Understanding and Improving I/O performance and Storage Class Memory on HPC systems

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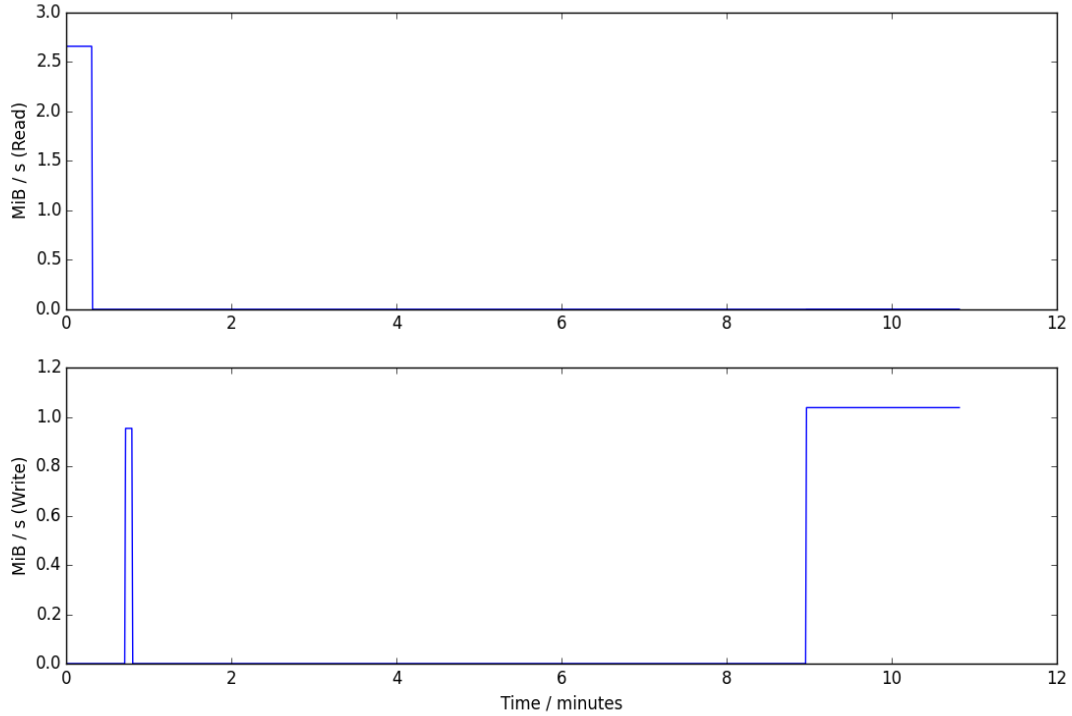
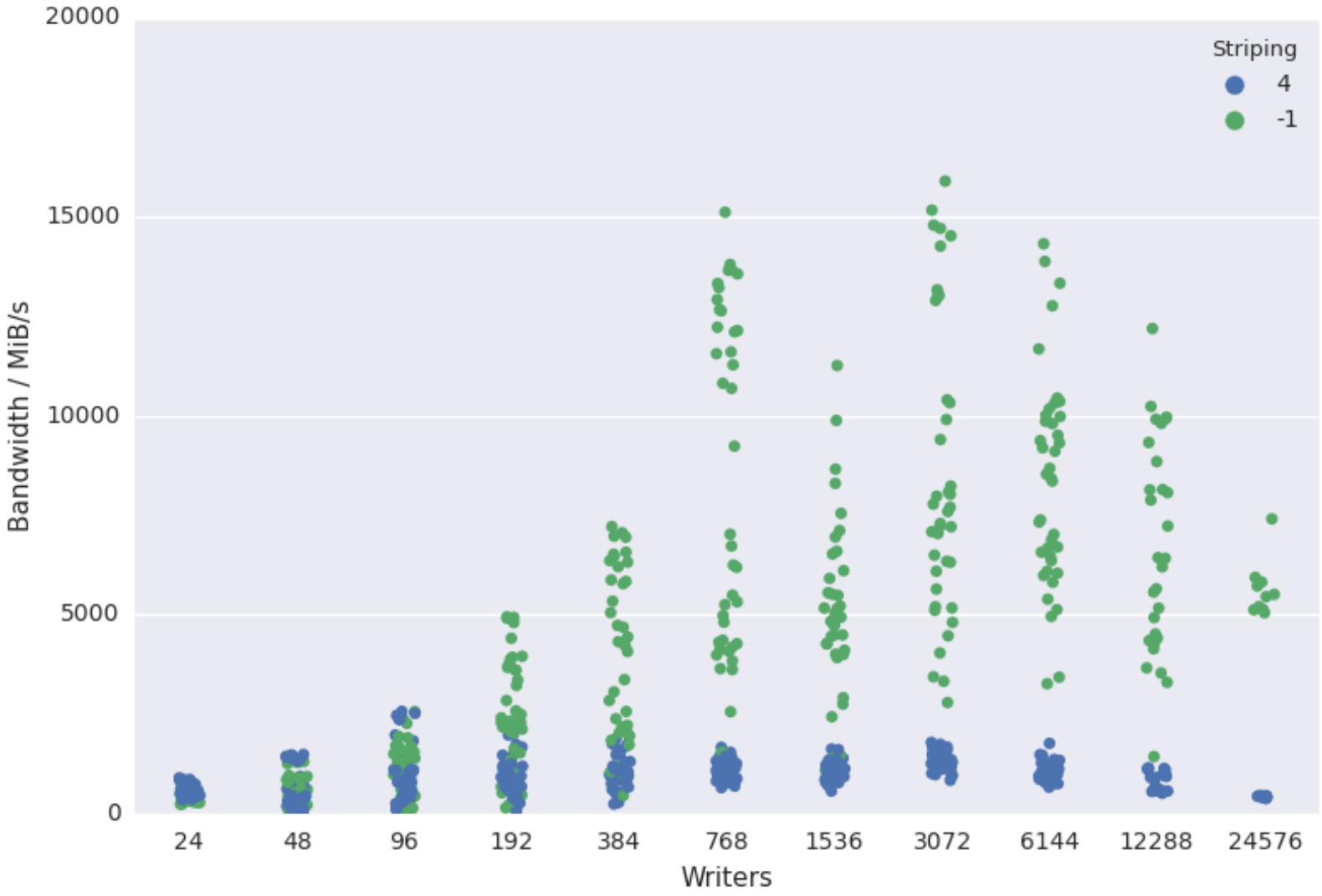
Warning!

- Terminology will be annoying:
  - NVDIMM
  - NVRAM
  - SCM
  - ……
- My fault, but people will argue which is the most appropriate
  - So using them all to annoy as many people as possible ☺

I/O

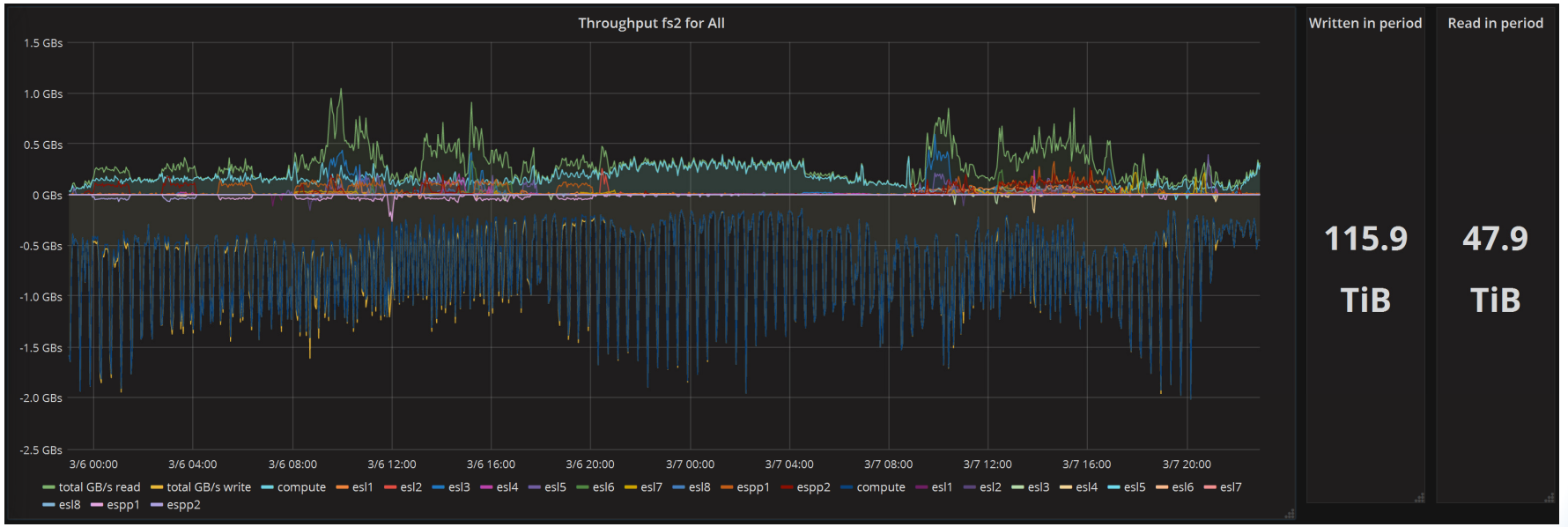

MiB / s (Read)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
MiB / s (Write)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Time / minutes

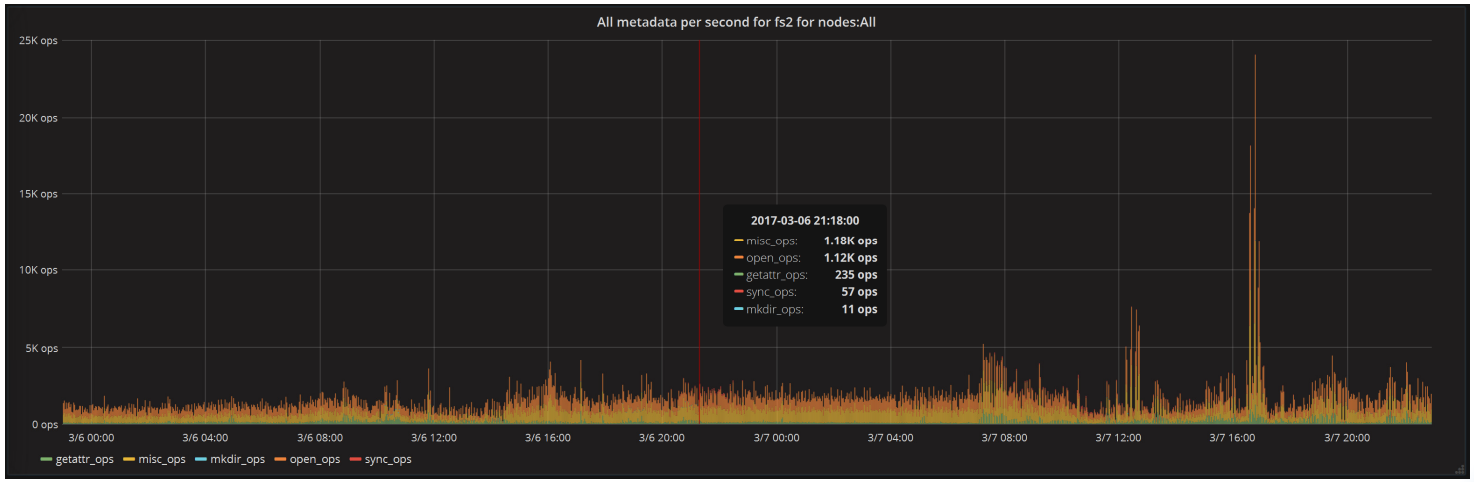
I/O Performance



- https://www.archer.ac.uk/documentation/white-papers/parallelIO-benchmarking/ARCHER-Parallel-IO-1.0.pdf

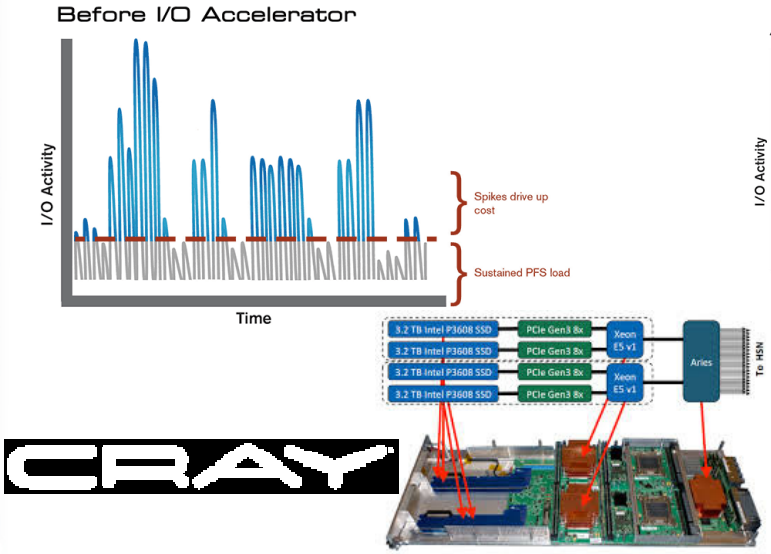
ARCHER workload

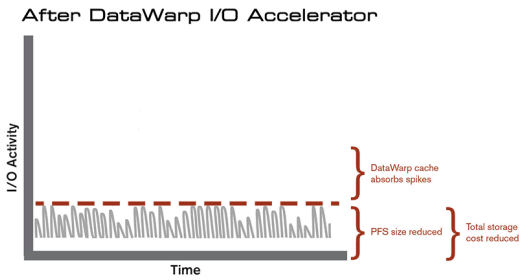


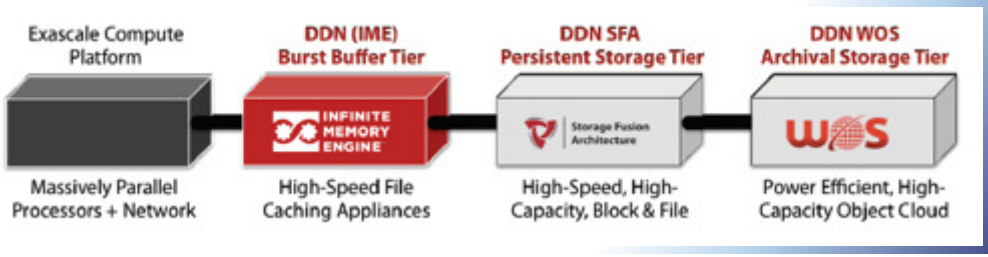


Burst Buffer

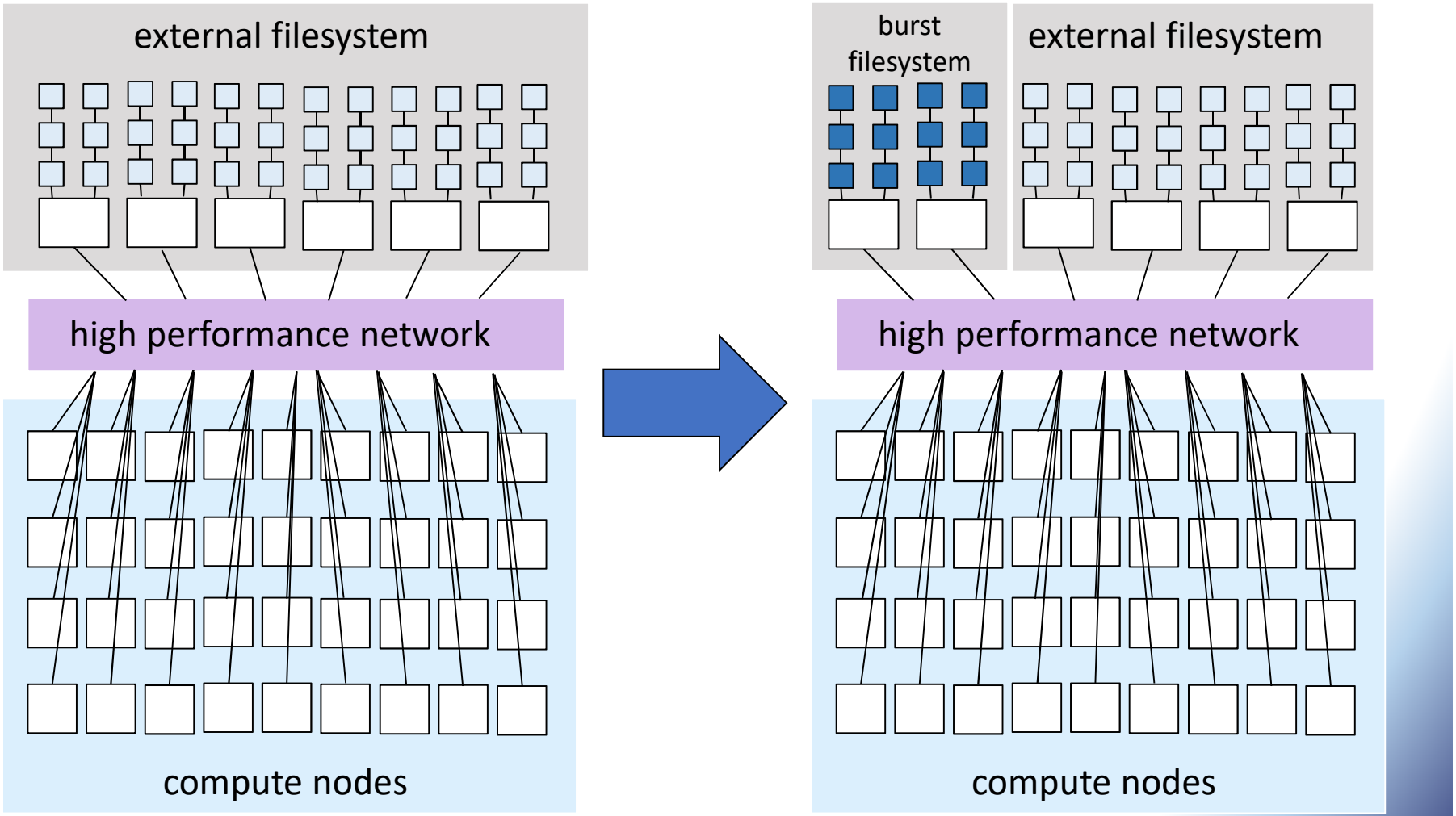
- Non-volatile already becoming part of HPC hardware stack
- SSDs offer high I/O performance but at a cost
  - How to utilise in large scale systems?
- Burst-buffer hardware accelerating parallel filesystem
  - Cray DataWarp
  - DDN IME (Infinite Memory Engine)





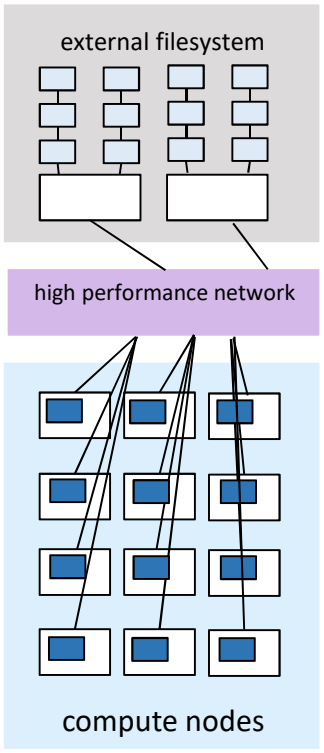


Burst buffer

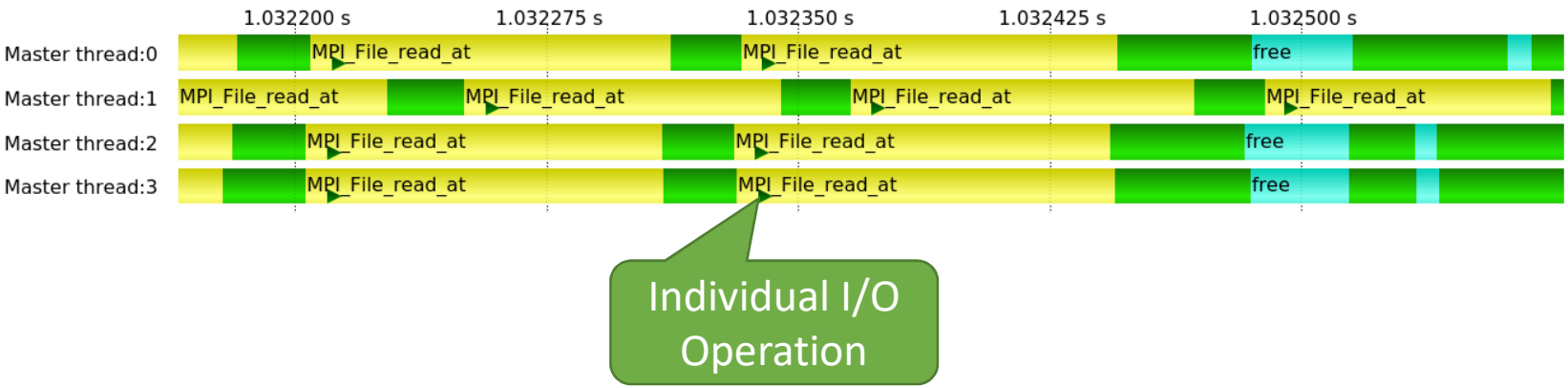


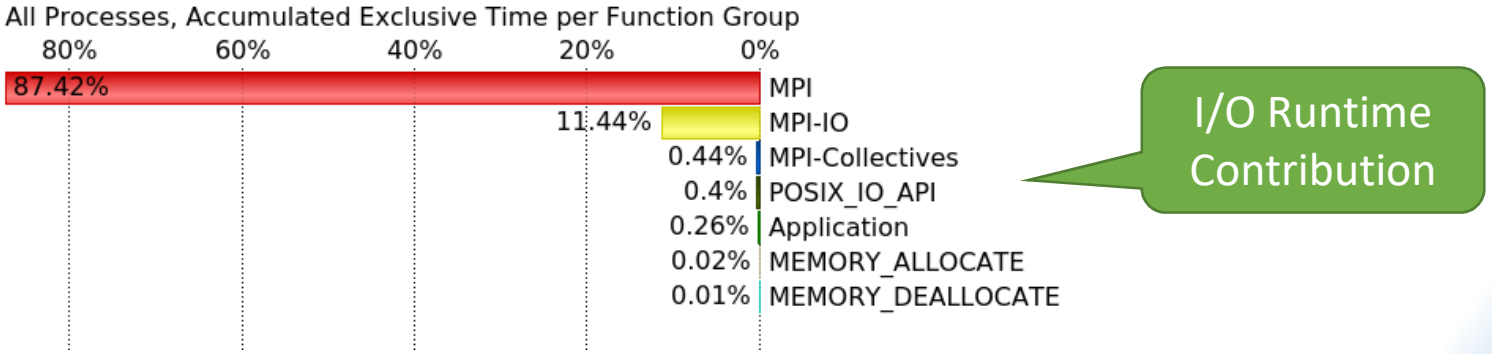
Moving beyond burst buffer

- Non-volatile is coming to the node rather than the filesystem
- Argonne Theta machine has 128GB SSD in each compute node
  - And lustre

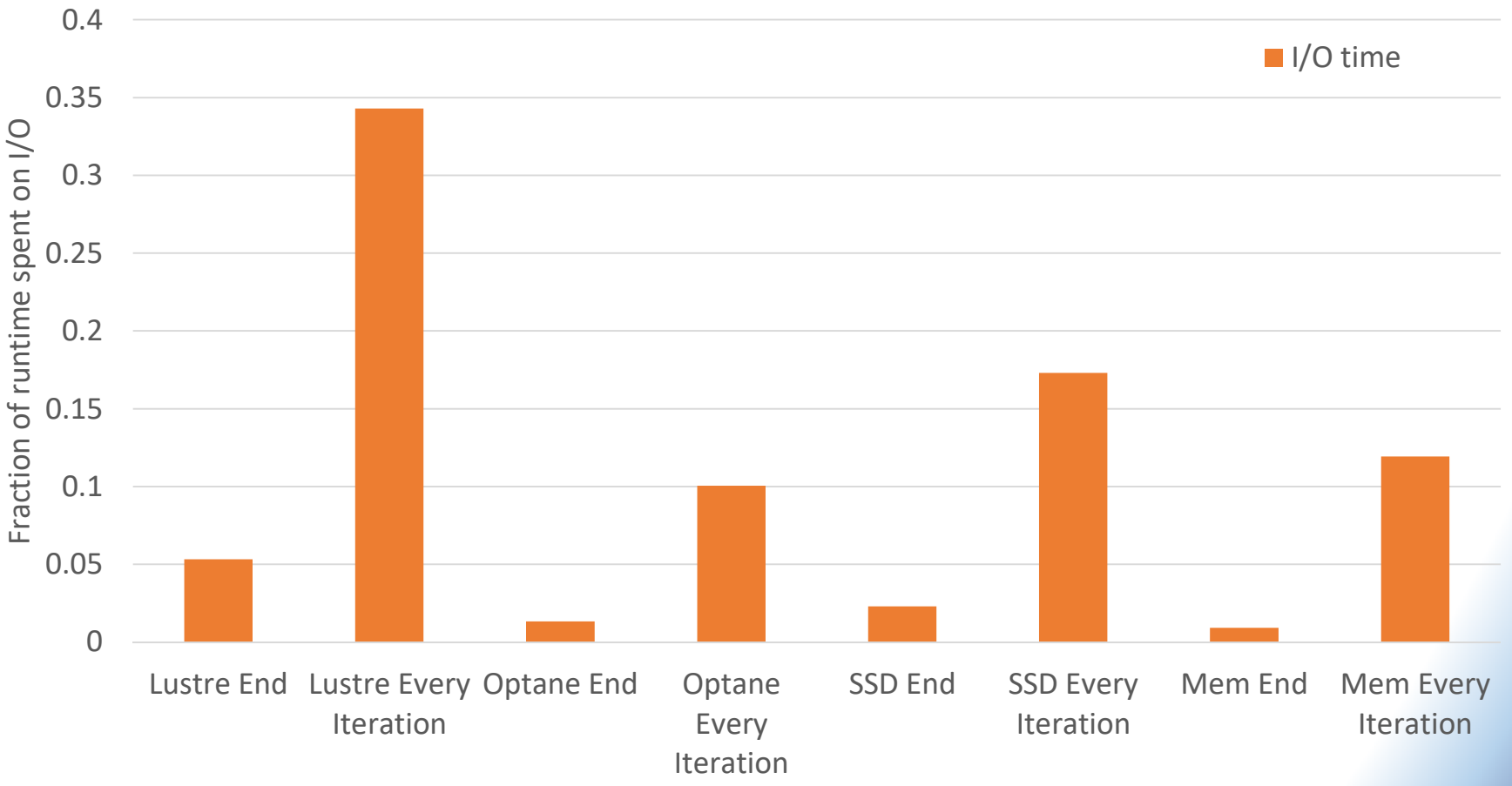


I/O application patterns



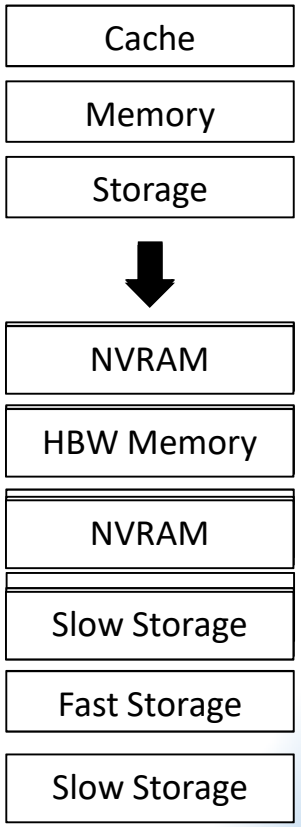


Enabling new I/O



New Memory Hierarchies

- High bandwidth, on processor memory
  - Large, high bandwidth cache
  - Latency cost for individual access may be an issue
- Main memory
  - DRAM
  - Costly in terms of energy, potential for lower latencies than high bandwidth memory
- Storage class memory
  - High capacity, ultra fast storage
  - Low energy (when at rest) but still slower than DRAM
  - Available through same memory controller as main memory, programs have access to memory address space

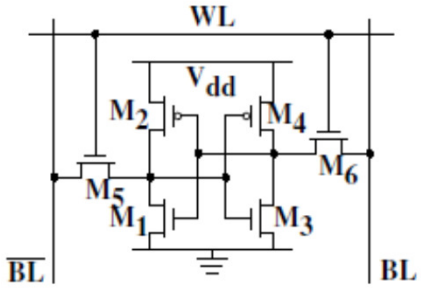


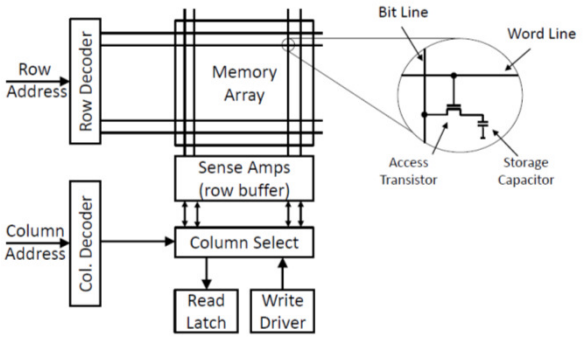
Non-volatile memory

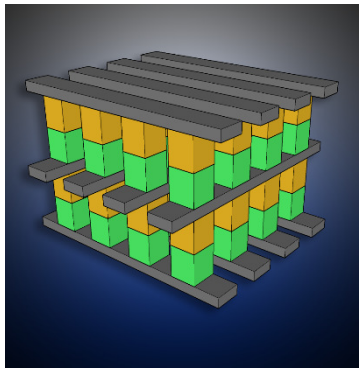
- Non-volatile RAM
  - 3D XPoint technology
  - STT-RAM
- Much larger capacity than DRAM
  - Hosted in the DRAM slots, controlled by a standard memory controller
- Slower than DRAM by a small factor, but significantly faster than SSDs
- STT-RAM
  - Read fast and low energy
  - Write slow and high energy
    - Trade off between durability and performance
    - Can sacrifice data persistence for faster writes

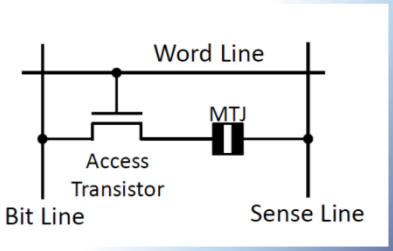
SRAM vs NVRAM

- SRAM used for cache
- High performance but costly
  - Die area
  - Energy leakage
- DRAM lower cost but lower performance
  - Higher power/refresh requirement
- NVRAM technologies offer
  - Much smaller implementation area
  - No refresh/ no/low energy leakage
  - Independent read/write cycles
- NVDIMM offers
  - Persistency
  - Direct access (DAX)







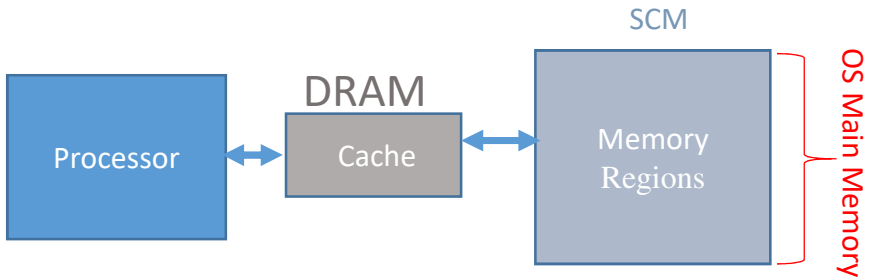


NVDIMMs

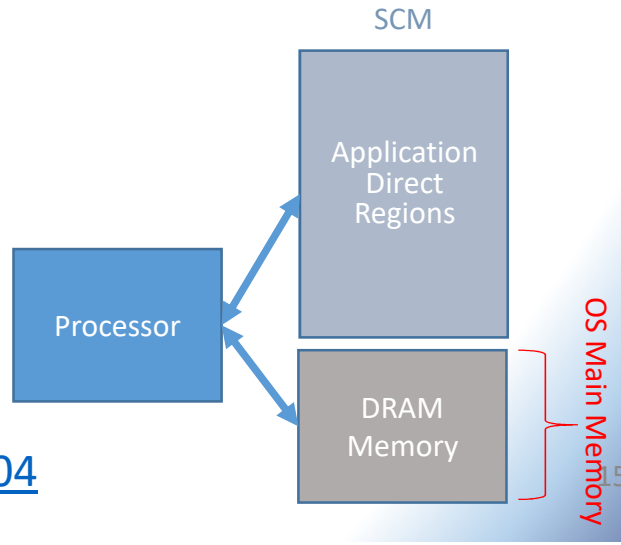
- Non-volatile memory already exists
  - NVDIMM-N:
    - DRAM with NAND Flash on board
    - External power source (i.e super capacitors)
    - Data automatically moved to flash on power failure with capacitor support, moved back when power restored
    - Persistence functionality with memory performance (and capacity)
  - NVDIMM-F:
    - NAND Flash in memory form
    - No DRAM
    - Accessed through block mode (like SSD)
  - NVDIMM-P:
    - Combination of N and F
    - Direct mapped DRAM and NAND Flash
    - Both block and direct memory access possible
- 3D Xpoint, when it comes
  - NVDIMM-P like (i.e. direct memory access and block)
  - But no DRAM on board
  - Likely to be paired with DRAM in the memory channel
  - Real differentiator (from NVDIMM-N) likely to be capacity and cost

Memory levels

- SCM in general is likely to have different memory modes* (like MCDRAM on KNL):
  - Two-level memory (2LM)



  - One-level memory (1LM)

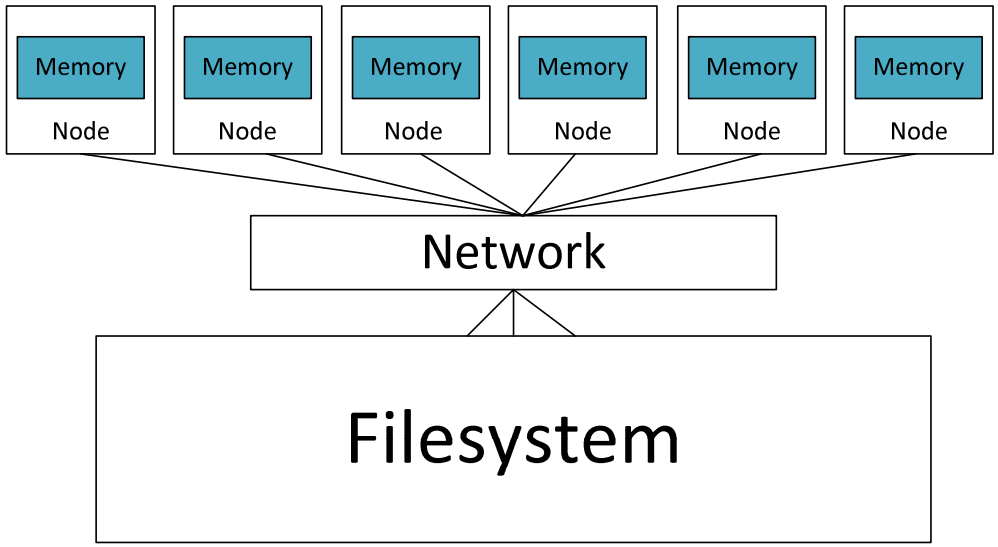


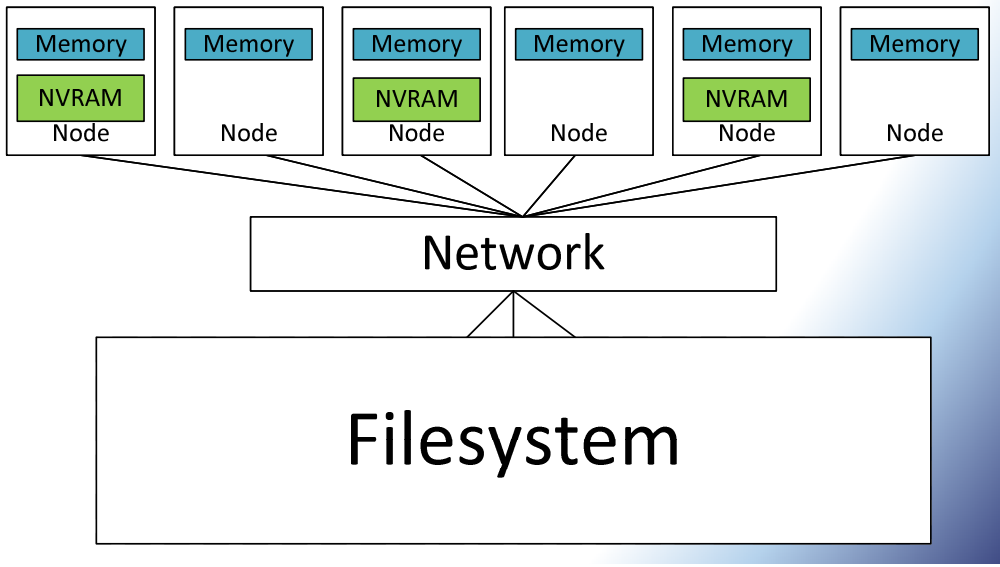
*https://www.google.com/patents/US20150178204

Storage Class Memory

- The “memory” usage model allows for the extension of the main memory
  - The data is volatile like normal DRAM based main memory
- The “storage” usage model which supports the use of NVRAM like a classic block device
  - E.g. like a very fast SSD
- The “application direct” (DAX) usage model maps persistent storage from the NVRAM directly into the main memory address space
  - Direct CPU load/store instructions for persistent main memory regions

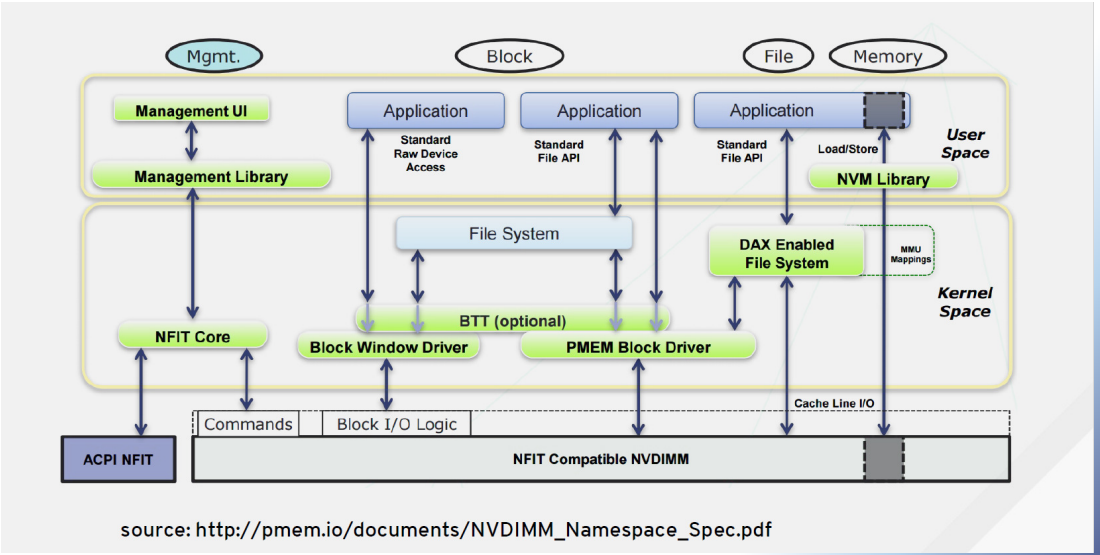
Exploiting distributed storage





Programming SCM

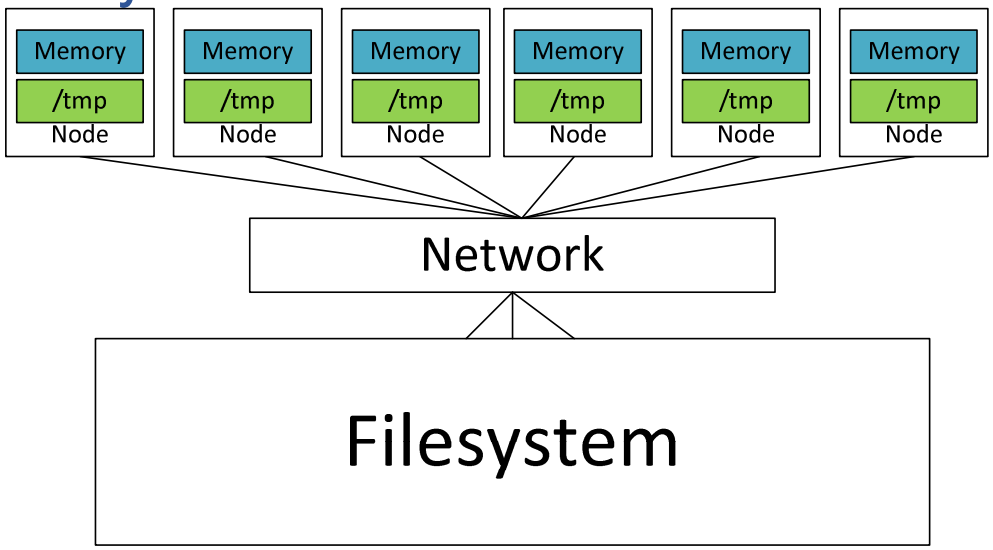
- Block memory mode
  - Standard filesystem api's
  - Will incur block mode overheads (not byte granularity, kernel interrupts, etc…)
- App Direct/DAX mode
  - Volatile memory access can use standard load/store
  - NVM library
    - pmem.io
    - Persistent load/store
    - memory mapped file like functionality



source: http://pmem.io/documents/NVDIMM_Namespace_Spec.pdf

Using distributed storage

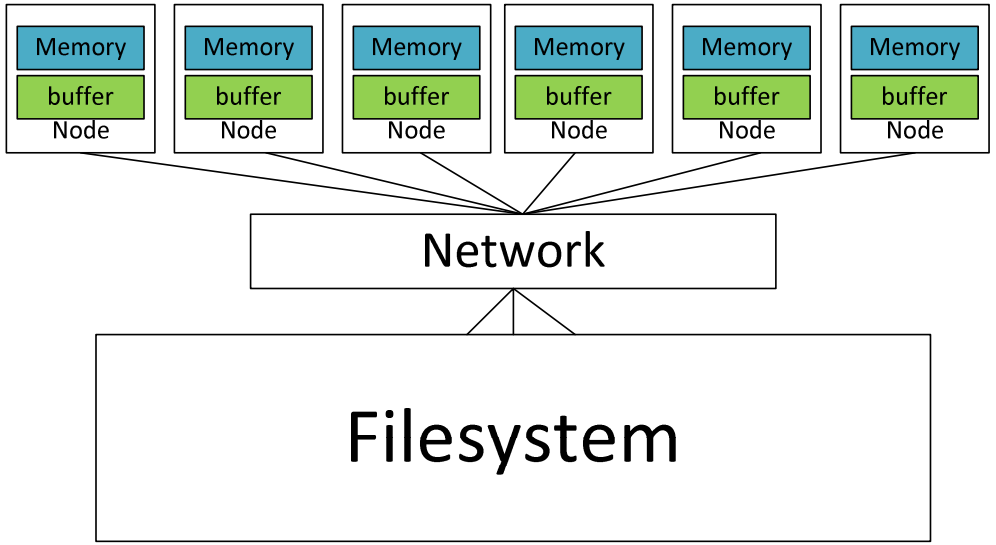
- Without changing applications
  - Large memory space/in-memory database etc…
  - Local filesystem



- Users manage data themselves
- No global data access/namespace, large number of files
- Still require global filesystem for persistence

Using distributed storage

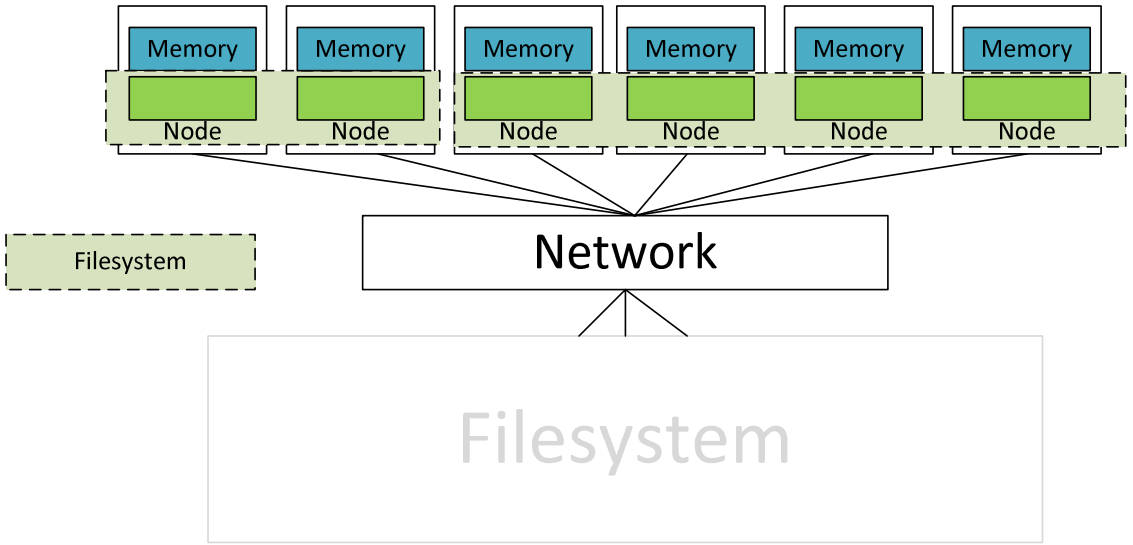
- Without changing applications
  - Filesystem buffer



- Pre-load data into NVRAM from filesystem
- Use NVRAM for I/O and write data back to filesystem at the end
- Requires systemware to preload and postmove data
- Uses filesystem as namespace manager

Using distributed storage

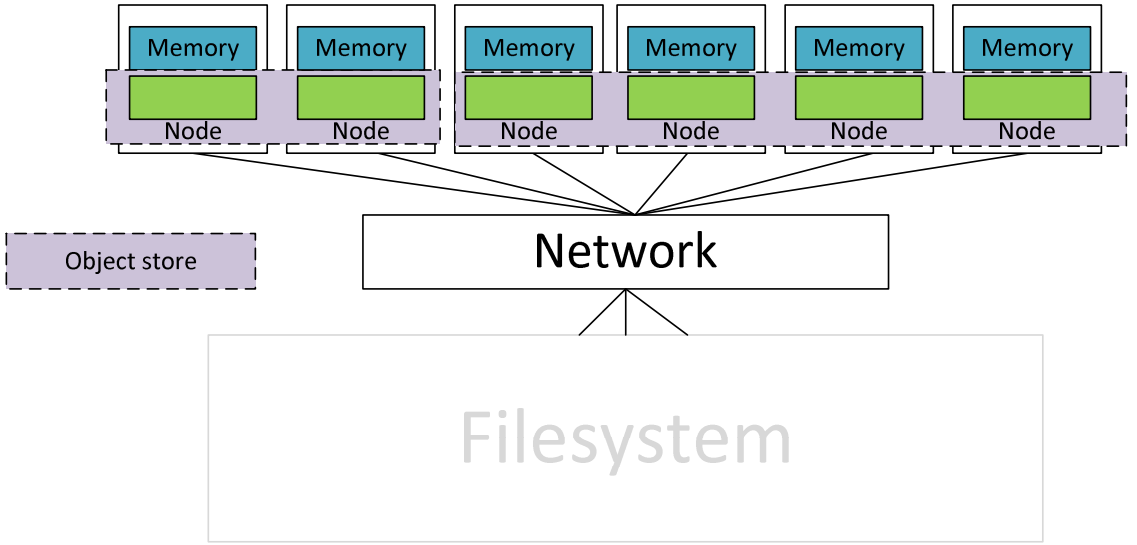
- Without changing applications
  - Global filesystem



  - Requires functionality to create and tear down global filesystems for individual jobs
  - Requires filesystem that works across nodes
  - Requires functionality to preload and postmove filesystems
  - Need to be able to support multiple filesystems across system

Using distributed storage

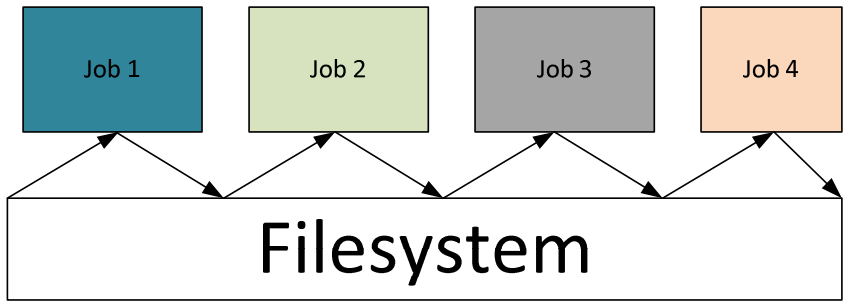
- With changes to applications
  - Object store



- Needs same functionality as global filesystem
- Removes need for POSIX, or POSIX-like functionality

Using distributed storage

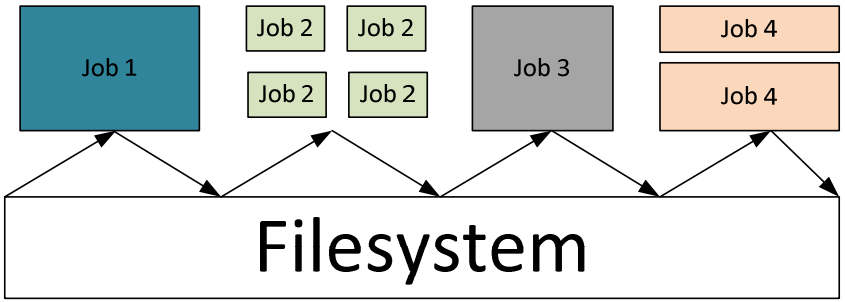
- New usage models
  - Resident data sets
    - Sharing preloaded data across a range of jobs
    - Data analytic workflows
    - How to control access/authorisation/security/etc….?
  - Workflows
    - Producer-consumer model



    - Remove filesystem from intermediate stages

Using distributed storage

- Workflows
  - How to enable different sized applications?



  - How to schedule these jobs fairly?
  - How to enable secure access?

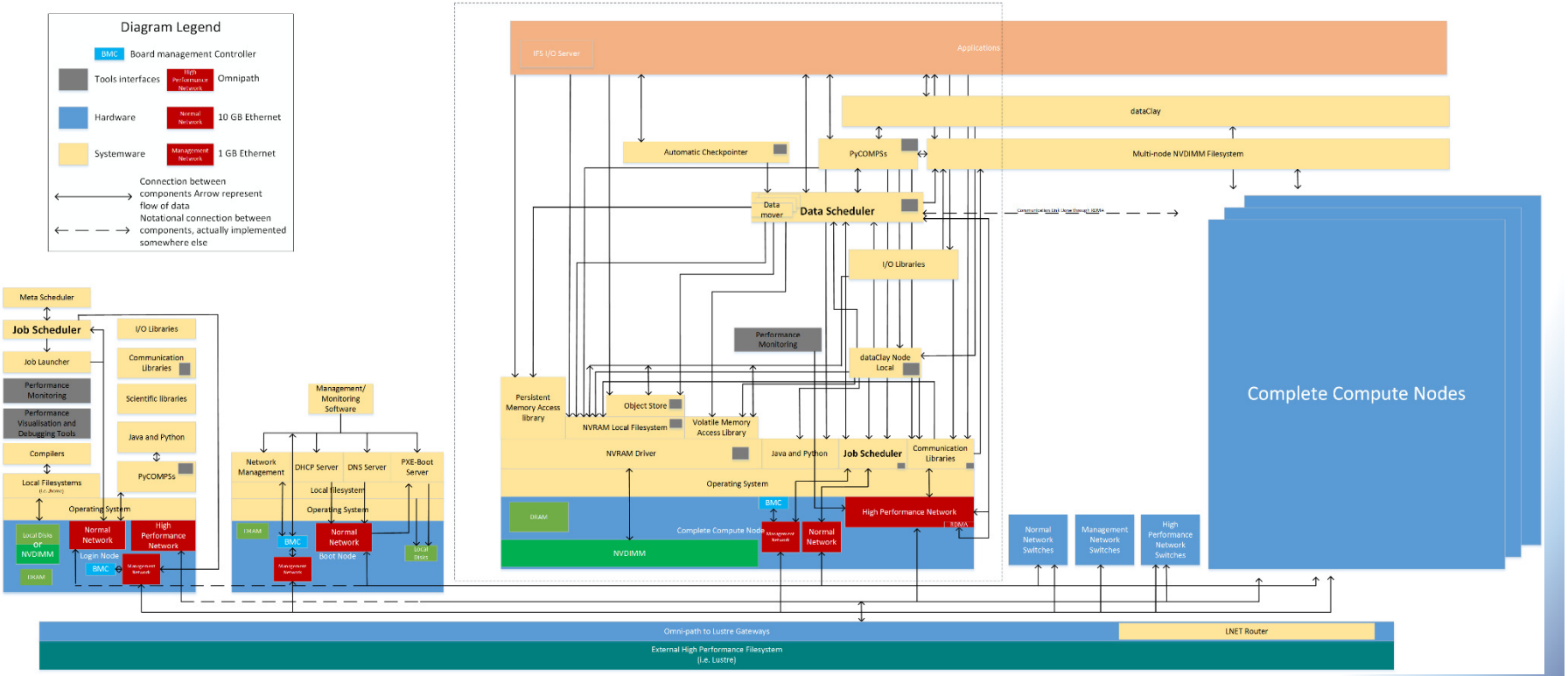
The challenge of distributed storage

- Enabling all the use cases in multi-user, multi-job environment is the real challenge
  - Heterogeneous scheduling mix
  - Different requirements on the SCM
  - Scheduling across these resources
  - Enabling sharing of nodes
  - Not impacting on node compute performance
  - etc….
- Enabling applications to do more I/O
  - Large numbers of our applications don't heavily use I/O at the moment
  - What can we enable if I/O is significantly cheaper

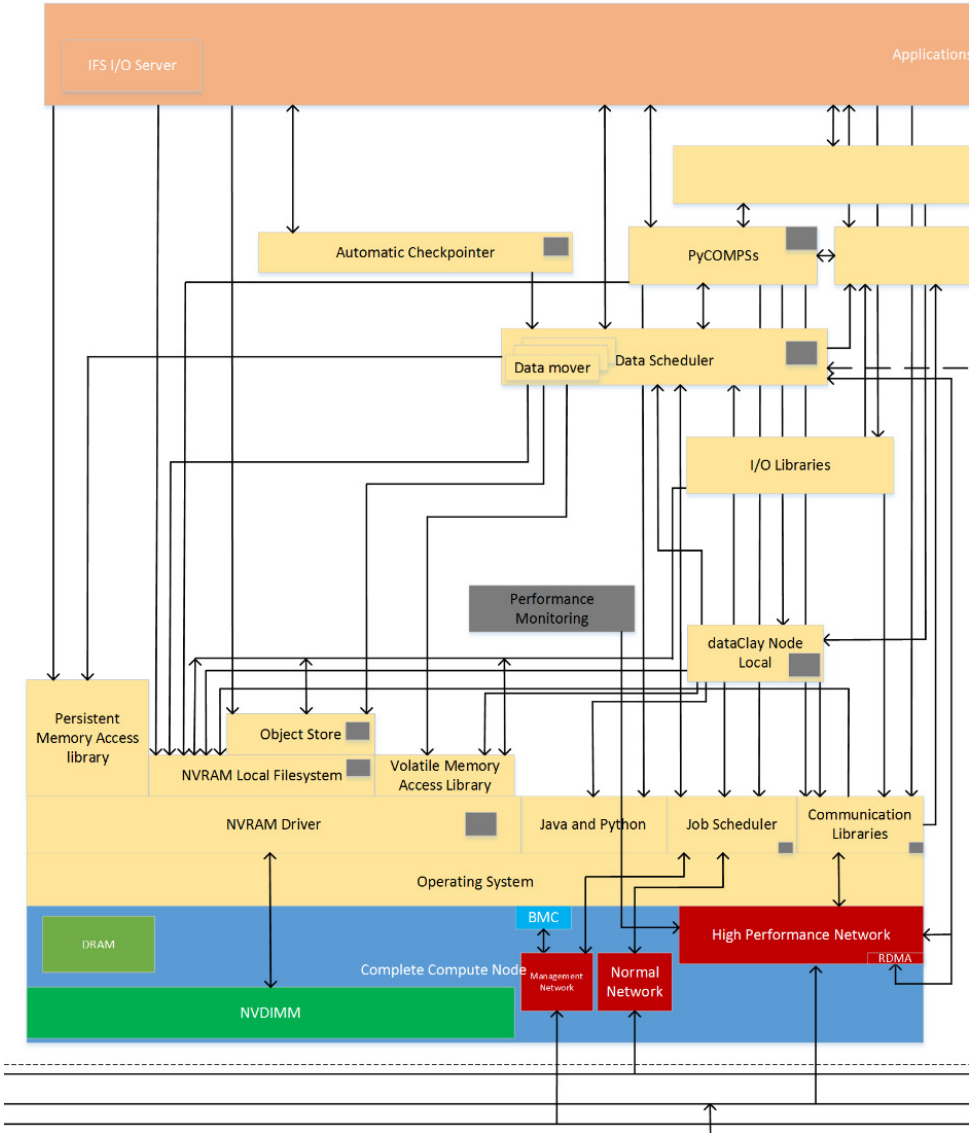
Potential solutions

- Large memory space
- Burst buffer
- Filesystem across NVRAM in nodes
- HSM functionality
- Object store across nodes
- Checkpointing and I/O libraries

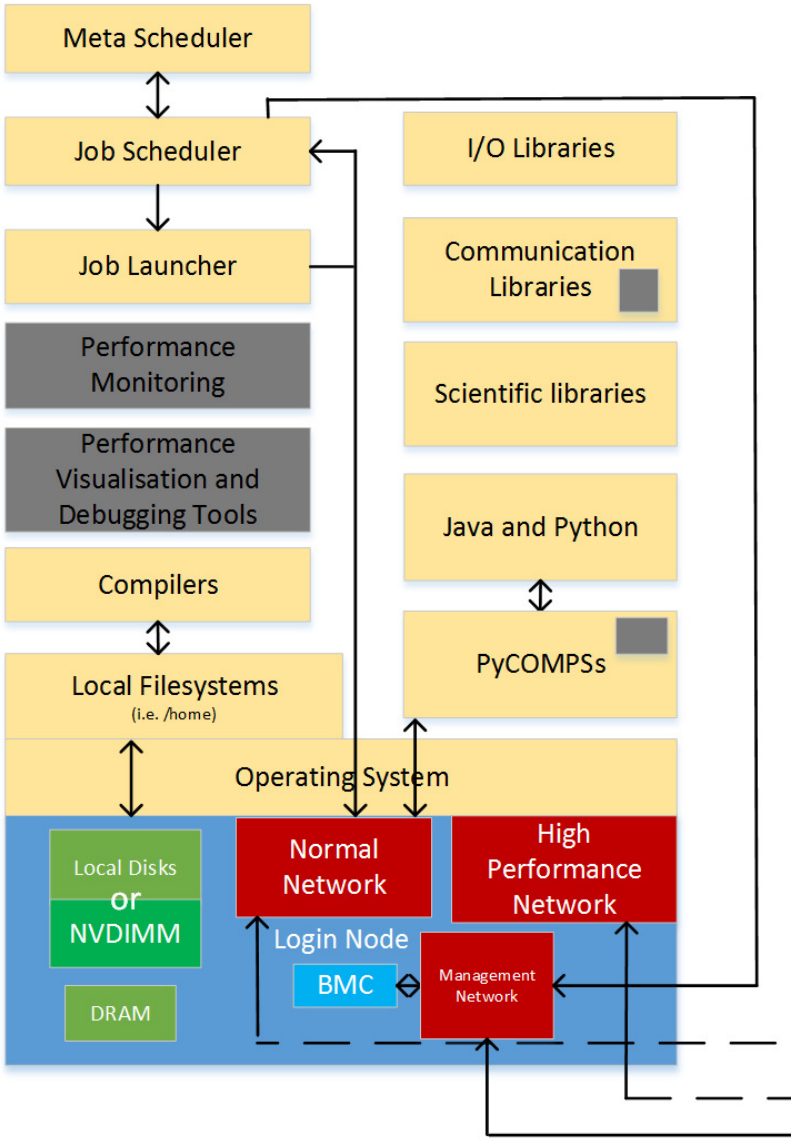
NEXTGenIO Systemware



Compute node systemware



User node systemware



Summary

- Storage class memory is coming
  - Price and capacity remains to be seen, but initial indications are interesting (large, cheaper than DRAM on a per GB)
  - In-node persistent storage likely to come to (maybe some) HPC and HPDA systems shortly
  - Applications can program directly but….
  - …potentially systemware can handle functionality for applications, at least in transition period
- Interesting times
  - Convergence of HPC and HPDA (maybe)
  - Different data usage/memory access models may become more interesting
  - Certainly benefits for single usage machines, i.e. bioinformatics, weather and climate, etc…