

Challenges and Opportunities in Large-Scale Storage Systems

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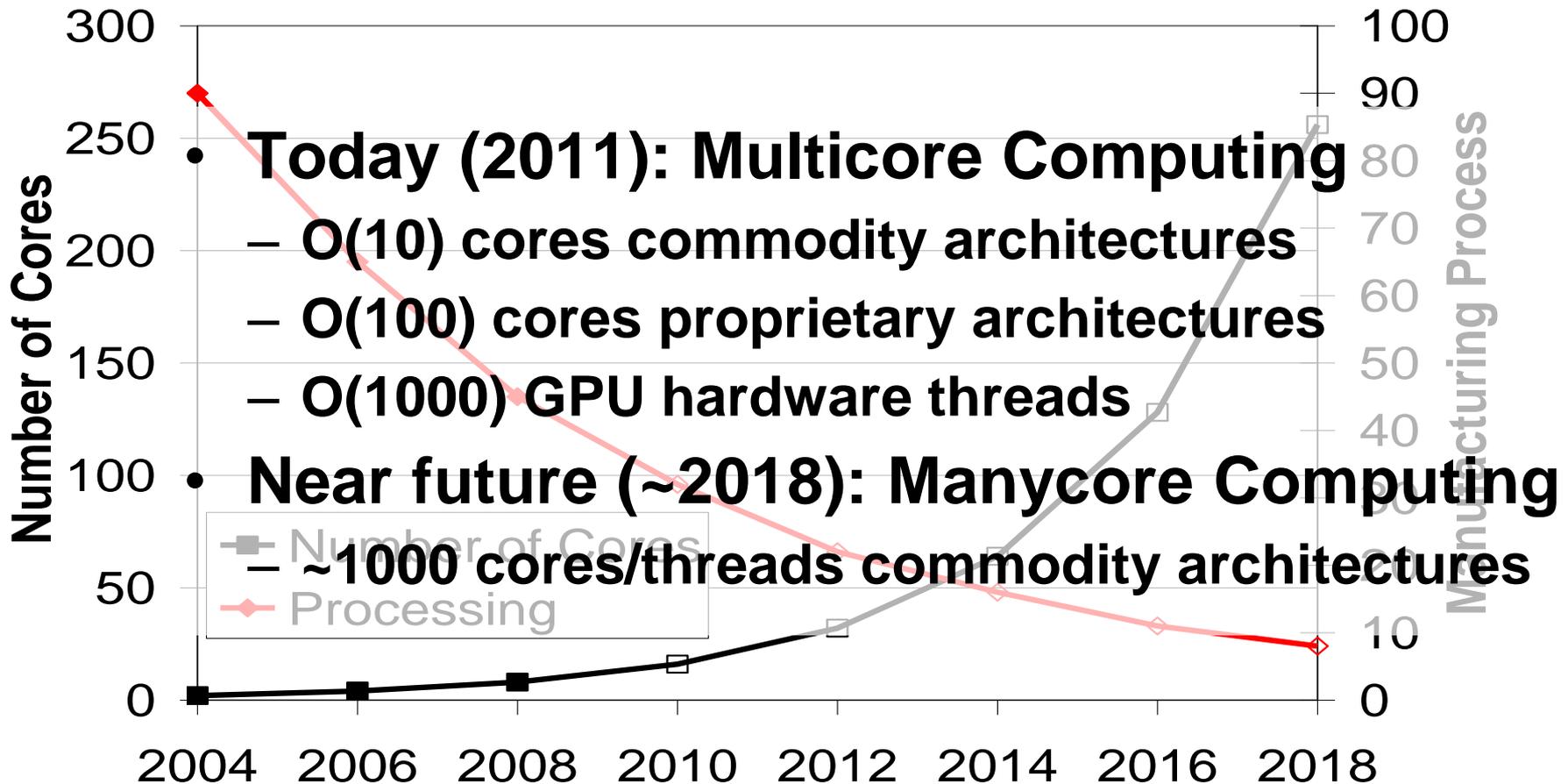
Computer Science Department
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CS 595: Data-Intensive Computing
November 21st, 2011

Overview

- **This talk covers material from the LSAP position paper:**
 - Ioan Raicu, Pete Beckman, Ian Foster. “[Making a Case for Distributed File Systems at Exascale](#)”, ACM Workshop on Large-scale System and Application Performance (LSAP), 2011
- **Which is based on my NSF CAREER award (2011-2015):**
 - Ioan Raicu, Arthur Barney Maccabe, Marc Snir, Rob Ross, Mike Wilde, Kamil Iskra, Jacob Furst, Mary Cummane. “[Avoiding Achilles’ Heel in Exascale Computing with Distributed File Systems](#)”, NSF OCI CAREER Award #1054974

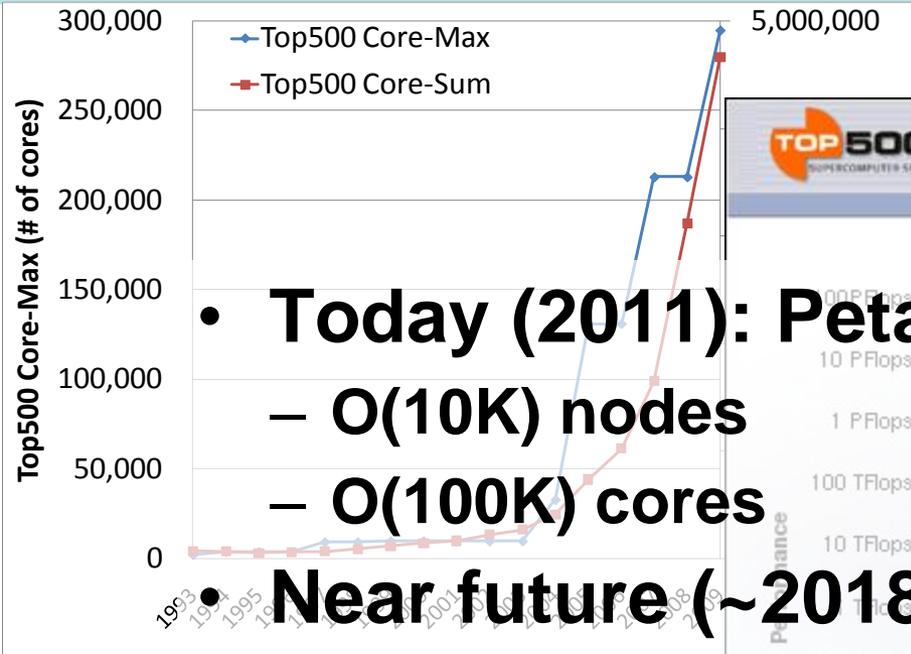
Manycore Computing



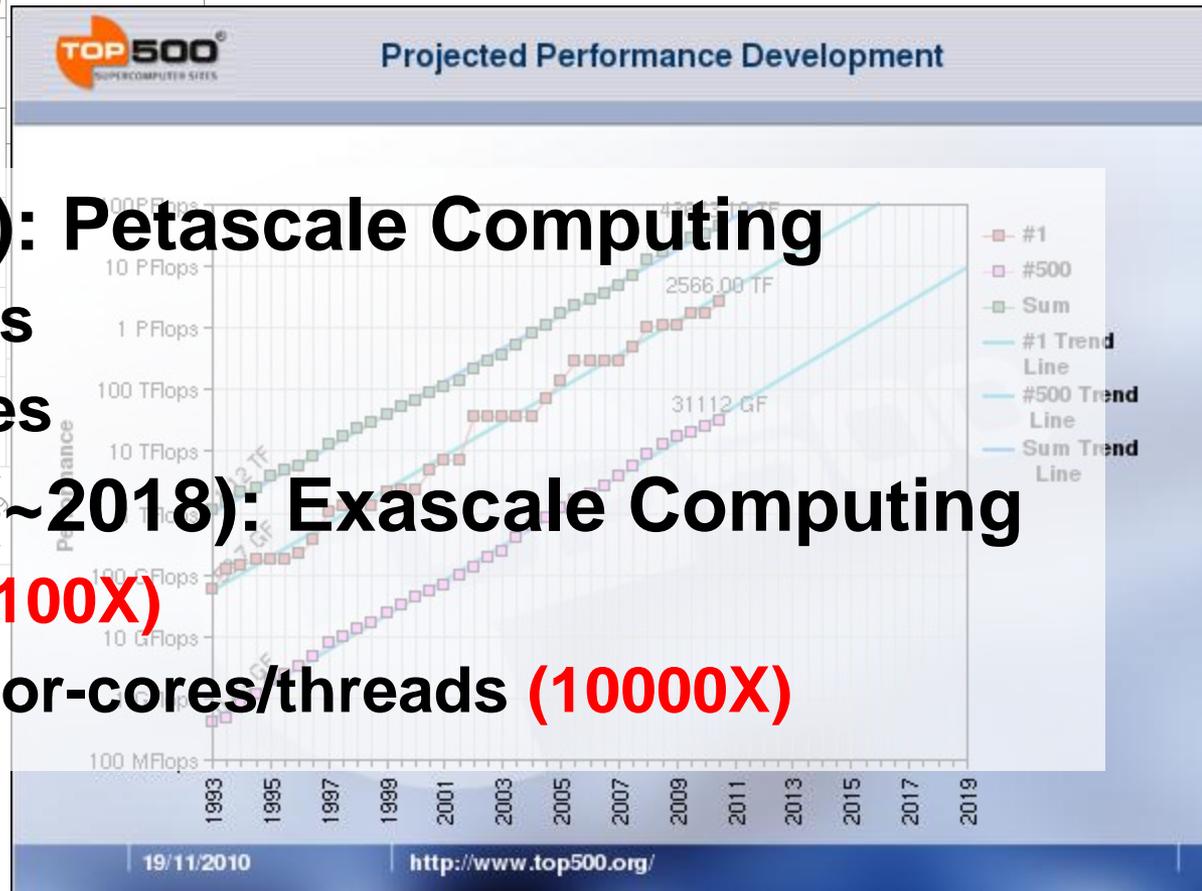
Pat Helland, Microsoft, The Irresistible Forces Meet the Movable

Objects, November 9th, 2007
 Challenges and Opportunities in Large-Scale Storage Systems

Exascale Computing



- **Today (2011): Petascale Computing**
 - O(10K) nodes
 - O(100K) cores
- **Near future (~2018): Exascale Computing**
 - ~1M nodes (**100X**)
 - ~1B processor-cores/threads (**10000X**)



Top500 Projected Development,

http://www.top500.org/lists/2010/11/performance_development

Cloud Computing

- Relatively new paradigm... 3~4 years old
- Amazon in 2009
 - 40K servers split over 6 zones
 - 320K-cores, 320K disks
 - \$100M costs + \$12M/year in energy costs
 - Revenues about \$250M/year
 - http://www.siliconvalleywatcher.com/mt/archives/2009/10/measuring_amaz.php
- Amazon in 2018
 - Will likely look similar to exascale computing
 - 100K~1M nodes, ~1B-cores, ~1M disks
 - \$100M~\$200M costs + \$10M~\$20M/year in energy
 - Revenues 100X~1000X of what they are today

Common Challenges

- Power efficiency
 - Will limit the number of cores on a chip (Manycore)
 - Will limit the number of nodes in cluster (Exascale and Cloud)
 - Will dictate a significant part of the cost of ownership
- Programming models/languages
 - Automatic parallelization
 - Threads, MPI, workflow systems, etc
 - Functional, imperative
 - Languages vs. Middleware

Common Challenges

- **Bottlenecks in scarce resources**
 - Storage (Exascale and Clouds)
 - Memory (Manycore)
- **Reliability**
 - How to keep systems operational in face of failures
 - Checkpointing (Exascale)
 - Node-level replication enabled by virtualization (Exascale and Clouds)
 - Hardware redundancy and hardware error correction (Manycore)

State-of-the-Art Storage Systems in HEC

Parallel File Systems

- Segregated storage and compute

- NFS, GPFS, PVFS, Lustre, Paragon

- Batch-scheduled Supercomputers

- Programming pa

- Located storage

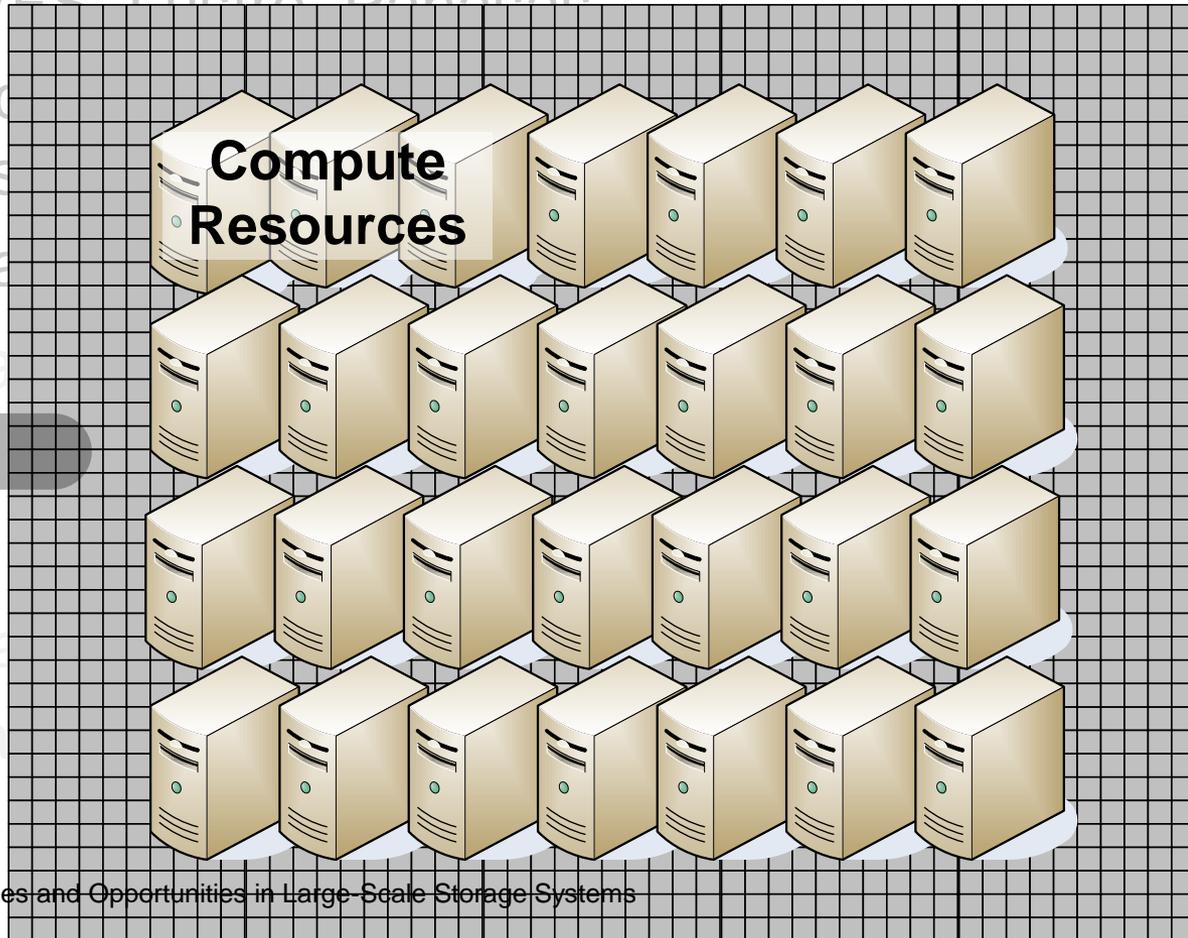
- Data centers at

- Programming pa

- Others from aca

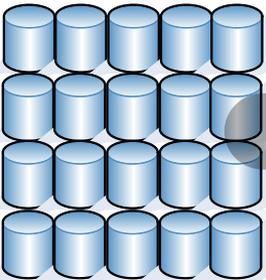
Network Fabric

Compute Resources



NAS

Network Link(s)

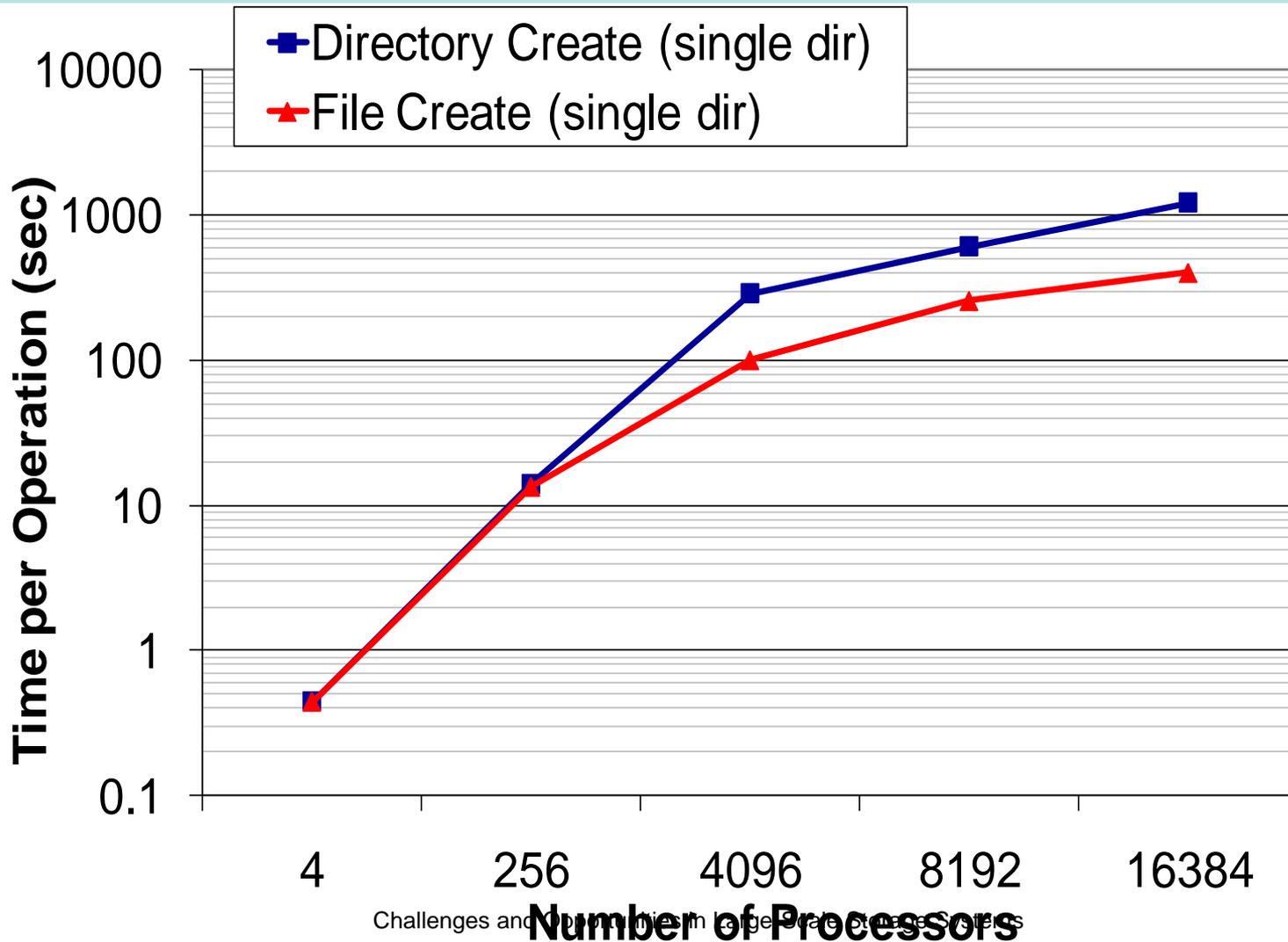


What are the key challenges?

- MTTF is likely to decrease with system size
- Support for data intensive applications/operations
 - Fueled by more complex questions, larger datasets, and the many-core computing era
 - **HPC**: OS booting, application loading, check-pointing
 - **HTC**: Inter-process communication
 - **MTC**: Metadata intensive workloads, inter-process communication

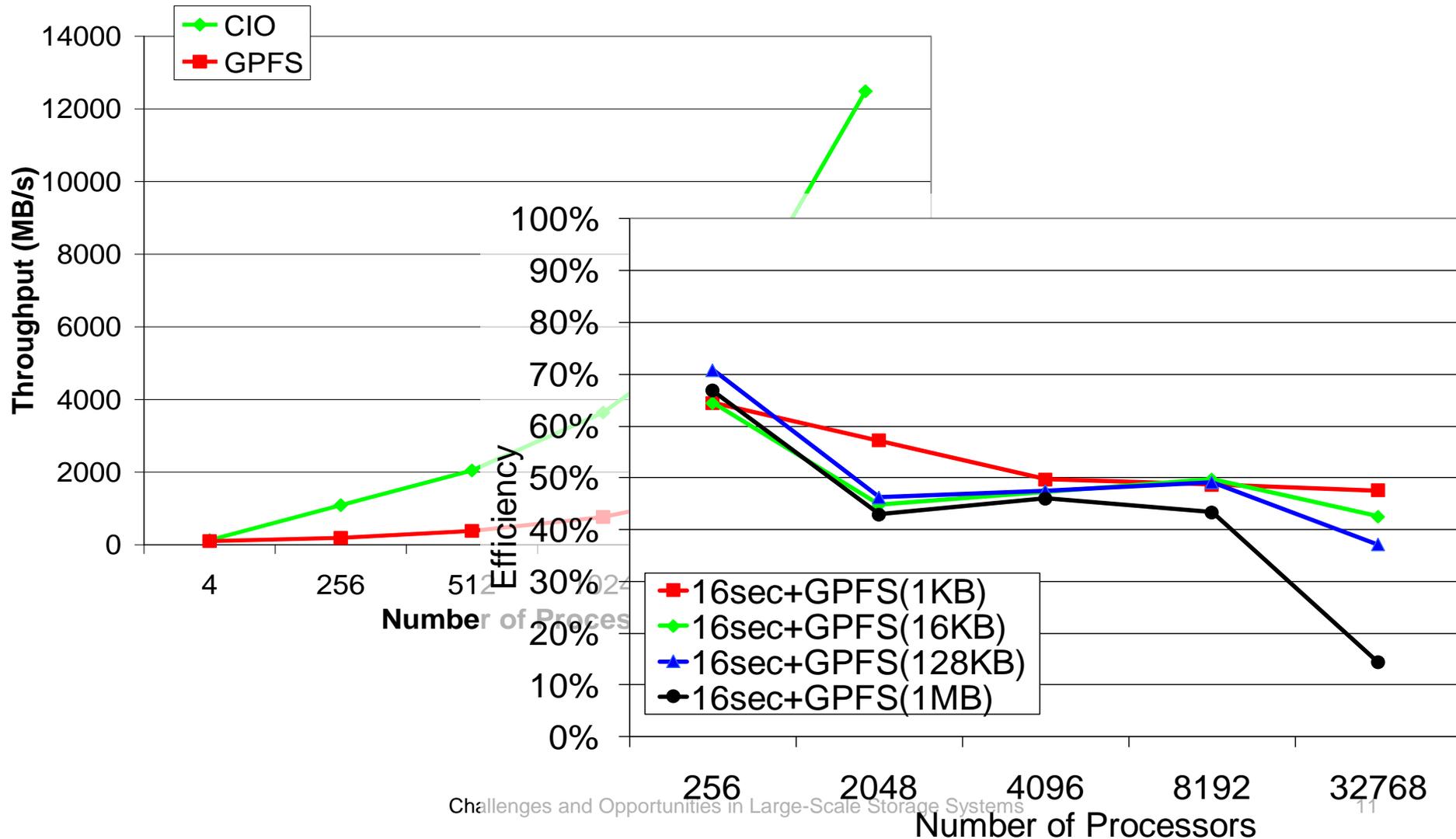
Some Challenges

Meta-data Operations on GPFS



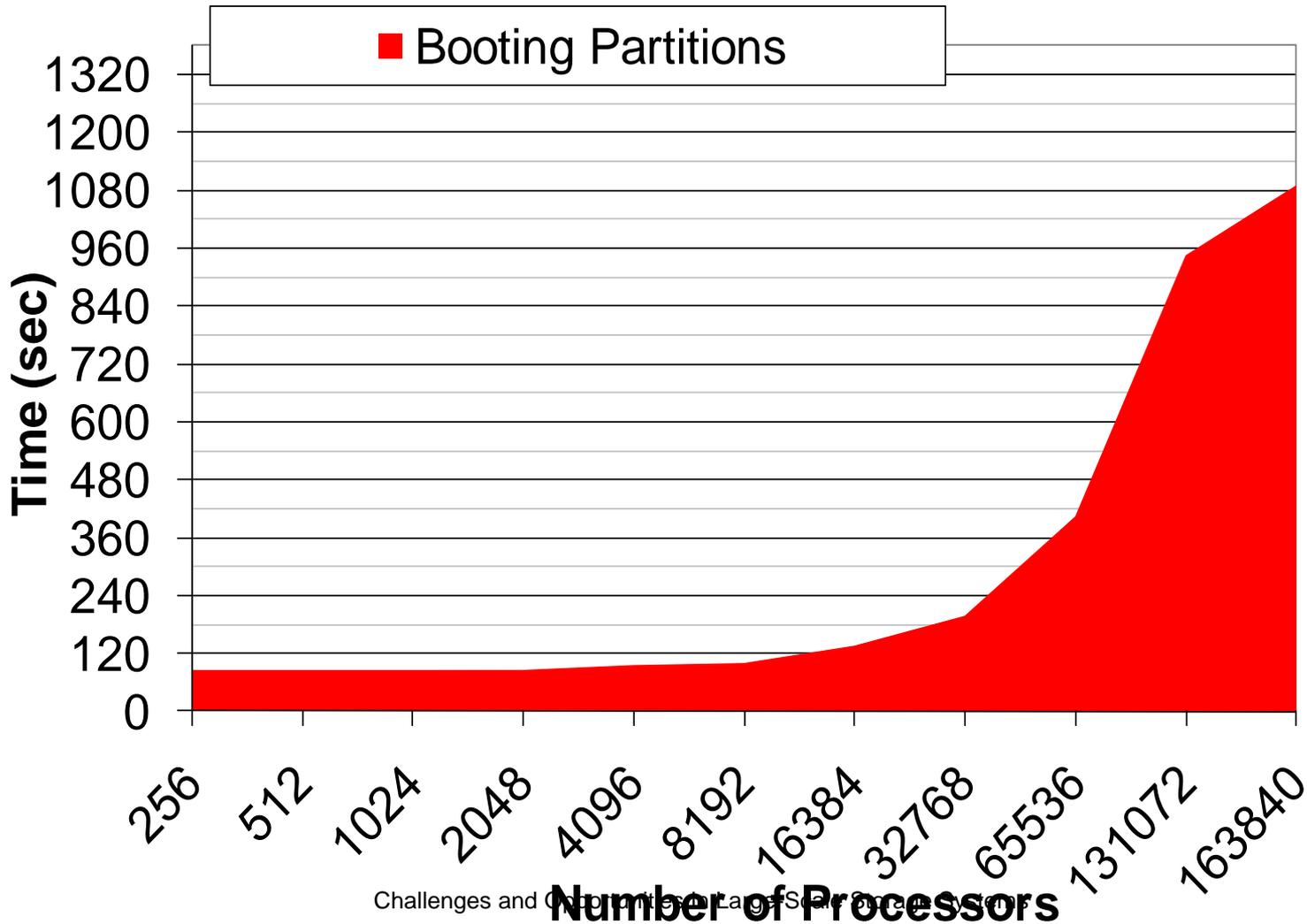
Some Challenges

Reading/Writing on GPFS



Some Challenges

Booting a IBM BlueGene/P



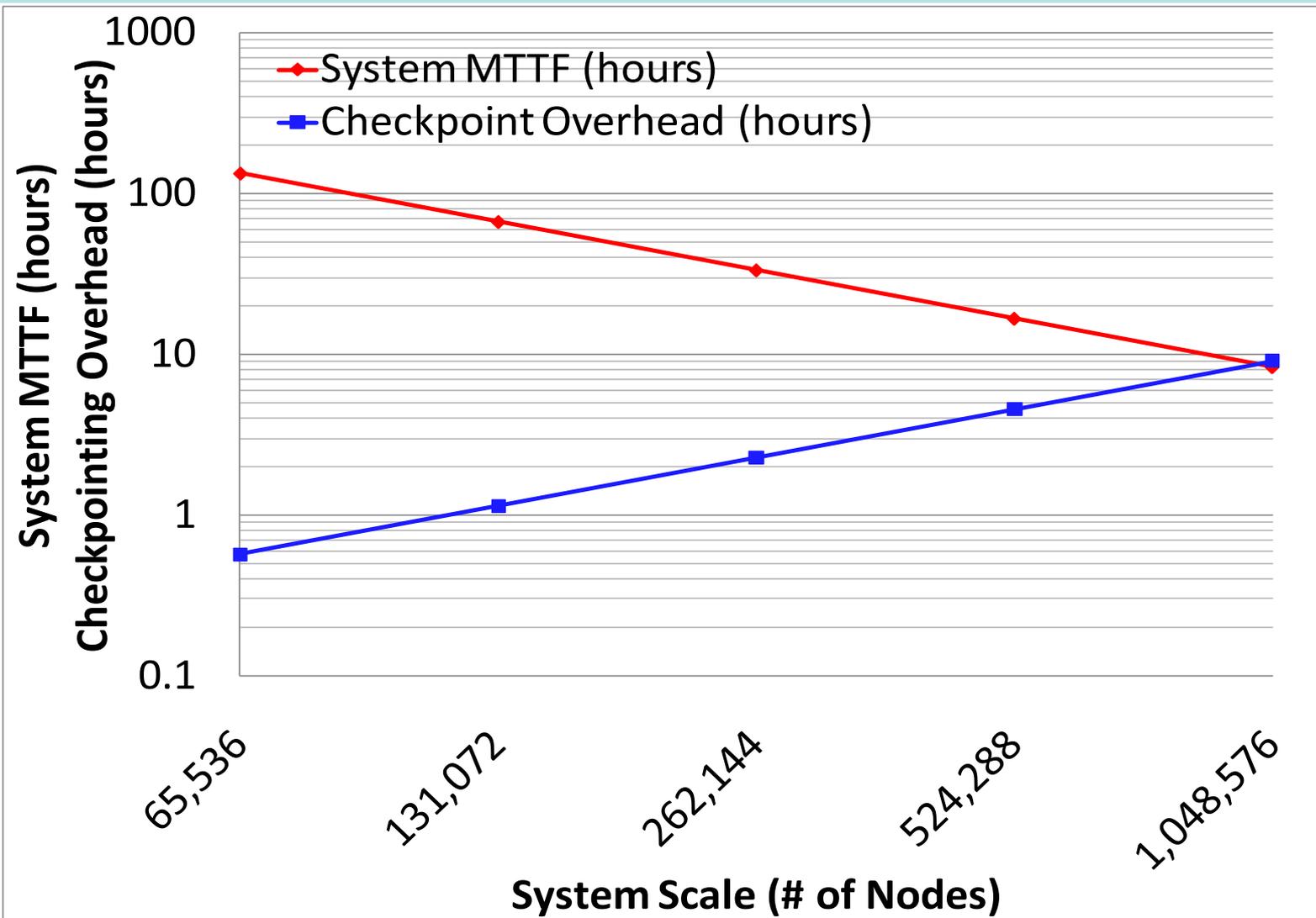
Exascale Supercomputing Architecture

- Compute
 - 1M nodes, with ~1K threads/cores per node
- Networking
 - N-dimensional torus
 - Meshes
- Storage
 - SANs with spinning disks will replace today's tape
 - SANs with SSDs might exist, replacing today's spinning disk SANs
 - SSDs might exist at every node

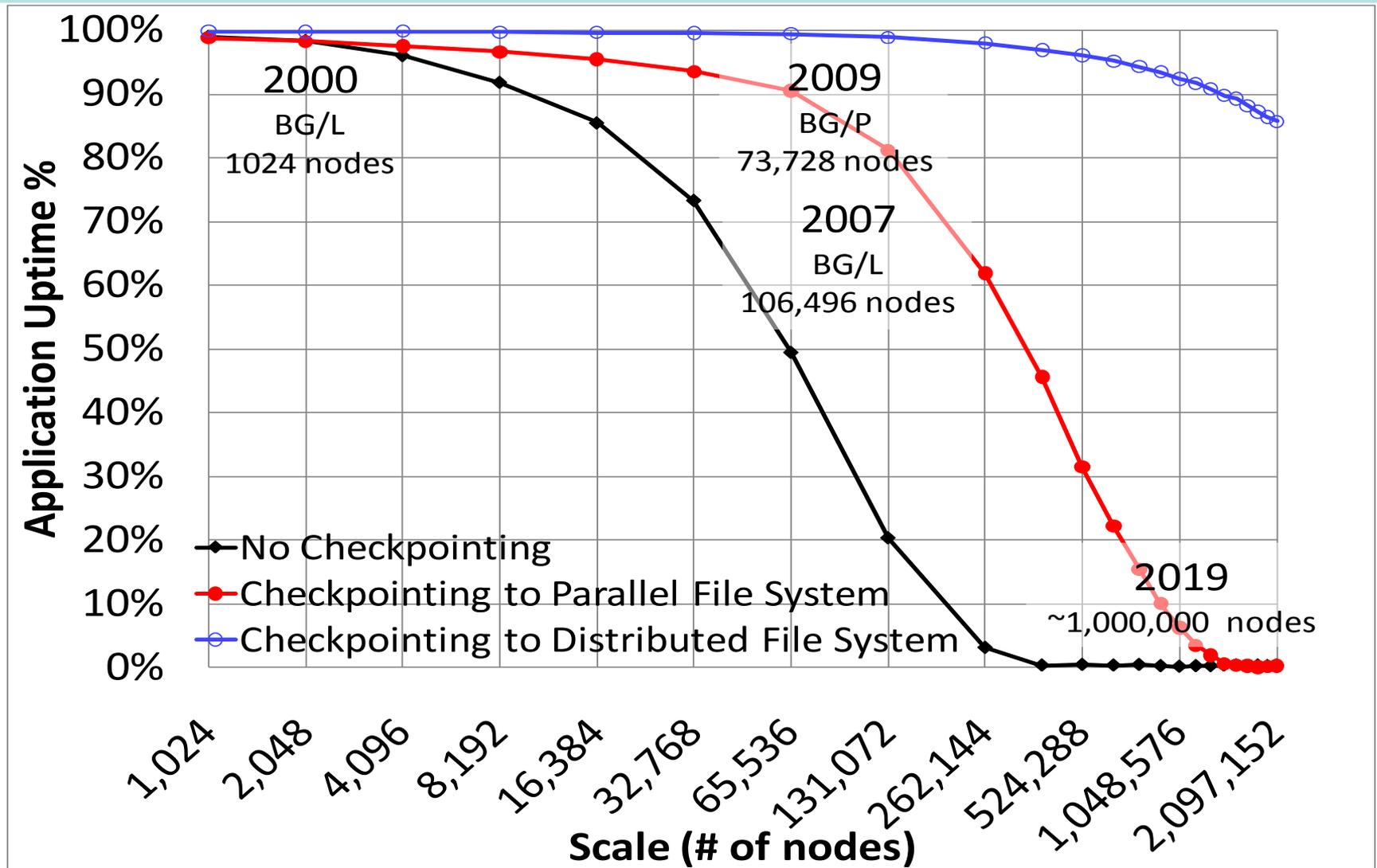
Some Challenges to Overcome at Exascale Computing

- Programming paradigms
 - HPC is dominated by MPI today
 - Will MPI scale another 4 orders of magnitude?
 - MTC has better scaling properties (due to its asynchronous nature)
- Network topology must be used in job management, data management, compilers, etc
- Storage systems will need to become more distributed to scale

Expected checkpointing cost and MTTF towards exascale



Simulation application uptime towards exascale



HEC FSIO 2008 Workshop Report

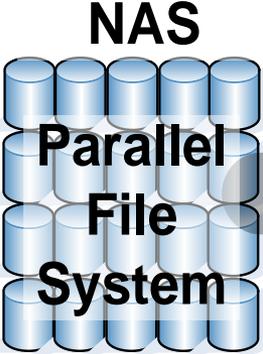
Data path today is the same as the data path 20 years ago. There is a need for new technologies that will offer greater scalability for file system metadata... Novel approaches to I/O and file systems also need to be explored including redistribution of intelligence, user space file systems, data-aware file systems, and the use of novel storage devices... Most, if not all progress to date in parallel file systems in HEC has been evolutionary; what is lacking is revolutionary research; no fundamental solutions are being proposed. Revolutionary I/O technologies developments (both software and hardware) are needed to address the growing technology gap.

Research Directions

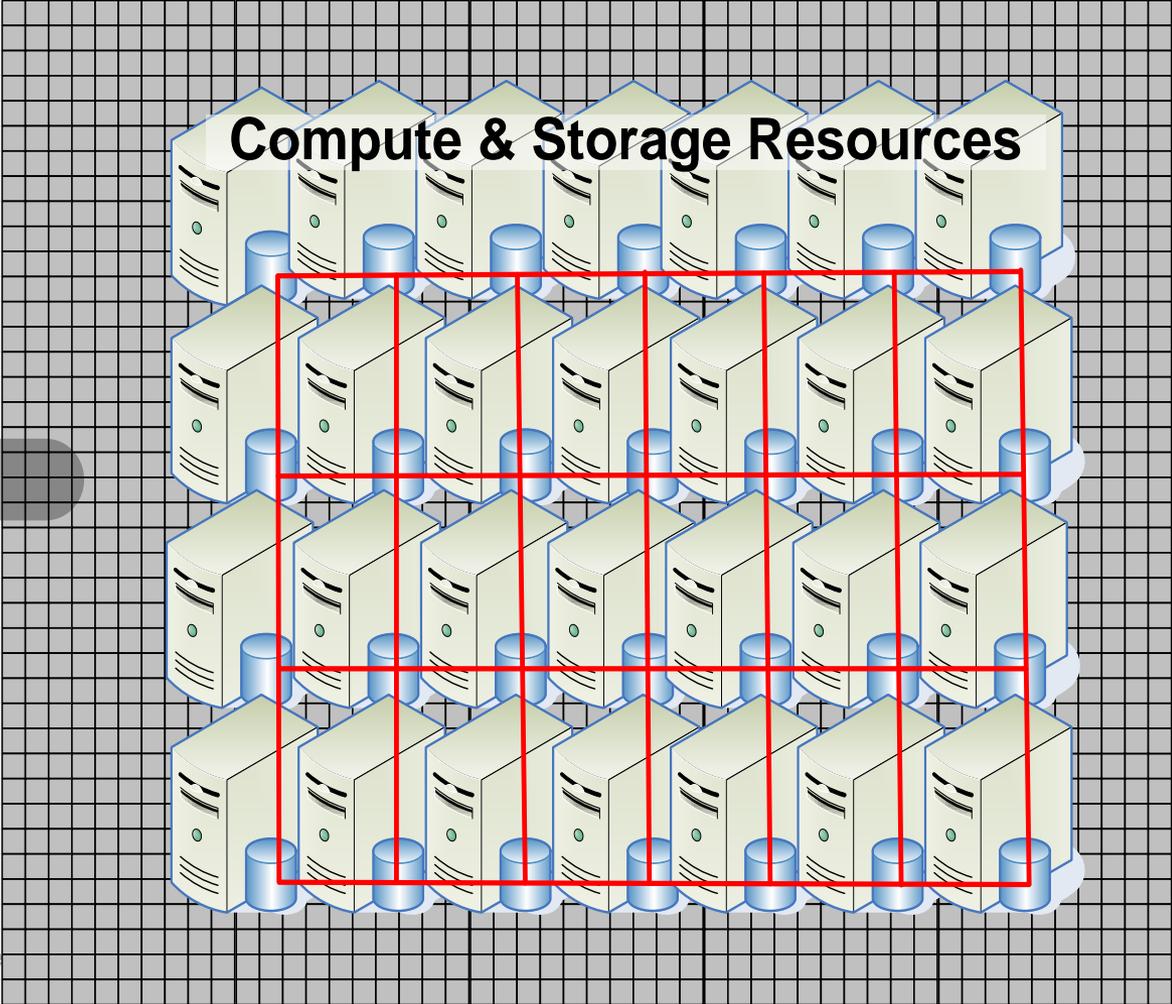
- ***Decentralization is critical***
 - Computational resource management (e.g. LRMs)
 - Storage systems (e.g. parallel file systems)
- ***Data locality must be maximized, while preserving I/O interfaces***
 - POSIX I/O on shared/parallel file systems ignore locality
 - Data-aware scheduling coupled with distributed file systems that expose locality is the key to scalability over the next decade

Storage System Architecture

Network Fabric



Network Link(s)



FusionFS: Fusion Distributed File System

- ***Building on my own research (e.g. data-diffusion), parallel file systems (PVFS), and distributed file systems (e.g. GFS) → FusionFS, a distributed file system for HEC***
 - It should complement parallel file systems, not replace them
- **Critical issues:**
 - Must mimic parallel file systems interfaces and features in order to get wide adoption (e.g. POSIX)
 - Must handle some workloads currently run on parallel file systems significantly better

FusionFS: Access Patterns

- **1-many read** (all processes read the same file and are not modified)
- **many-many read/write** (each process read/write to a unique file)
- **write-once read-many** (files are not modified after it is written)
- **append-only** (files can only be modified by appending at the end of files)
- **metadata** (metadata is created, modified, and/or destroyed at a high rate).

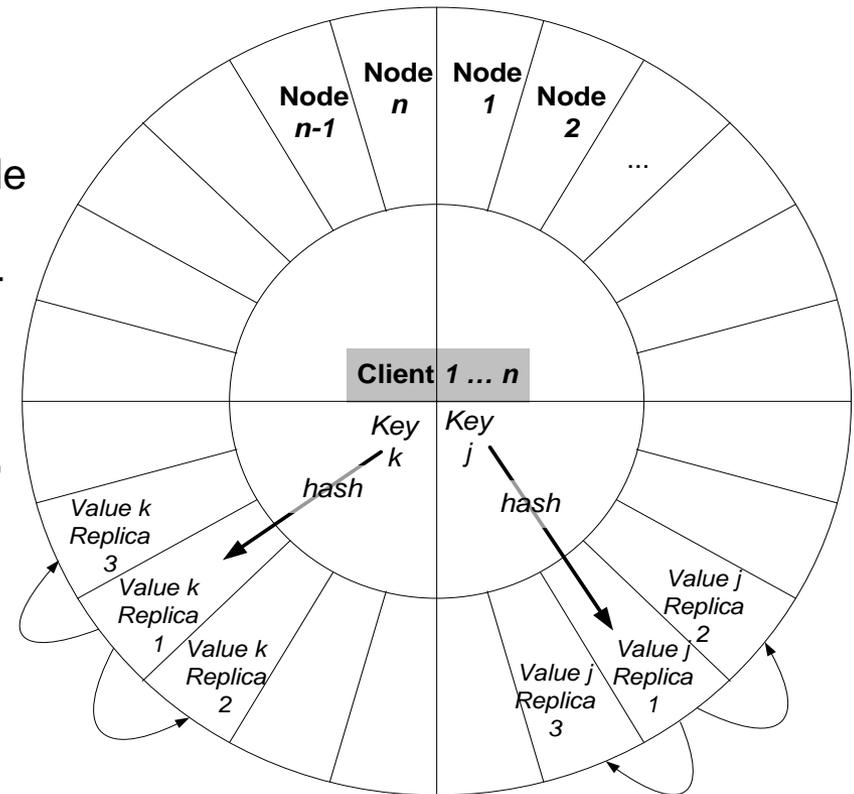
FusionFS: Usage Scenarios

- **machine boot-up** (e.g. reading OS image on all nodes)
- **application loading** (e.g. reading scripts, binaries, and libraries on all nodes/processes)
- **common user data loading** (e.g. reading a common read-only database on all nodes/processes)
- **checkpointing** (e.g. writing unique files per node/process)
- **log writing** (writing unique files per node/process)
- **many-task computing** (each process reads some files, unique or shared, and each process writes unique files)

ZHT:

Zero Hop Distributed Hash Table

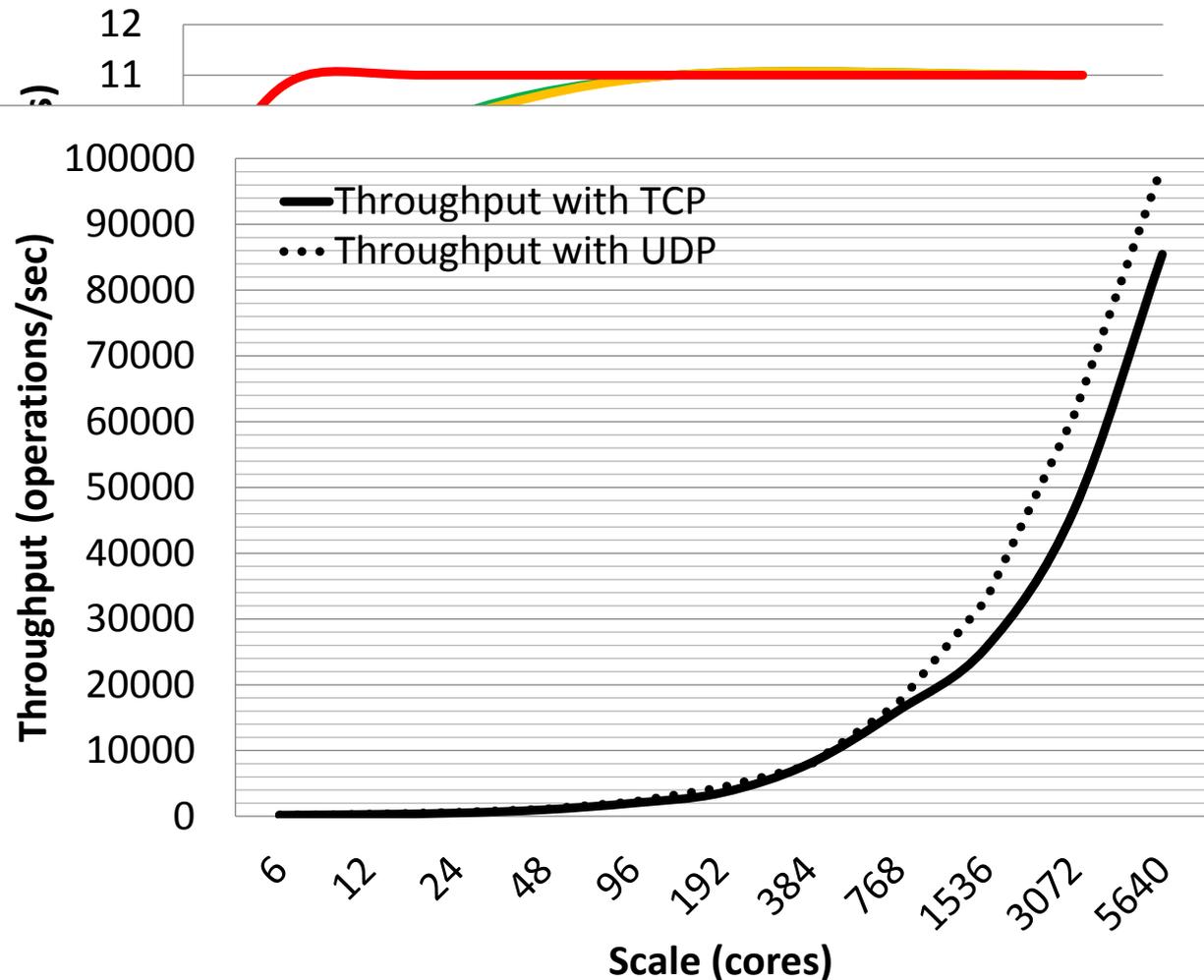
- Simplified distributed hash table tuned for the specific requirements of HEC
- Emphasized key features of HEC are:
 - Trustworthy/reliable hardware, fast network interconnects, non-existent node "churn", the requirement for low latencies, and scientific computing data-access patterns
- Primary goals:
 - Excellent availability and fault tolerance, with low latencies
- ZHT details:
 - Static membership function
 - Network topology aware node ID space
 - Replication and Caching
 - Efficient 1-to-all communication through spanning trees
 - Persistence



ZHT Prototype

Implementation and Performance

- C++/Linux
- Simple API
 - Insert, Find, Remove
- Communication
 - TCP & UDP
 - Evaluating MPI & BMI
- Hashing functions
 - SuperFastHash, FNVHash, alphaNumHash, BobJenkins, SDBM, CRC32, OneAtATimeHash
- Leverages other work
 - Google Buffer
 - Kyoto Cabinet



Conclusions

- We MUST depart from traditional HEC architectures and approaches to reach exascales
- Scalable storage will open doors for novel research in programming paradigm shifts (e.g. MTC)
- This work has potential to touch every branch of computing, enabling efficient access, processing, storage, and sharing of valuable scientific data from many disciplines
 - Medicine, astronomy, bioinformatics, chemistry, aeronautics, analytics, economics, and new emerging computational areas in humanities, arts, and education
- Solutions for extreme scale HEC should be applicable to data centers and cloud infrastructures of tomorrow

Main Message

- ***Preserving locality is critical!***
- *Segregating storage from compute resources is **BAD***
- *Parallel file systems + distributed file systems + distributed hash tables + nonvolatile memory*
→ new storage architecture for extreme-scale HEC
- *Co-locating storage and compute is **GOOD***
 - *Leverage the abundance of processing power, bisection bandwidth, and local I/O*

Teaching

- **Master Of Computer Science With a Specialization in Distributed and Cloud Computing**
 - http://www.iit.edu/csl/cs/programs/grad/mcs_dcc.shtml
- **Relevant Future Courses**
 - Spring 2012: **Cloud Computing (CS553)**
 - <http://www.cs.iit.edu/~iraicu/teaching/CS553-S12/>
 - Fall 2012: **Advanced Operating Systems (CS550)**

Recent Relevant Workshops

- **IEEE MTAGS 2011:** IEEE/ACM Workshop on Many-Task Computing on Grids and Supercomputers, co-located with IEEE/ACM Supercomputing
 - <http://datasys.cs.iit.edu/events/MTAGS11/index.html>
 - <http://datasys.cs.iit.edu/events/MTAGS10/index.html>
 - <http://datasys.cs.iit.edu/events/MTAGS09/index.html>
 - <http://datasys.cs.iit.edu/events/MTAGS08/index.html>
- **IEEE DataCloud-SC11 2011:** IEEE/ACM Workshop on Data Intensive Computing in the Clouds, co-located with IEEE/ACM Supercomputing and IEEE IPDPS
 - <http://datasys.cs.iit.edu/events/DataCloud-SC11/index.html>
 - <http://www.cse.buffalo.edu/faculty/tkosar/datacloud2011/>
- **ACM ScienceCloud 2011:** Workshop on Scientific Cloud Computing, co-located with ACM HPDC
 - <http://datasys.cs.iit.edu/events/ScienceCloud2011/>
 - <http://datasys.cs.iit.edu/events/ScienceCloud2010/>

Recent Relevant Journals

- **Scientific Programming Journal**, Special Issue on Science-driven Cloud Computing, Volume 19, Number 2-3 / 2011
 - SI: http://datasys.cs.iit.edu/events/SPJ_ScienceCloud_2011/
 - Table of Contents: <http://iospress.metapress.com/content/n561462255r3/>
 - Editorial: <http://iospress.metapress.com/content/d421756381083576/fulltext.pdf>
- **IEEE Transactions on Parallel and Distributed Systems**, Special Issue on Many-Task Computing, June 2011; vol. 22 no. 6
 - SI: http://datasys.cs.iit.edu/events/TPDS_MTC/
 - Table of Contents: <http://www.computer.org/portal/web/csdl/abs/trans/td/2011/06/ttd201106toc.htm>
 - Editorial: <http://www.computer.org/portal/web/csdl/abs/html/trans/td/2011/06/ttd2011060897.htm>
- **JGC: Springer Journal of Grid Computing**, Special Issue on Data Intensive Computing in the Clouds, to appear in 2012
 - SI: <http://datasys.cs.iit.edu/events/JGC-DataCloud-2012/index.html>

Relevant Conferences

- IEEE/ACM Grid 2011
- IEEE/ACM SC 2011
- ACM HPDC 2012
- IEEE eScience 2012
- IEEE/ACM CCGrid 2012
- USENIX OSDI
- USENIX NSDI
- IEEE CLOUD
- IEEE CloudCom

More Information

- More information:
 - <http://www.cs.iit.edu/~iraicu/>
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- Questions?