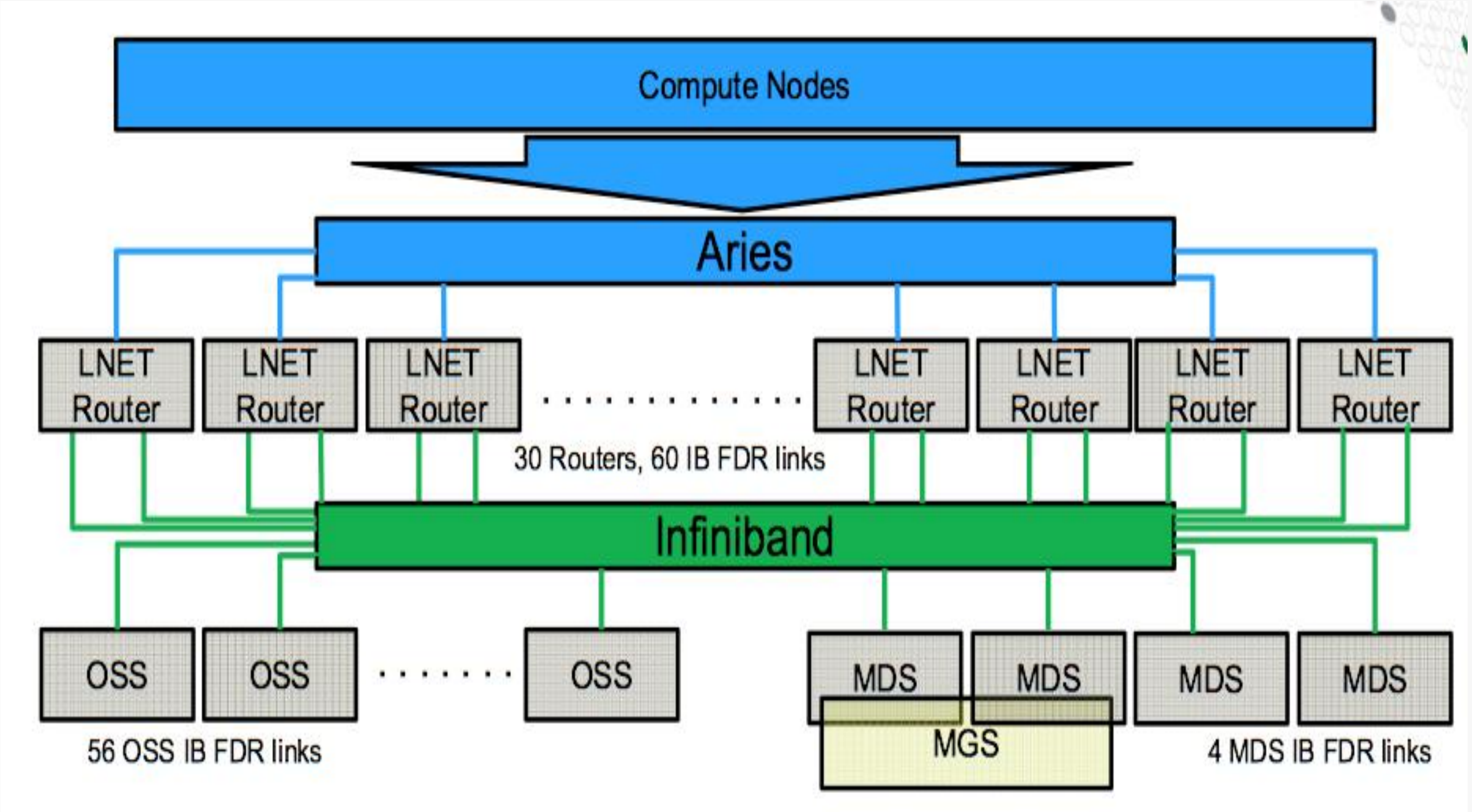
Questions?

Appendix

Lustre Architecture On Theta



- **IO Forwarding from compute node to LNET Service Node / Router**
  - LNet Aries NIC on compute side, 2 IB links on Object Storage Server (OSS) side
  - OSS handles communication from LNet Router to Object Storage Target (OST) which is the physical storage device
  - Although there are 4 MDTs only 1 currently has directories placed on it

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