xyratex

Advancing Digital Storage Innovation

Bridging the peta- to exa-scale I/O gap

Peter Braam

Dwarfs and offspring under the roofs

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Forward Looking Statement

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Goal of this talk

- Who is Xyratex?
- Exa-scale systems
- A sample use case
- Characterizing load
- Reasoning about performance
- Examples

Who is Xyratex?

Xyratex - Unique and Deep Understanding of Storage

NETWORKED STORAGE SOLUTIONS

High-Capacity Storage Systems

STORAGE INFRASTRUCTURE

High-Density Disk Drive Testing

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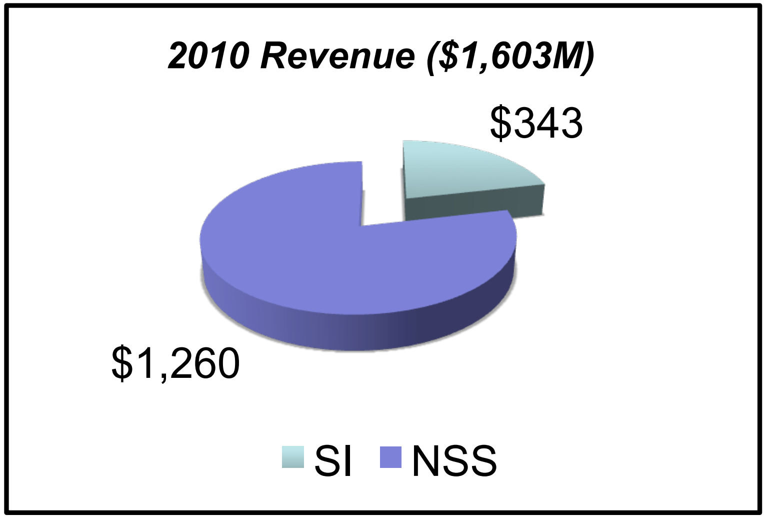
Leading OEM Provider of Digital Storage Technology

- *SI: Largest independent supplier of Disk Drive Capital Equipment*
  - ***~ 50% of w/w disk drives are produced utilizing Xyratex Technology***
  - ***~ 75% of w/w 3.5" LFF disk drives***
- *NSS: Largest OEM Disk Storage System Supplier*
  - ***33% WW OEM Market Share in 2009, 5 Tier-1 OEM's***
  - ***16% of worldwide external storage capacity shipped in 2009 (IDC)***
  - ***> 3.0 Exabyte's of storage shipped in 2010***
  - ***~ 139,000 storage enclosures shipped in 2010***



Xyratex – Storage Hardware & Software

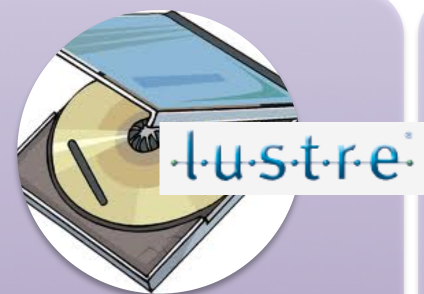
Firmware

Designs, Develops & Firmware for enclosures & controllers

OS

Linux based Storage Appliance

File Systems



World-Class Clustered File System Development & Support Expertise

Management

Storage Management Framework

Unique Ability to Deliver and Support Storage Solutions

Lustre is doing well: Top 500

- Nov 2010:
  - 9 of top 10 systems run Lustre
  - >70 of the top 100 systems run Lustre
- Dozens of research efforts modify it
- Dozens of OEMs have shipped it
- IDC indicates its future is *very* bright

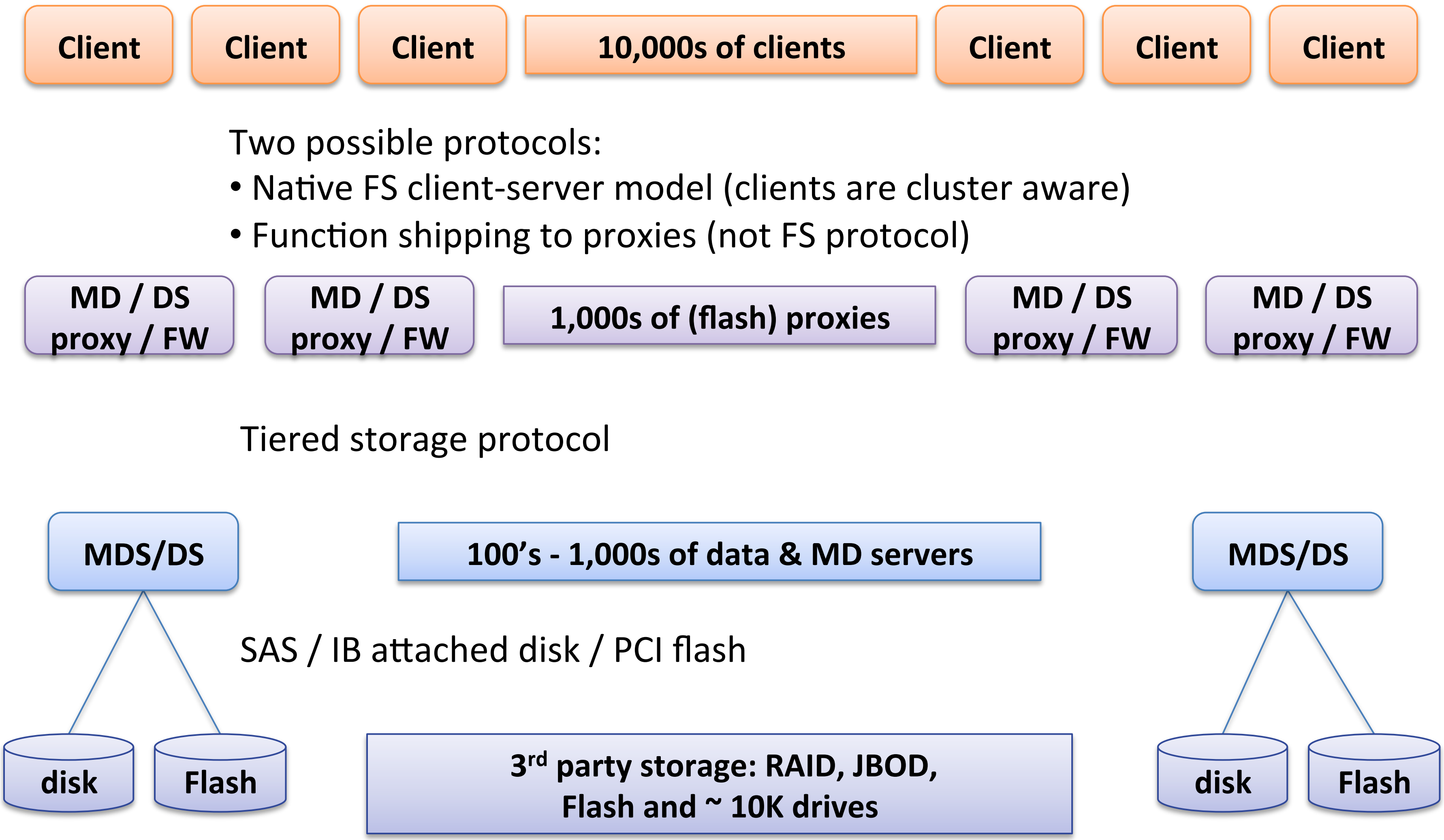
Peta & Exa-scale systems

Exa scale clusters

- Exa scale systems
  - 10^8 cores – each ~10GF/sec, each ~1G RAM
  - 5,000 cores / node, 5 TB RAM / node (50 TF / node)
  - 20K cluster nodes, 100 PB RAM / cluster
  - I/O: 300 TB / sec, one node 15 GB / sec
  - File system > 1 EB
- Technology revolutions
  - File system clients will have ~10,000 cores
  - Architectures will be heterogeneous
  - Flash and/or PCM storage leads to tiered storage
  - Anti revolution – disks will only be a bit faster than today

Sample use case

Example deployment styles



Lessons from benchmarking

- 1 TB FATSAS drives (Seagate Barracuda)
  - 120 MB/sec bandwidth with cache off
  - 4MB allocation unit is “optimal”
- PCI flash and NFSv4.1 RPC system
  - IB connection
  - Embedded database backend
  - 100K transactions / sec aggregate, sustained
    - Update 2 tables and using transaction log
    - One server

100 PF Solution

- 500 servers, each acting as MDS and DS
- Disk capacity 500 x 8TB x 40 dr = 160 PB raw
  - BW ~ 20,000 x 120 MB/sec = 2.4 TB /sec
- Network 4x EDR IB – effective BW 25 GB/sec
- PCI flash
  - capacity 500 x 6 TB = 3 PB
  - BW/node: 25 GB/sec, aggregate: 12.5 TB/sec
- MD throughput aggregate: 50M trans / sec
  - 1 copy of MD remains in flash
  - 10^12 inodes x 150 B = 150 TB, or 5% of flash

HDF5 file I/O – use case

- HDF5 is a file format containing directories and data
- Servers detect ongoing small I/O on part of a file
- It chooses to migrate a section of the file and the file allocation data into flash

- During migration, small I/O stops briefly
- Now 100K iops are available to flash
- When file is quiescent, data migrates back
- In summary: treat disk as HSM when needed

- Promising!

But…

- Flash
  - price and performance aren’t scaling as we were hoping
- Current systems have shown low disk BW utilization
  - On ‘optimal benchmarks’ ~ 50% (then try dbench 100)
  - This picture may not help that
- Bridging the last 10x from 100 PF to 1EF gap looks hard
  - Remember the disk drives
- The exa-scale community is open to revolution

Describe an approach to performance modeling & analysis

- Simple enough that it can easily be done
  - Contrast with simulation, which appears to be hard
- Semi-quantitative
  - Ideal numbers and boundaries are easily visible
- Systematic
- Applies to all kinds of devices and to clusters

Acknowledgement

- P. Colella, “Defining Software Requirements for Scientific Computing,” presentation, 2004.
- The Landscape of Parallel Computing Research: A View from Berkeley. Many authors, Report, Berkeley, 2006.
- Roofline: An insightful Visual Performance model for multicore Architectures (Williams, Waterman, Patterson, IEEE Computer 2009)

What about the remainder?

- There are good modeling frameworks for availability
  - Markov models and state machines
- They are not widely used, but provide crystal clear guidance on availability models for a product
- This talk isn't focusing on that.

Seven I/O Dwarfs

Mimic Berkeley – seven I/O Dwarfs

- There are far too many I/O benchmarks
- Identify the typical I/O kernels
- These kernels are called dwarfs

- Requirements on set of dwarfs
  - Small enough to be manageable
  - Broad enough to cover essential points in architecture
    - Typically some dwarfs may require special architecture

List of the dwarfs

1. Download
   - Summary: All clients read the same file
   - Key problem: server bottlenecks
2. SSF Write
   - Summary: All clients / threads write to one file
   - Key problem: Many partial stripe writes are inefficient
3. Tree read
   - Summary: Many clients do small I/O with seeks on large file
   - Key problem: Seeks make I/O inefficient
4. FPP Write
   - Summary: All processes write their own file
   - Key problem: Storm of file creates

List of the dwarfs - ctd

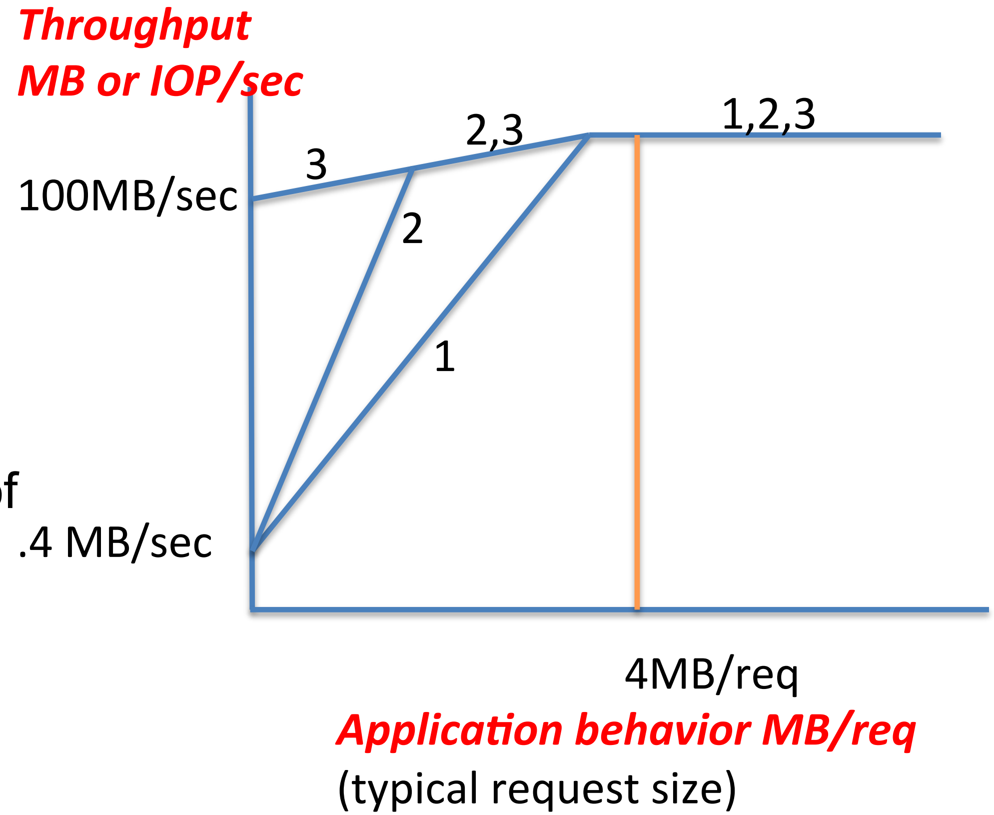
5. Metadata and Small I/O
   - Summary: find, ls –l, rsync, rm –r, tar {cx}f (on a large tree)
   - Key problem: Performance, locality
6. Highly multithreaded I/O
   - Summary: Thousands of threads do FS operations on one node
   - Key problems: Fragmentation, fairness
7. Cache integration
   - Summary: A cache with many objects migrates to slower tier
   - Key problem: Iteration

- Some dwarfs are undoubtedly missing
  - One is obliged to start with 7

Rooflines

Roofline

- Rooflines indicate ***maximum possible performance*** given typical request size
- Multiple roof lines
  - Associated with presence of optimizations
- E.g.
  - Sample graph for disk
  - 3 no rotational delay, no seek
  - 2 rotational delay, no seek
  - 1 rotational delay & seek (random)



Sample rooflines for hard drive

Rooflines – applicability

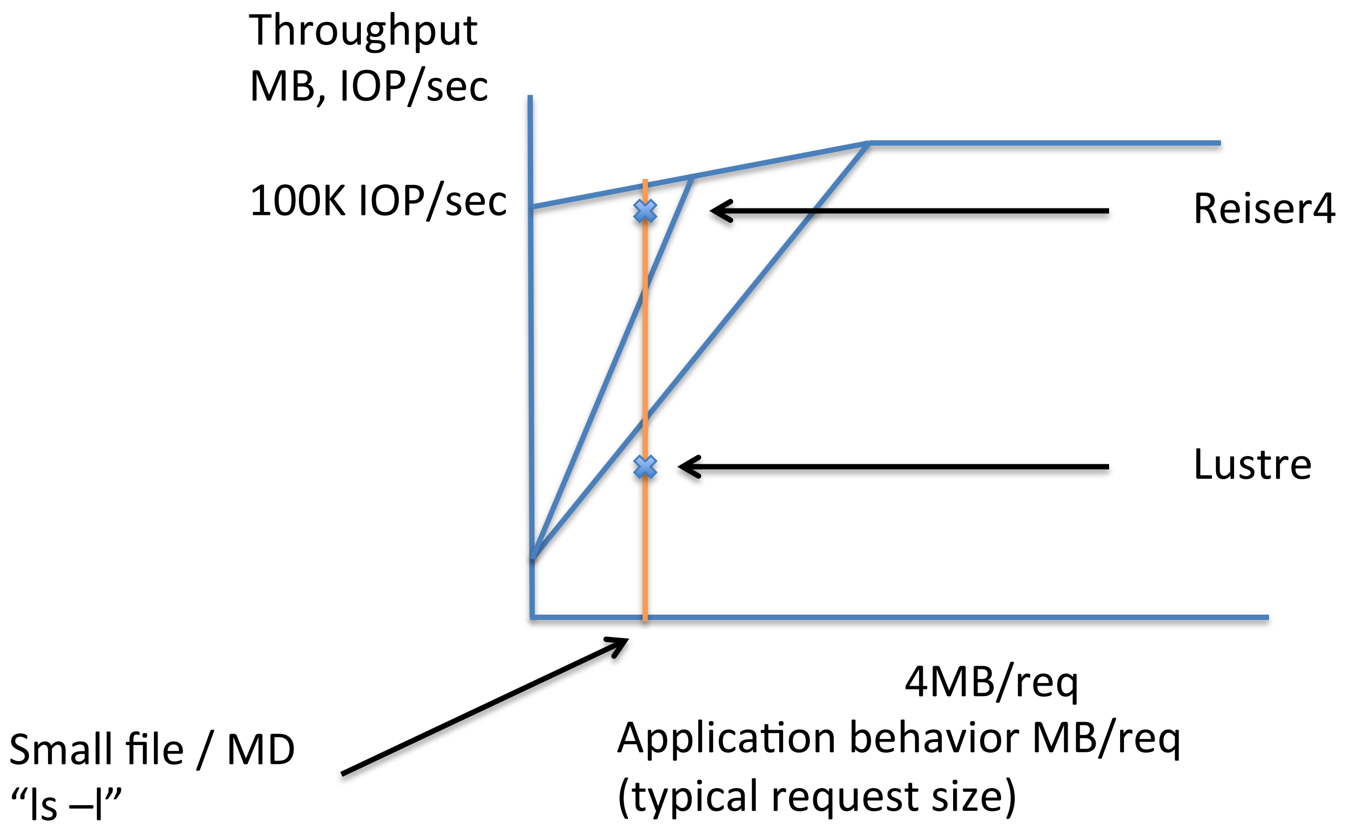
- Applicable to any storage related system
  - Clients
  - Enclosures
  - Servers
  - Drives, Flash
- Semi-quantitative
- Different parameters define regions
  - For enclosure the SAS HBA and expander may be important
  - For clients memory, network, CPU

Dwarf Applications

- Dwarf application has typical I/O size
  - Hence determines a point on the horizontal axis
  - If you change the application, the point may move
    - This can be an optimization, e.g. do larger I/O

- The dwarf's performance is the y-coordinate
  - By optimizing the storage system, this can go up

Sample, hypothetical application & roofline

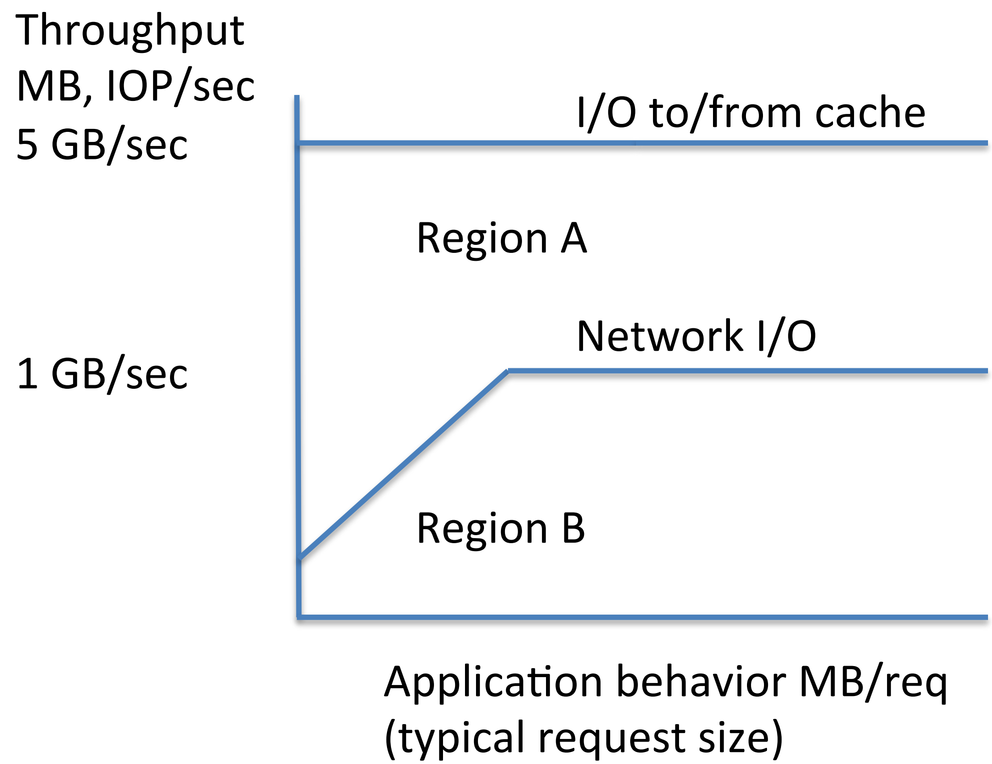


Optimizations

- A seemingly finite set of regions indicate what optimization might be most fruitful, e.g.
  - Larger I/O
  - Aligned I/O – don't write half stripes
  - Eliminate rotational delays or seeks
  - Caching for aggregation
  - Introducing a changelog to avoid scanning
  - Read ahead
  - Collective operations
  - RAM or flash caches
  - Re-ordering (elevators, network request schedulers)
  - Avoiding lock revocations in protocols

File system client rooflines

- If a dwarf is in region A
  - Eliminate remaining network I/O
  - Optimize memory access & threading
- If a dwarf is in region B
  - Increase I/O sizes (e.g. read-ahead)
  - Start leveraging caches
- Note: not necessarily one “best approach”



Dwarfs have offspring

- Striping
  - One I/O load on a client become a set of loads on servers
- Client server model
  - Many loads on clients combine to one load on servers
- Thread to node
  - Many threads combine to a load on a node

Exa-scale I/O

High end HPC storage systems

- 10 years ago, Fortran ruled
- Now new methods are embraced
  - Global address spaces (PGAS), languages (e.g. X10), ..
- File systems cause HPC I/O bottlenecks: remedies
  1. **Surrender control to an I/O library used with application**
  2. **Embrace local storage – much higher aggregate BW**
- But
  - POSIX operations will remain important
  - Data re-organization is a central part of HPC I/O
- Begin to develop a new I/O library
  - Not layered on file systems, using deeper API's
  - Obviously this needs to be an open effort

Some examples what you cannot do with file systems

- Overlapping stripes from different clients
  - Very costly to write
  - An I/O library can detect this
- I/O models, free of locking with barriers
  - Very similar to what HPC applications do anyway
  - Tuned to HPC like Hadoop was to map-reduce
- Compiler supported speculative & aligned read-ahead
- Allow applications to simply map data structures
- PGAS like location / layout descriptors
- Integrate HDF5 / NetCDF formats into file system
  - Do not use file I/O do to metadata (current practice)

Conclusions

Summary

- 100PF is “easy”
- There is a better design methodology
- A new style of doing I/O holds promise

Thank you