I/O Threads to Reduce Checkpoint Blocking for an EM Solver on Blue Gene/P and Cray XK6

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June 29, 2012

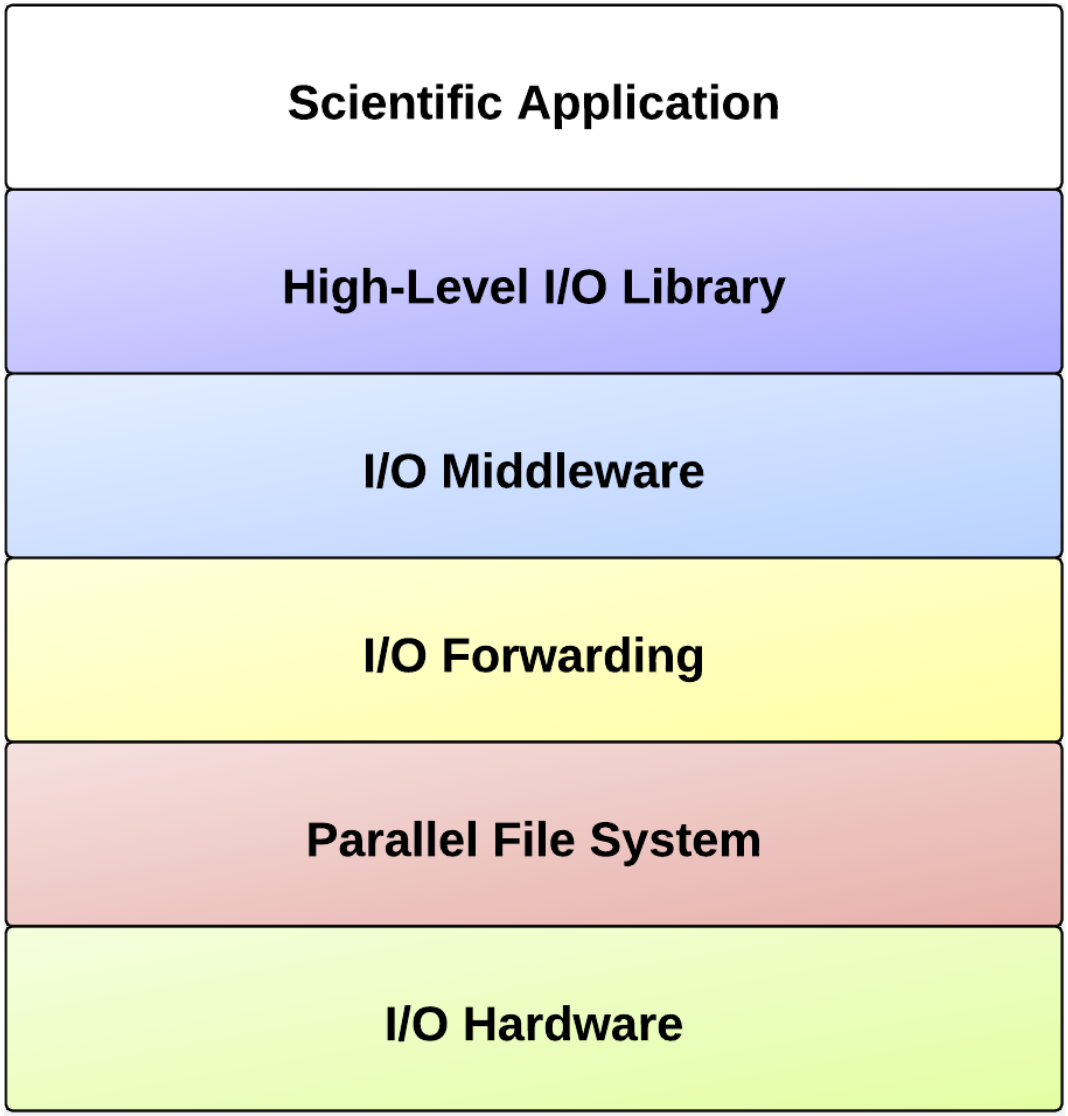
Presentation Outline

- **Introduction**
- **Approaches**
- **Performance and Analysis**
- **Summary**

Solver systems and checkpointing

- *Parallel Partitioned Solver Systems* are being applied to tackle hard problems in science & engineering, e.g. *PHASTA* (CFD), *Nek5000* (CFD), *NekCEM* (CEM)
- These applications scale well on massively parallel platforms (strong scaling on 100,000s of cores)
- Traditional I/O doesn't scale as well, may suffer at large scale
- In this talk, we focus on the use of I/O threads for an EM solver (NekCEM) checkpoint on BG/P and Cray XK6

I/O software stack of a typical HPC system



Bursty I/O

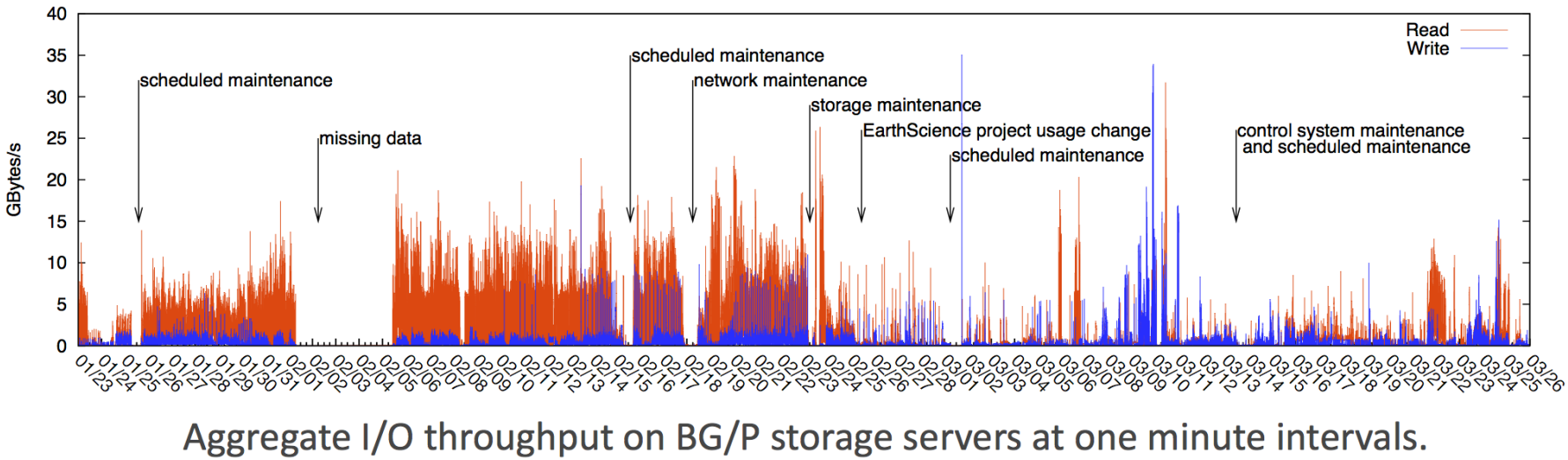


Figure: I/O workload in ANL, image courtesy of Rob Ross

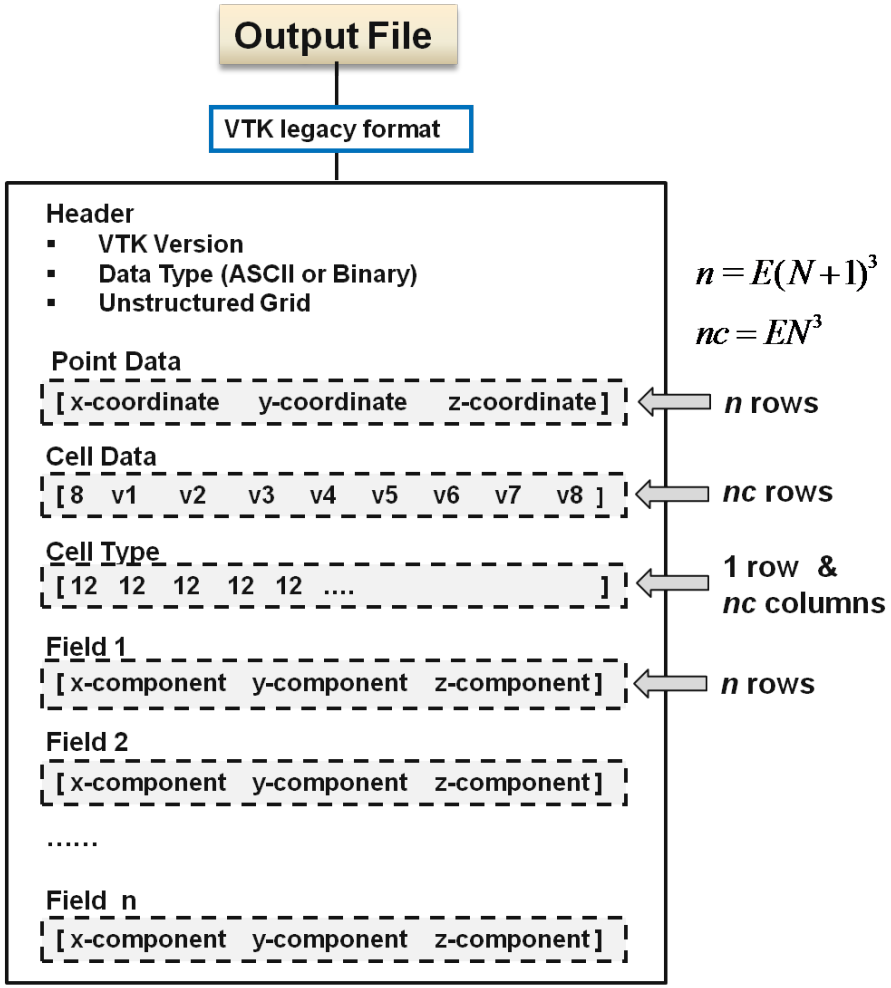
- Pattern: X steps comp. $\rightarrow$ checkpoint $\rightarrow$ X steps comp. ...
- Core assumption: **synchronized** writes among all processors (lack of well-supported asynchronous I/O on supercomputers)

Checkpoint File Structure

File Body

Header:	part 0, field 0
Data:	part 0, field 0
Header:	part 1, field 0
Data:	part 1, field 0
Header:	part 2, field 0
Data:	part 2, field 0
Header:	part 3, field 0
Data:	part 3, field 0
Header:	part 0, field 1
Data:	part 0, field 1
Header:	part 1, field 1
Data:	part 1, field 1
Header:	part 2, field 1
Data:	part 2, field 1
Header:	part 3, field 1
Data:	part 3, field 1

(a) Typical File Structure



(b) NekCEM File Structure

Related Work and Our Objective

Related Work

- Scalable Checkpoint/Restart, Lawrence Livermore National Lab
- ADaptable IO System, Oak Ridge National Lab
- I/O Delegate Cache System, Northwestern University

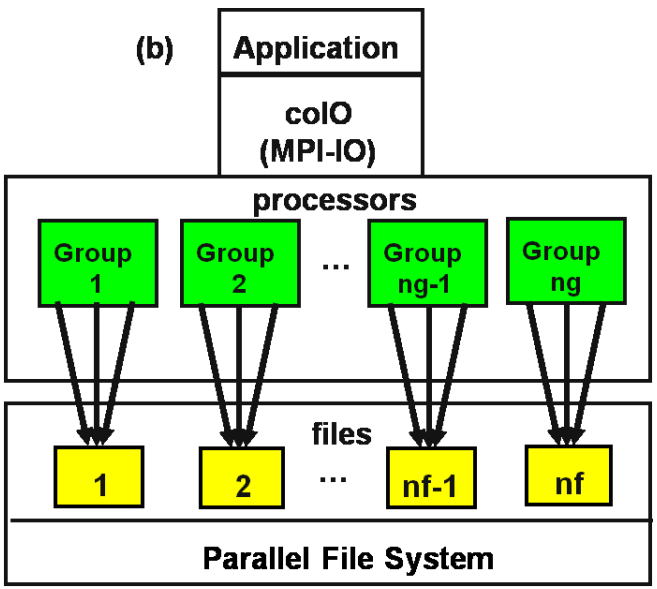
Design Factors

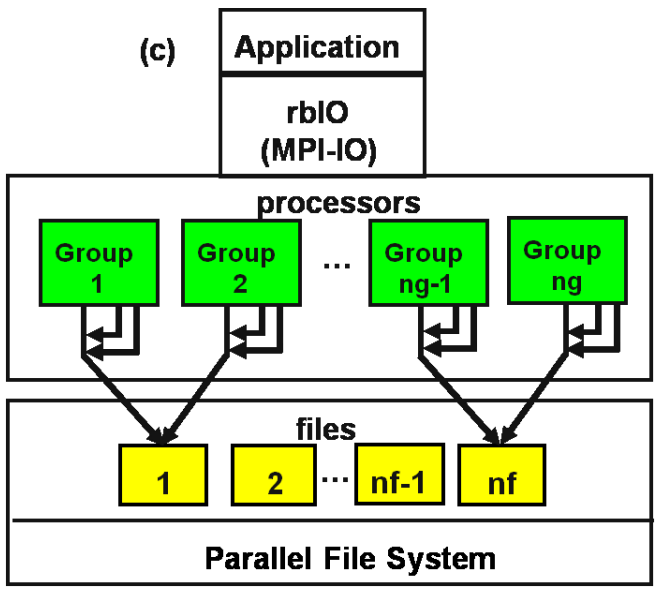
- design space; platform dependency; application transparency

Our Objective

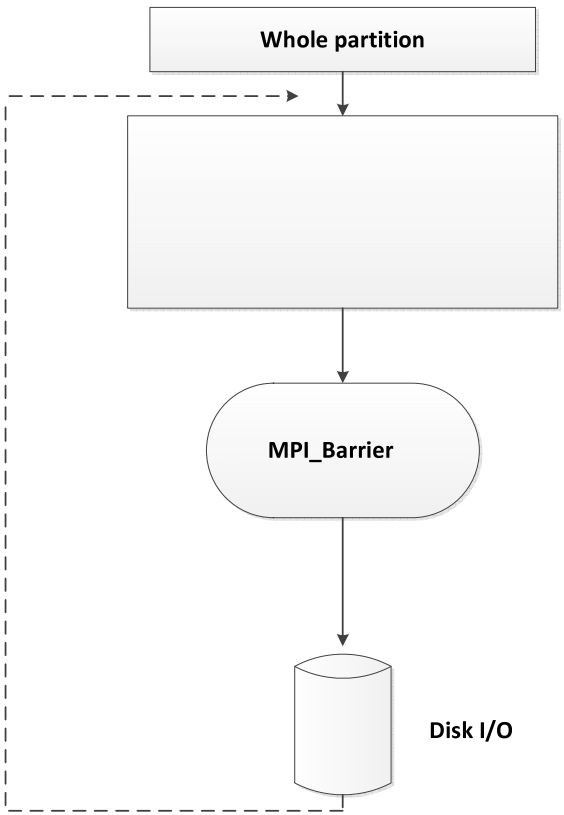
- Goal: performance at scale
- user space, portable, reasonably generic

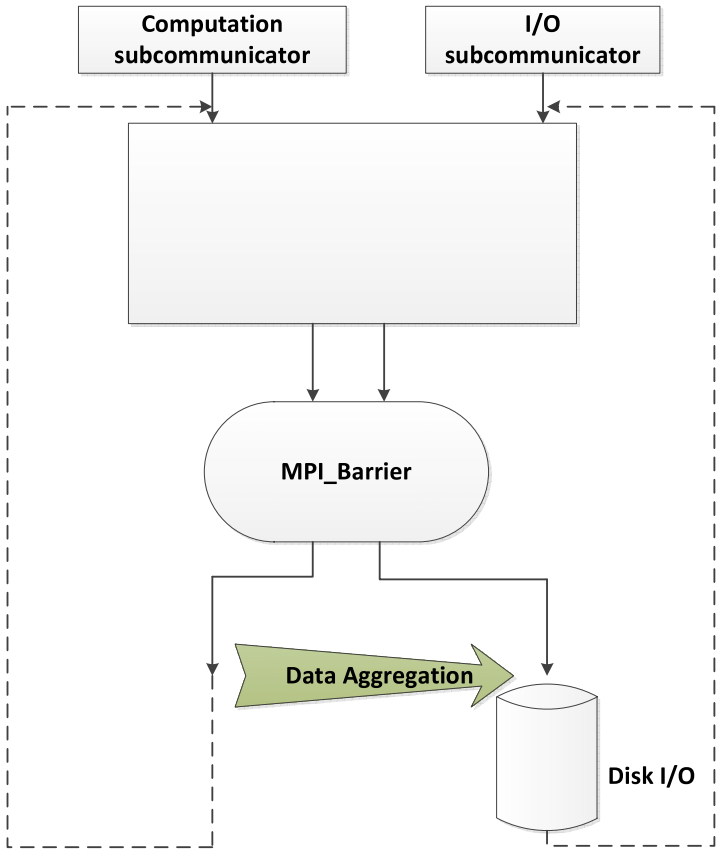
Previous work: from *coIO* to naive *rbIO*





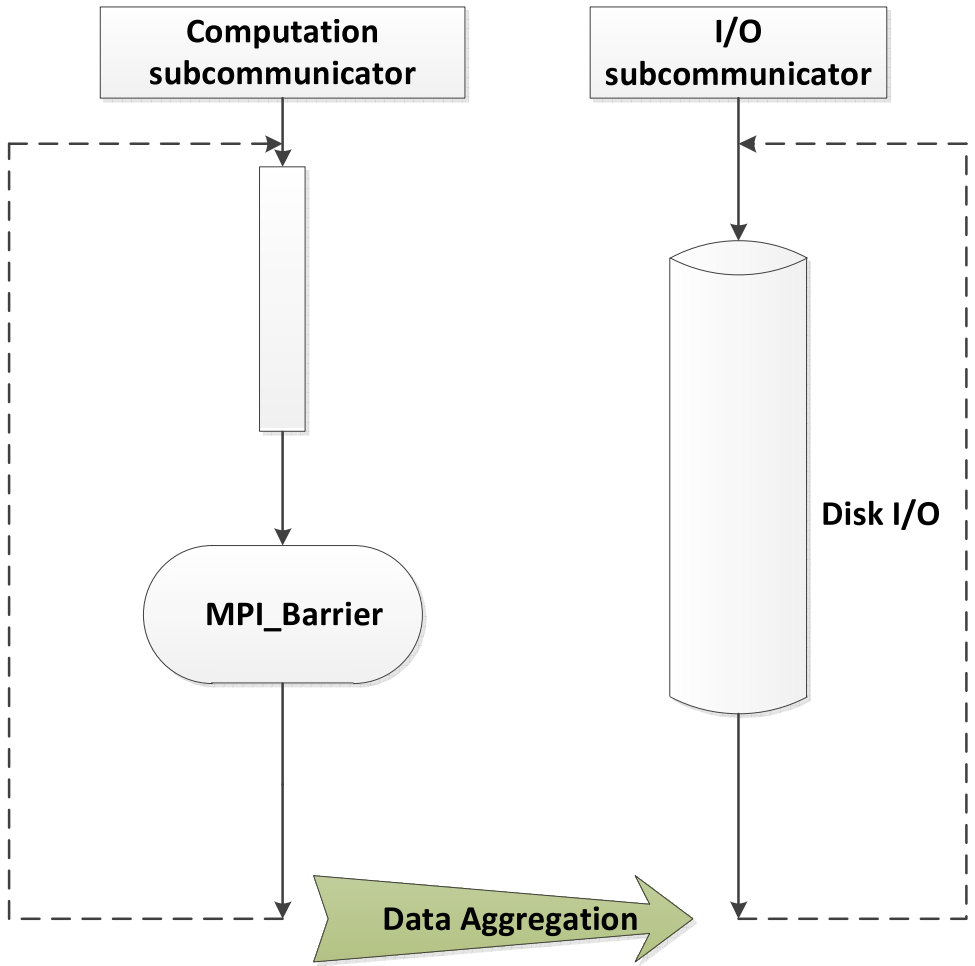
from *coIO* to naive *rbIO*





Method 1: Completely split rbIO

- dedicated I/O writers
- overlap computation and I/O
- lose a small portion of computing resources
- other problems?



Potential limitations with completely split rbIO

- break collective operation optimizations on Blue Gene systems
- collective operations on subcomm go through torus not tree
- 10× slower on torus

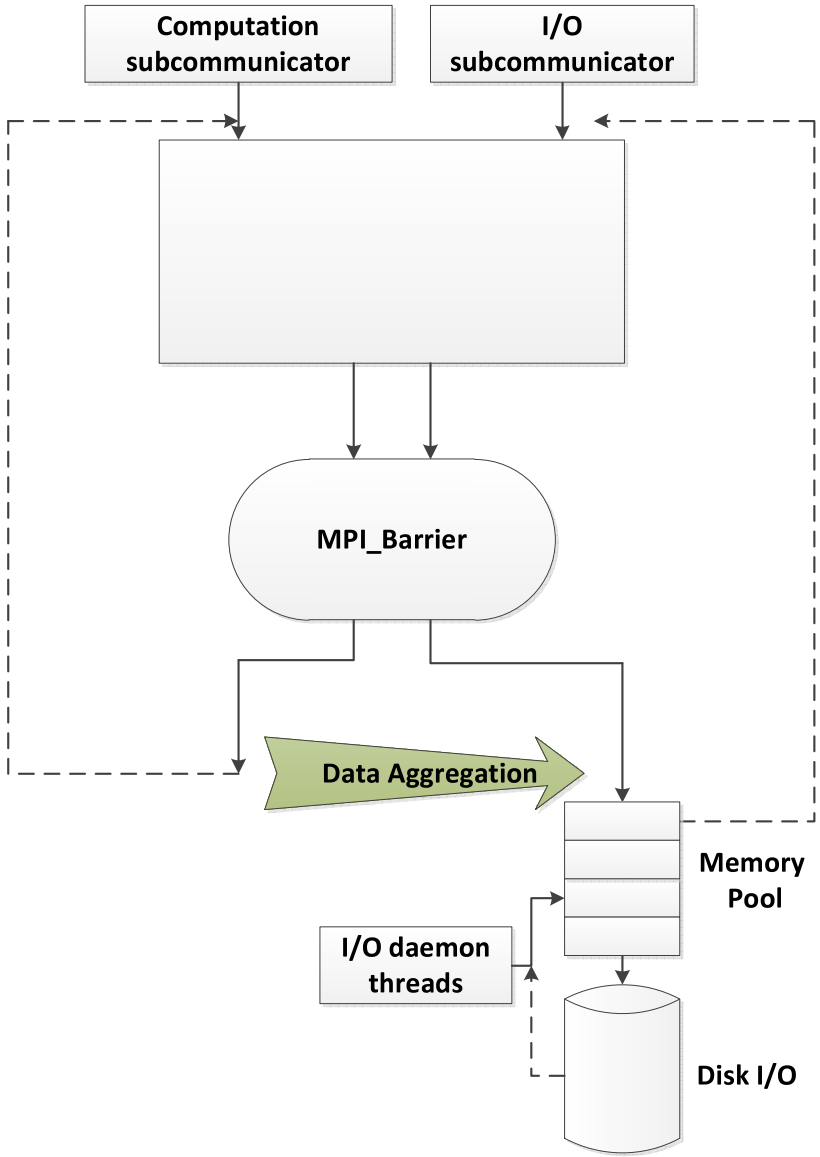
Table: The time (in μs) *MPI_Allreduce* spends on BG/P

#nodes	Time on Tree	Time on Torus	Ratio
4096	7.68	55.65	7.24
8192	7.72	61.88	8.01
16384	8.19	67.66	8.26

- performance impact on applications: 1 - 2% time spent on collective now means 10 -20%
- can be verified by running application with tree network off on BG/P

Method 2: rbIO with I/O daemon threads

- global communicator
- simple control flow
- threading supercomputers?



Potential limitations of threading rbIO

- BG/P has limited threading capability
- default to one, up to three threads per core
- does not support automatic thread switching
- have to use hardware thread in SMP mode
- experiment for demo purpose

- load balancing issue for those that fully support threads, e.g. Cray XK6?

NekCEM I/O on Blue Gene/P

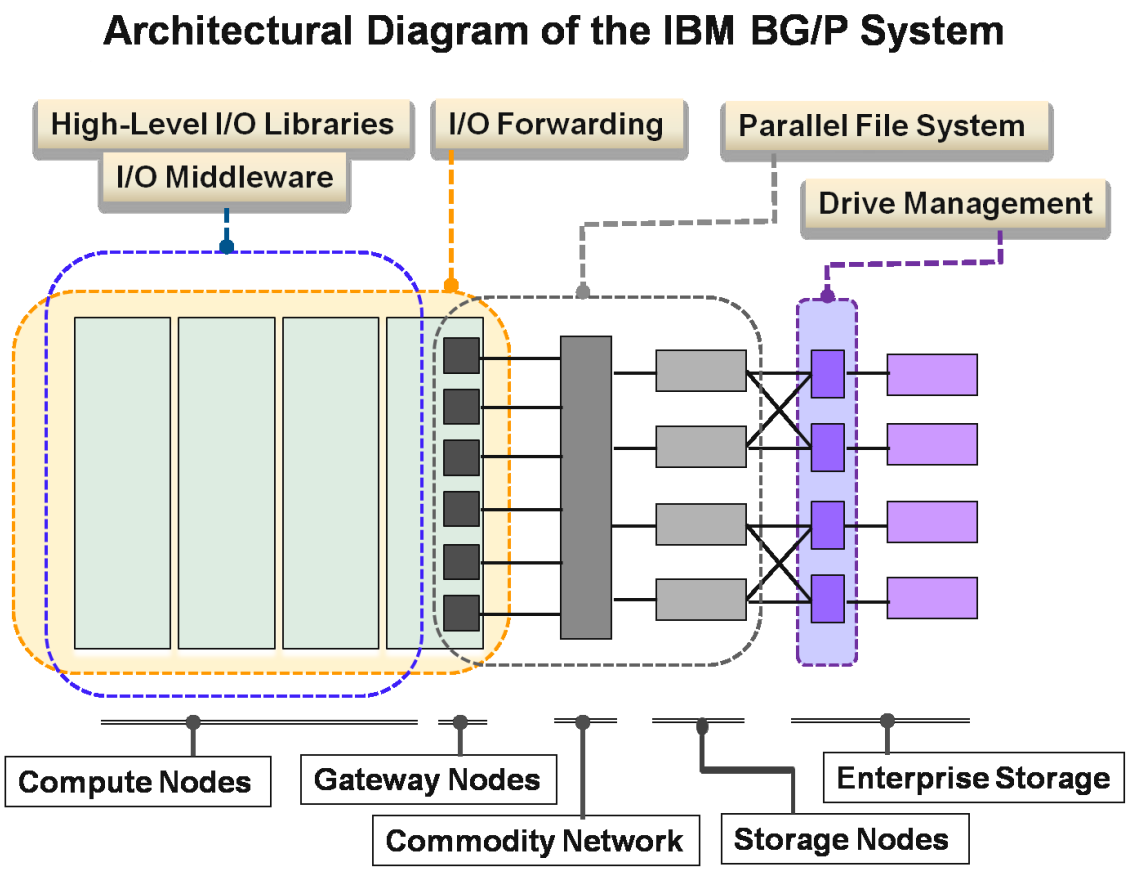
Blue Gene/P Spec

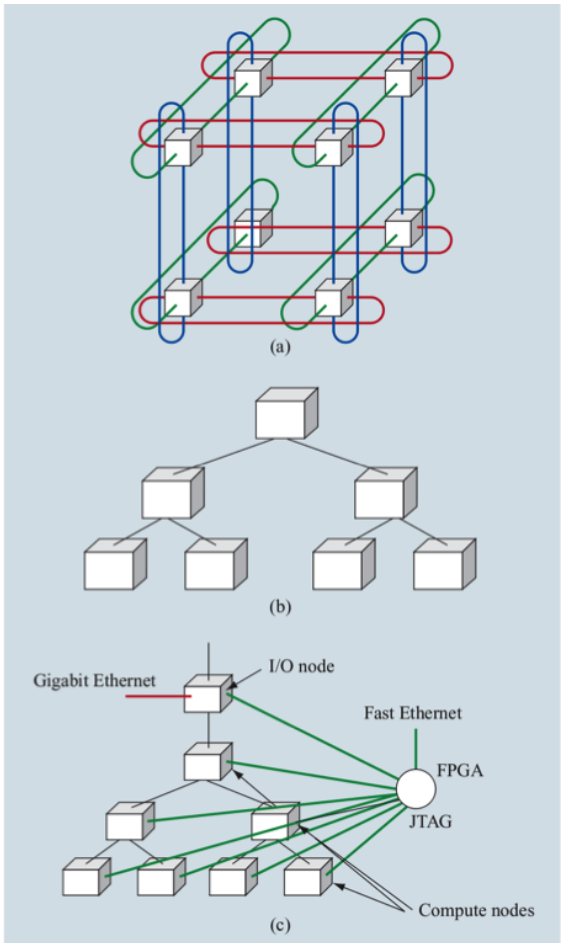
- 163,840 cores, 80 TB RAM, 557 teraflops ("*Intrepid*"@ANL)
- GPFS/PVFS, 128 file servers connected to 16 DDN 9900, 10 PB
- pset (1 ION to 64 4-core CN), 640 ION to 128 file servers by 10GB/s Myricom switch
- 4MB block size, read peak 60 GB/s, write peak 47 GB/s

Experiment Setup

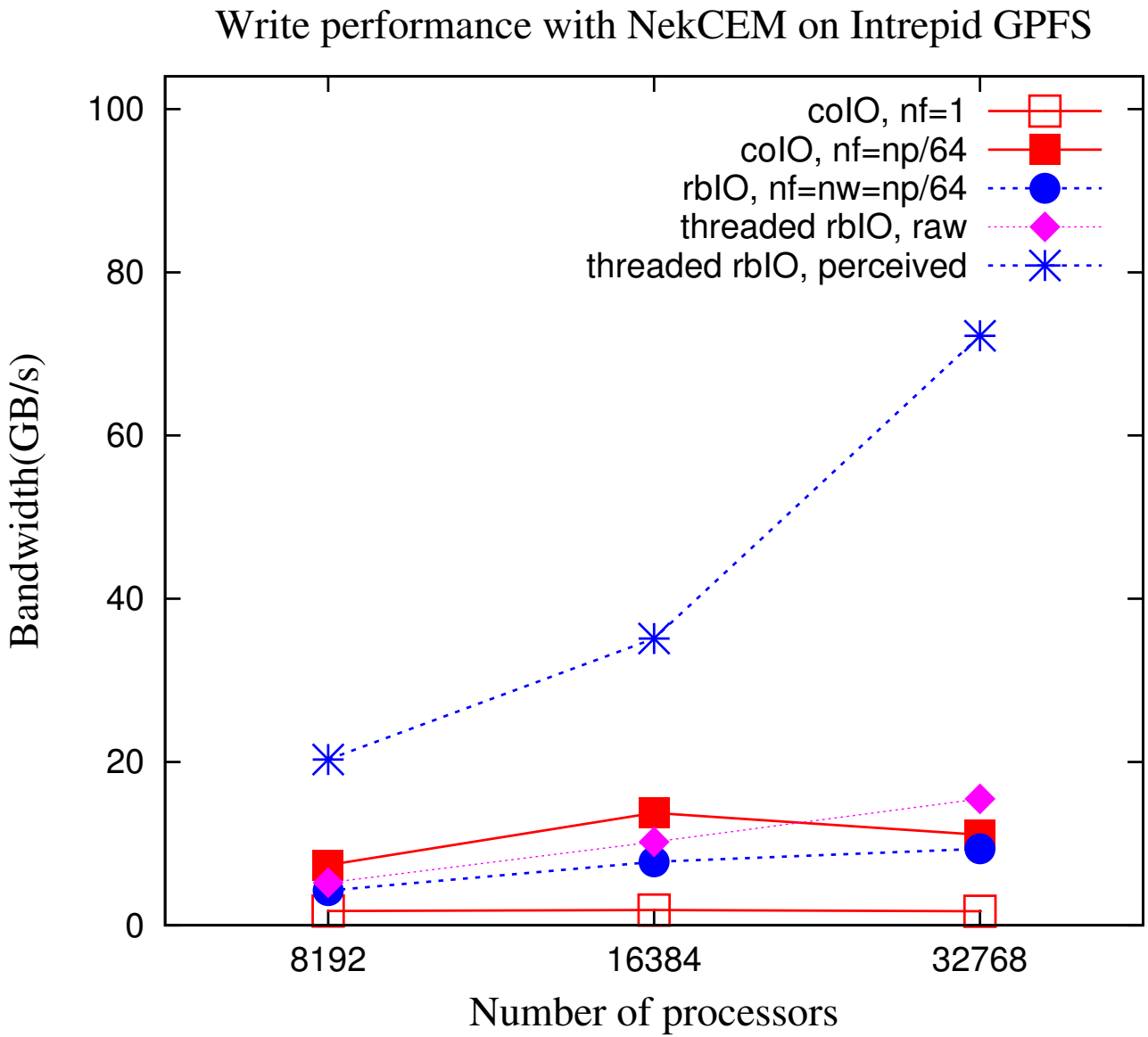
- 3D cylindrical waveguide simulation for different meshes
- (grid points, total size) = {(143M, 13GB), (275M, 26 GB), (550M, 52 GB)}
- Weak scaling tests

Overview of the Blue Gene system

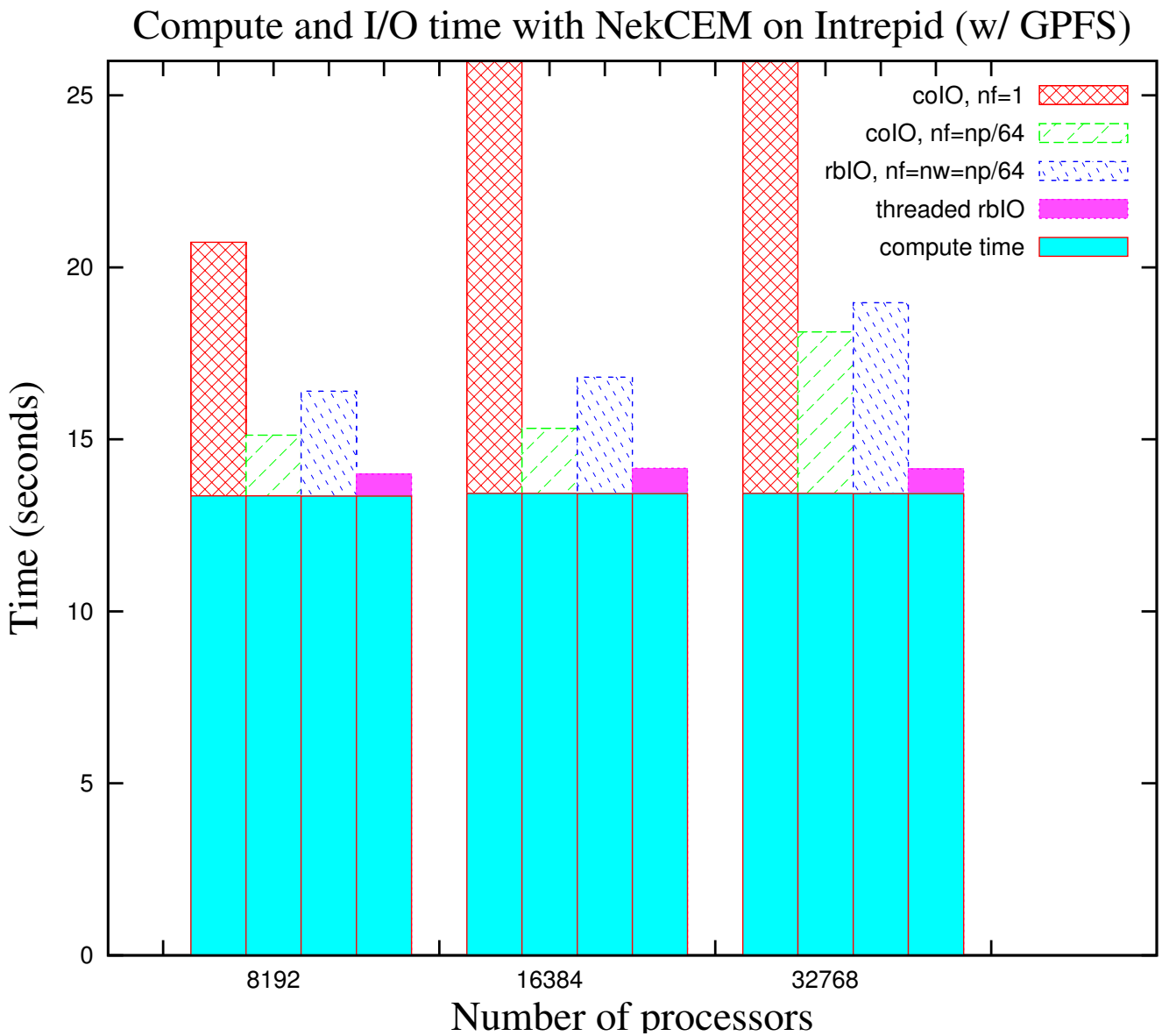




NekCEM I/O on BG/P: *bandwidth*



NekCEM I/O on BG/P: *overall time*



NekCEM I/O on Cray XK6

Cray XK6 Spec

- 299,008 cores (AMD Opteron Interlagos, on Cray Linux microkernel), 598 TB RAM, 2.63 petaflops ("*Jaguar*"@ORNL)
- Lustre, 192 OSS servers to 96 DDN 9900s (7 RAID-6 (8+2)/OSS), 10 PB
- 4MB block size, peak 120 GB/s

Overview of the Cray system

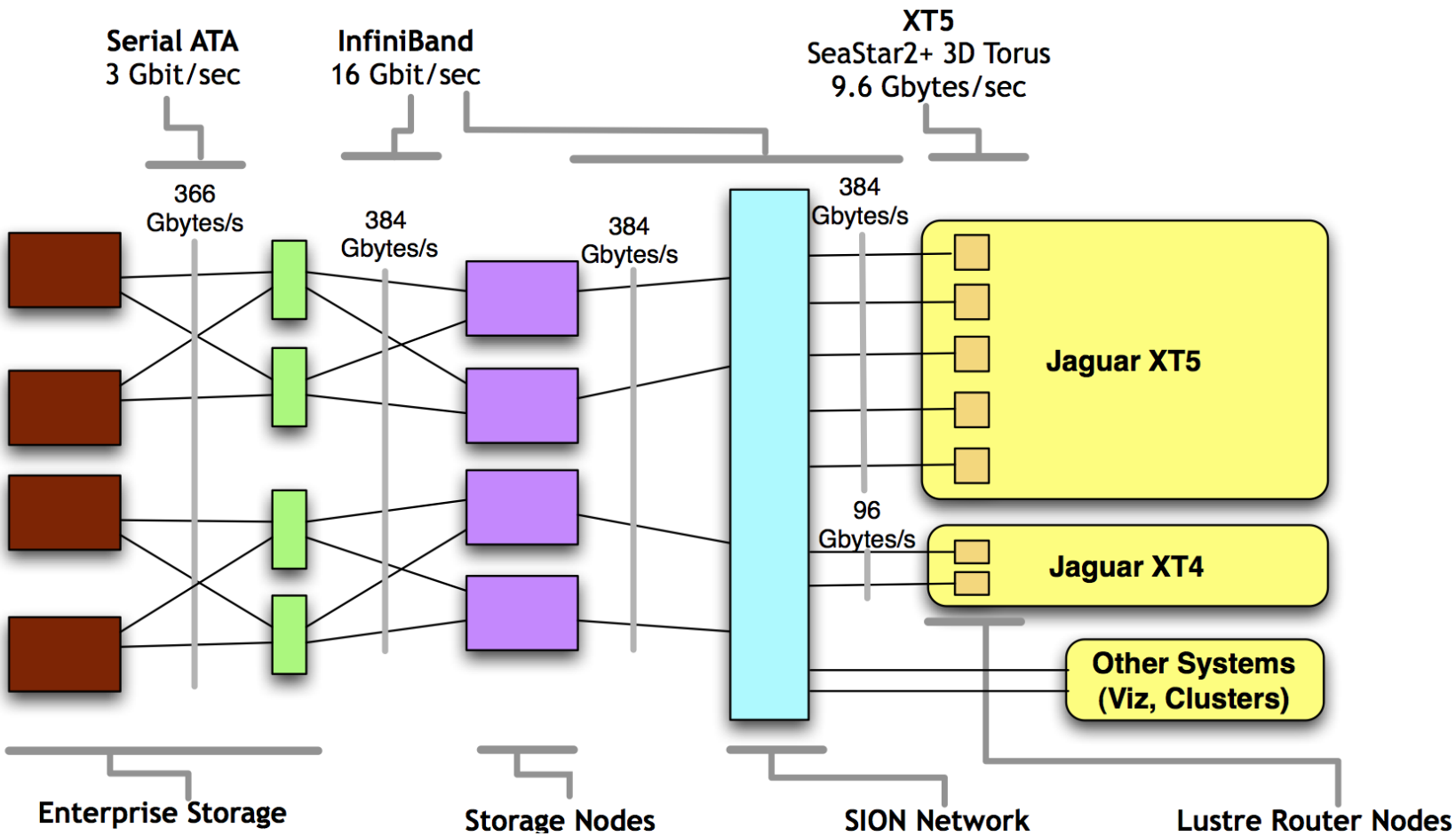
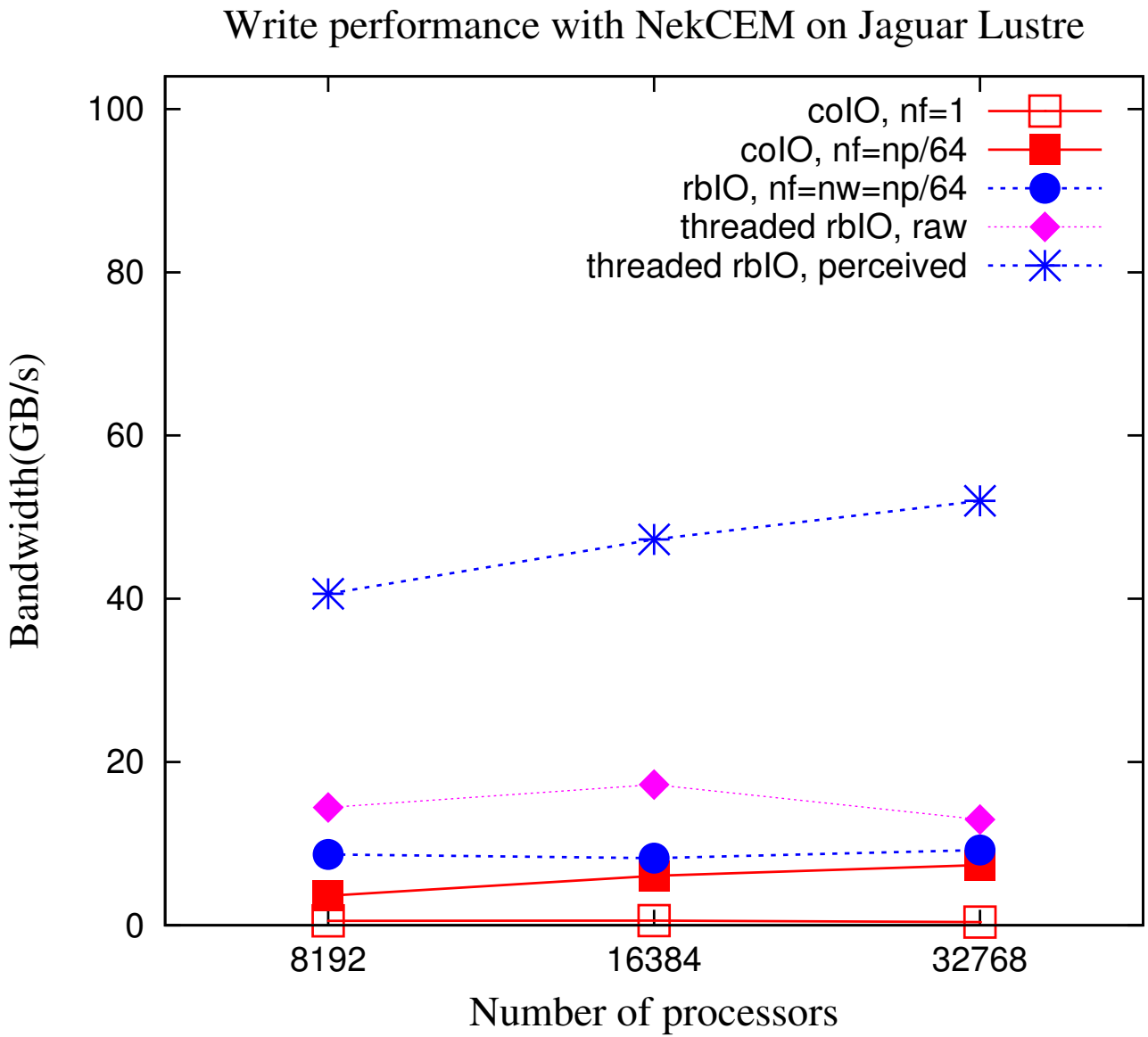
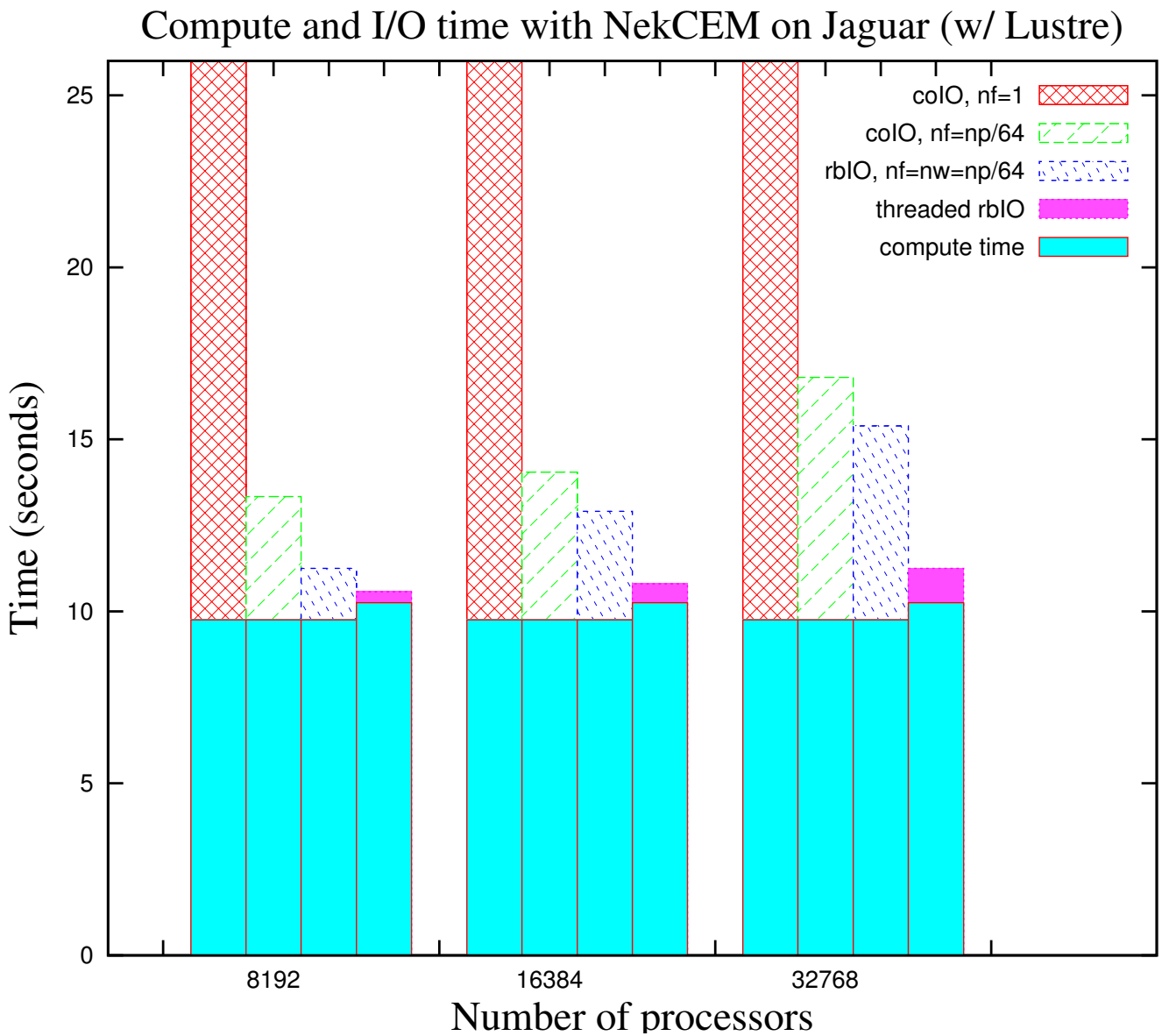


Figure: Architecture diagram of Jaguar@ORNL, image courtesy of Rob Ross

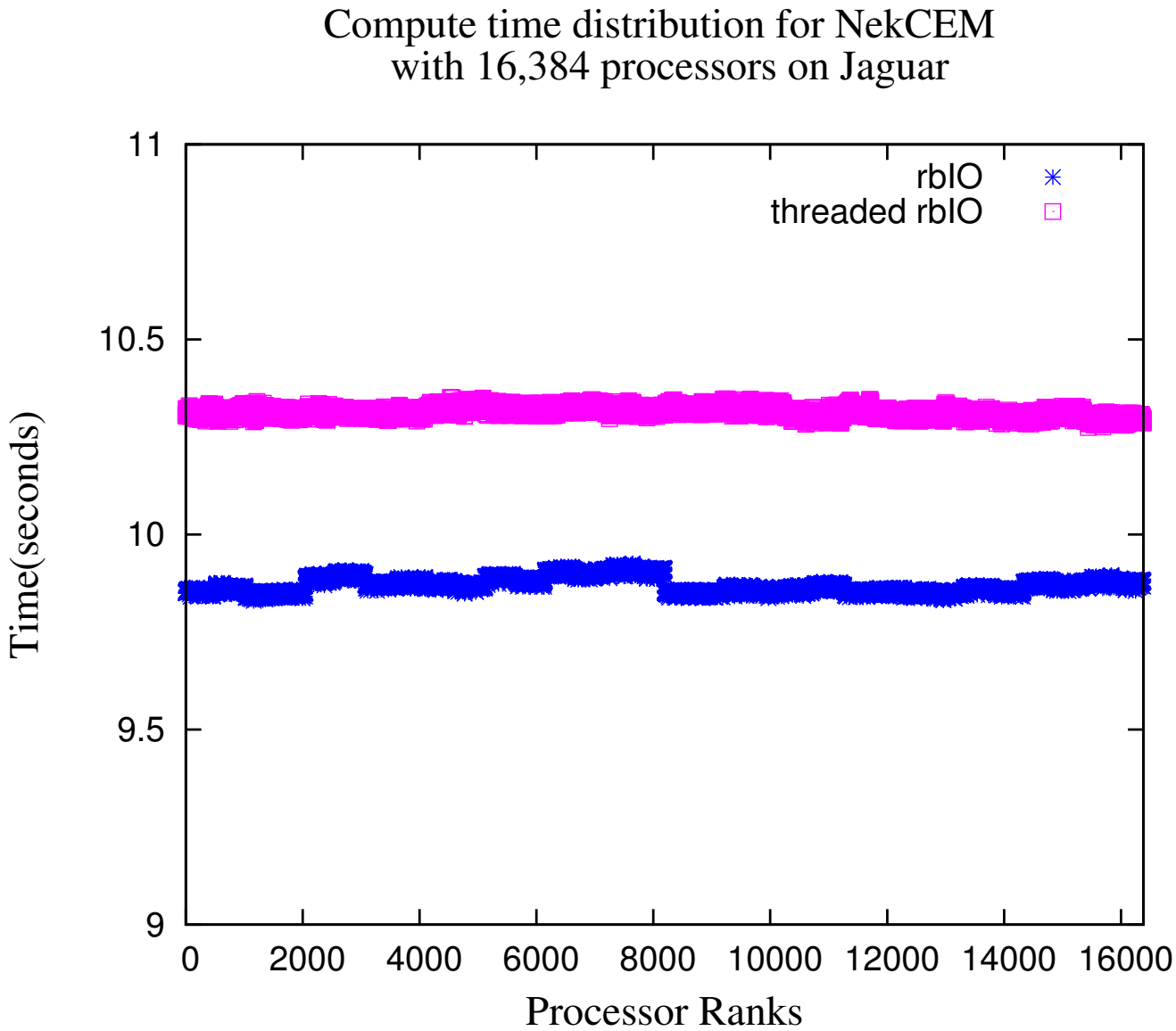
NekCEM I/O on Cray: *bandwidth*



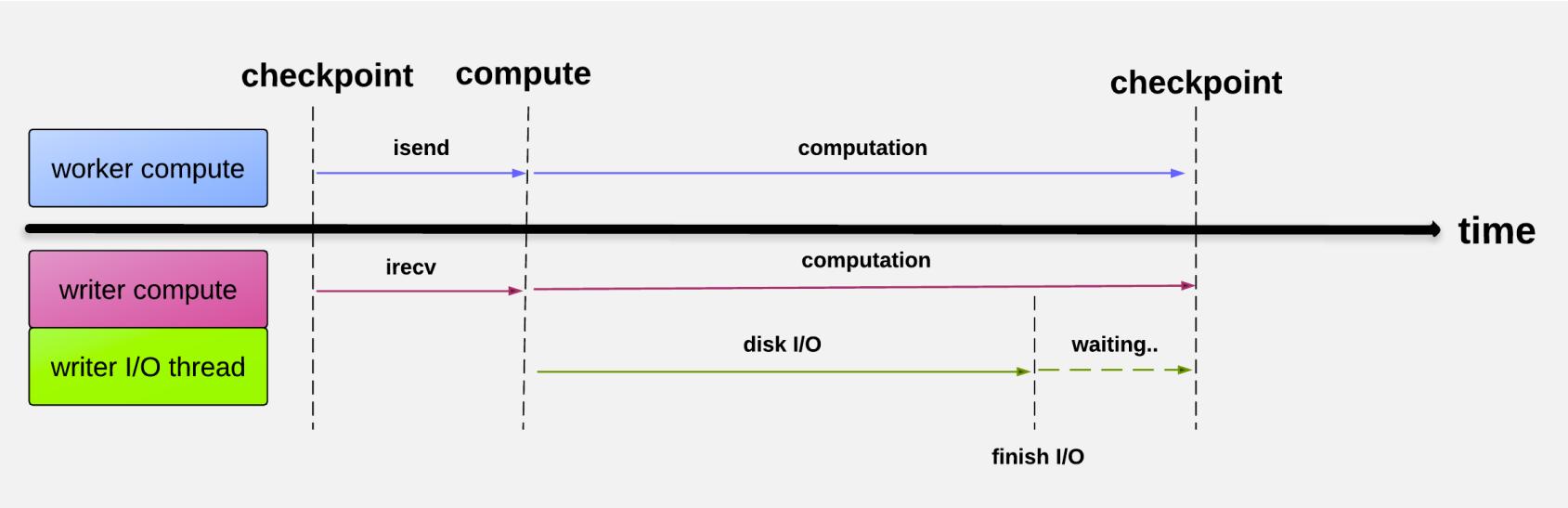
NekCEM I/O on Cray: *overall time*



NekCEM I/O on Cray: *profiling compute time*



NekCEM I/O on Cray: *Threaded rbIO Timing Analysis*



NekCEM I/O on Cray: *Speedup Analysis*

$$
\begin{aligned}
Speedup_{prod} &= \frac{T_{coIO} + T_{comp}^{\text{coIO}}}{T_{trbIO} + T_{comp}^{\text{trbIO}}} \\
&= \frac{X_{coIO} * t_{comp}^{\text{coIO}} + f_{cp} * t_{comp}^{\text{coIO}}}{X_{trbIO} * t_{comp}^{\text{trbIO}} + f_{cp} * t_{comp}^{\text{trbIO}}} \\
&= \frac{X_{coIO} + f_{cp}}{X_{trbIO} + f_{cp}} * \frac{1}{1+\delta},
\end{aligned}
$$

where X is the number of computation steps that a checkpoint time equals to, f_{cp} denotes number of computation steps between two checkpoints, and δ is the overhead of a single step computation with threaded rbIO compared with nonthreaded I/O (i.e., $t_{comp}^{\text{trbIO}} = (1+\delta) * t_{comp}^{\text{coIO}}$).

Roughly 50% speedup on 32K procs Jaguar.

Summary

- Application-transparent optimizations (MPI-IO collective) with good tuning practice can provide decent performance on some platforms
- Application-level optimizations exploit application-specific information and provide tuning options (*nf, ng, I/O thread*) and good performance on most platforms
- Data staging (on RAM, RAM disk, SSD) helps ease out pressure of bursty I/O for file system, trending technique in design of storage system for Exascale era

- What happens on Mira and Blue Waters?

Collaborators

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Questions?