Lecture 22
I/O Performance and Checkpoints

EN 600.320/420/620

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The I/O Crisis in HPC

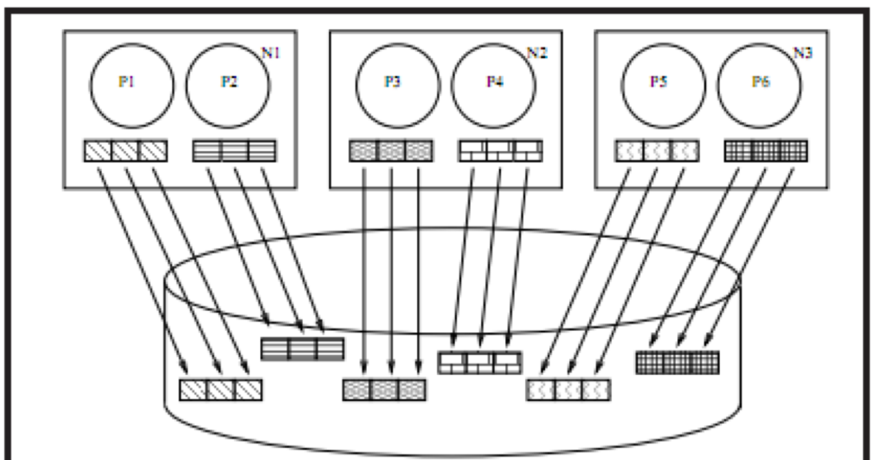
In a world where FLOPS is the commodity…….

…..Disk I/O often limits performance

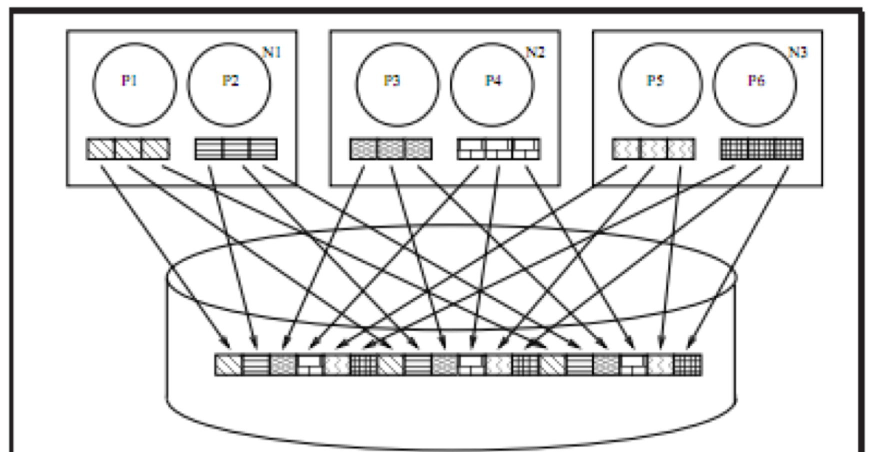
- Any persistent data must make it off the supercomputer
  - To magnetic or solid state storage
- Storage is not as connected to the high-speed network as compute
  - Because it needs to be shared with other computers
  - Because it doesn't add to TOP500 benchmarks

Where does the I/O Come From?

- Checkpointing!
  - And, writing output from simulation (which is checkpointing)
- Checkpoint workload
  - Every node node writes local state to a shared file system
  - Using POSIX calls (FS parallelized) or MPI I/O



(a) N-N



(c) N-1 strided

J. Bent et al. PLFS: A Checkpoint File Systems for Parallel Applications. SC, 2009.

Why Checkpointing

- At scale failures occur inevitably
  - MPI synchronous model means that a failure breaks the code
  - Lose all work since start (or restart)
- Each checkpoint provides a restart point
  - Limits exposure, loss of work to last checkpoint
- By policy, all codes that run at scale on supercomputers MUST checkpoint!
  - HPC centers want codes to do useful work

Checkpoint Approaches

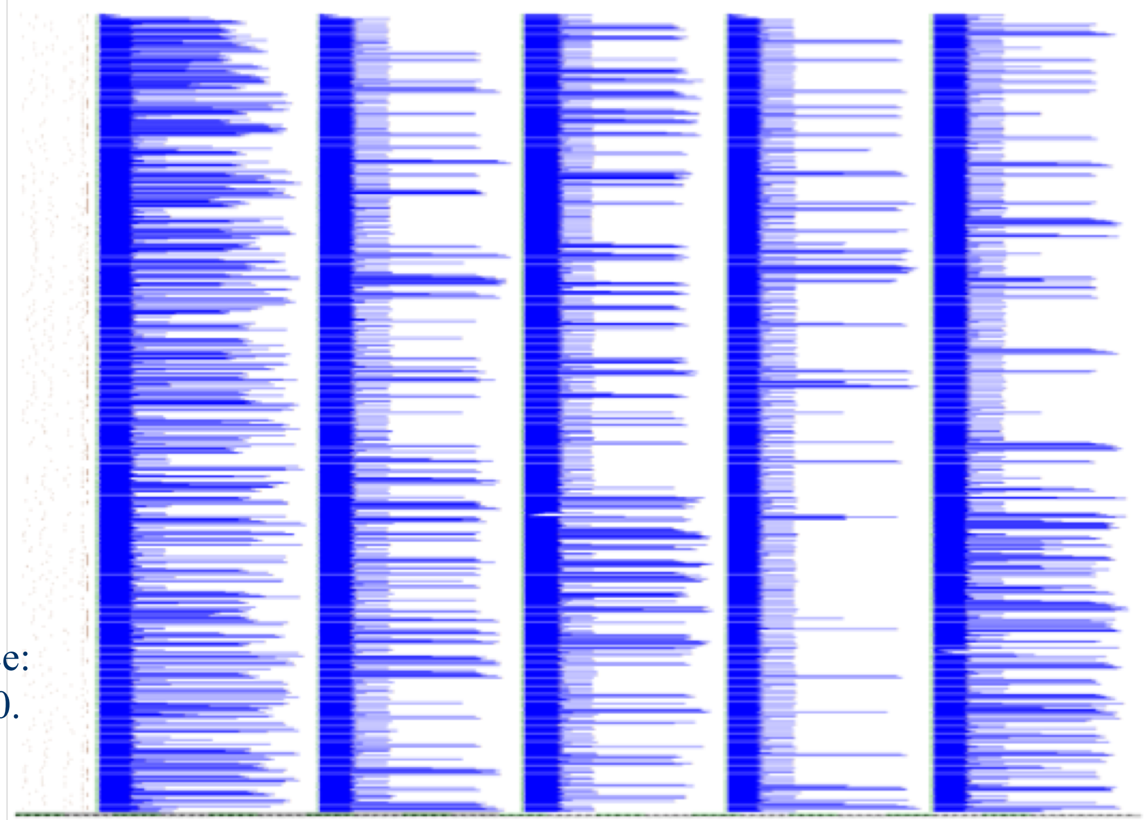
- Automatic: store contents of memory and program counters
  - Brute force, large data, inefficient
  - But easy, no development effort
  - New interest in this approach with the emergence of VMs and containers in HPC.
- Application specific: keep data structures and metadata representing current progress. Hand coded by developer.
  - Smaller, faster, preferred, but tedious.
  - Almost all "good" codes have application specific checkpoints

A Checkpoint Workload

- IOR benchmark
  - Each node transfers 512 MB
- Barriers

- *How much parallelism?*
- *What effects?*

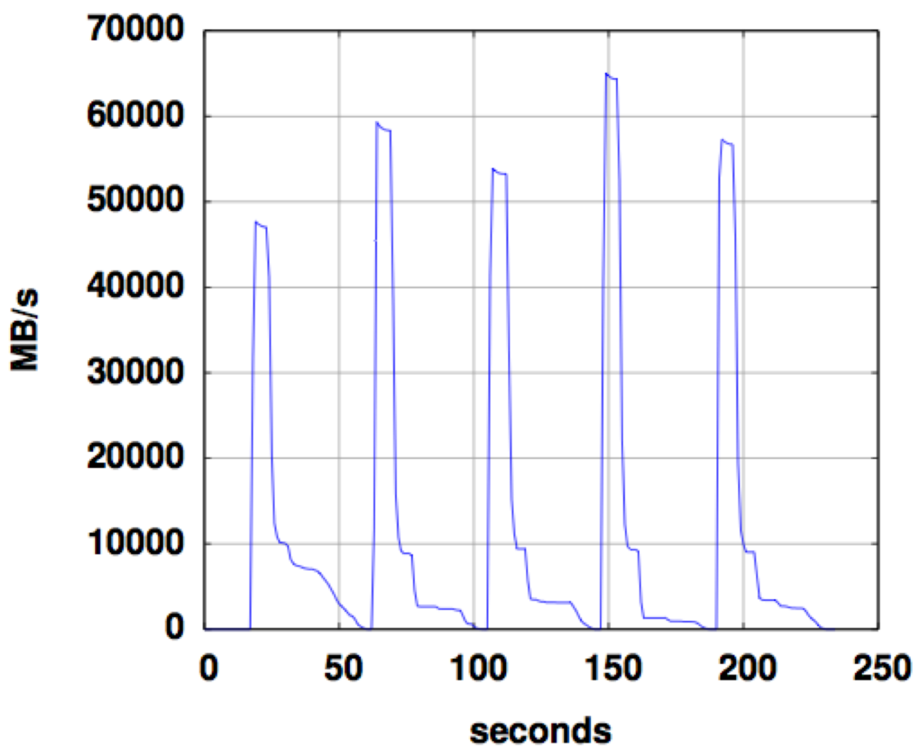
M. Uselton et al. Parallel I/O Performance: From Events to Ensembles. IPDPS, 2010.



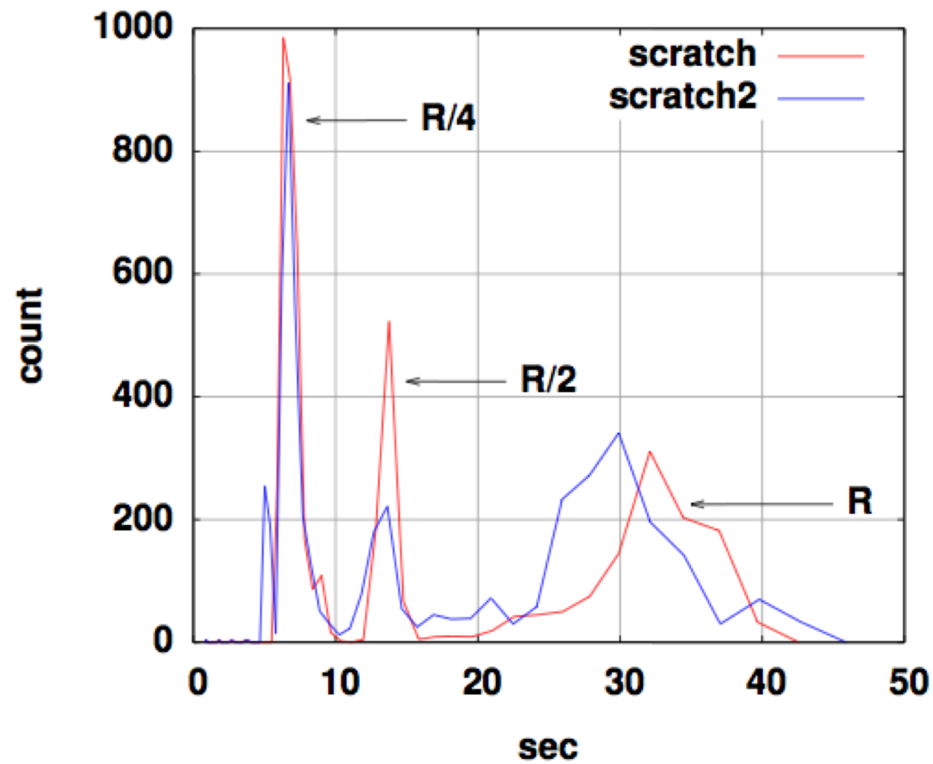
(a) I/O trace diagram

I/O Rates and PDF

- *What features do you observe?*



(b) Aggregate I/O rate

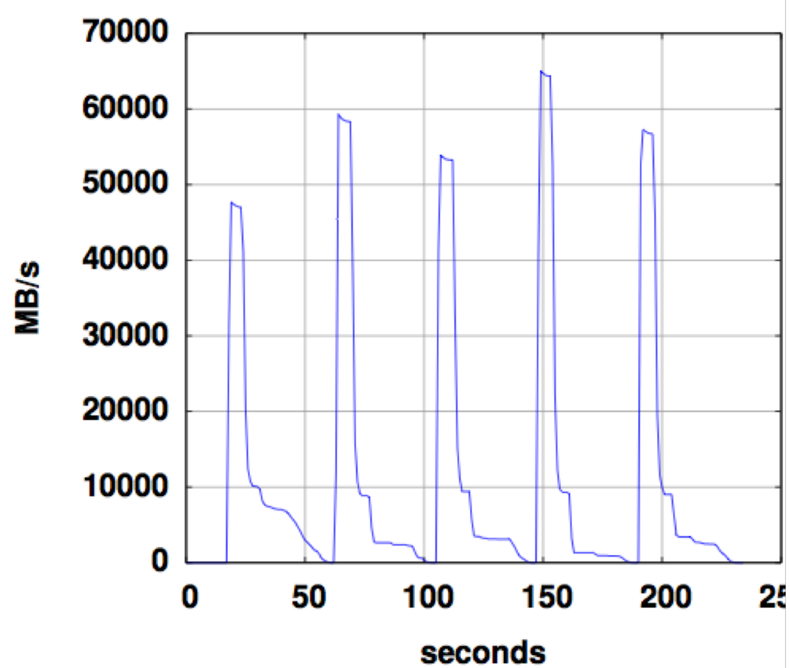


(c) I/O time distribution

M. Uselton et al. Parallel I/O Performance: From Events to Ensembles. IPDPS, 2010.

I/O Rates and PDF

- *What features do you observe?*
  - Lagging processes = not realizing peak I/O performance
  - Harmonics in I/O distribution = unfair resource sharing



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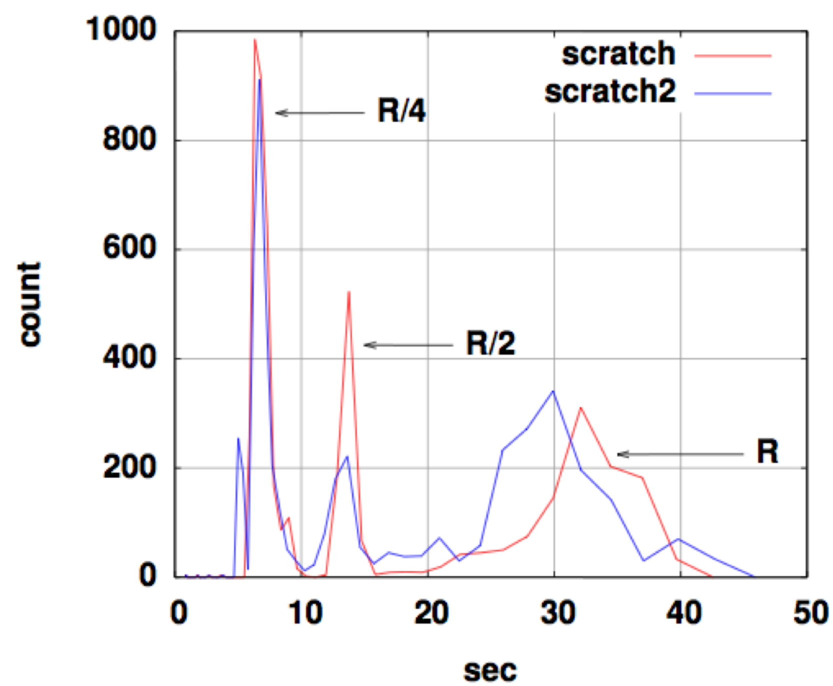

(c) I/O time distribution

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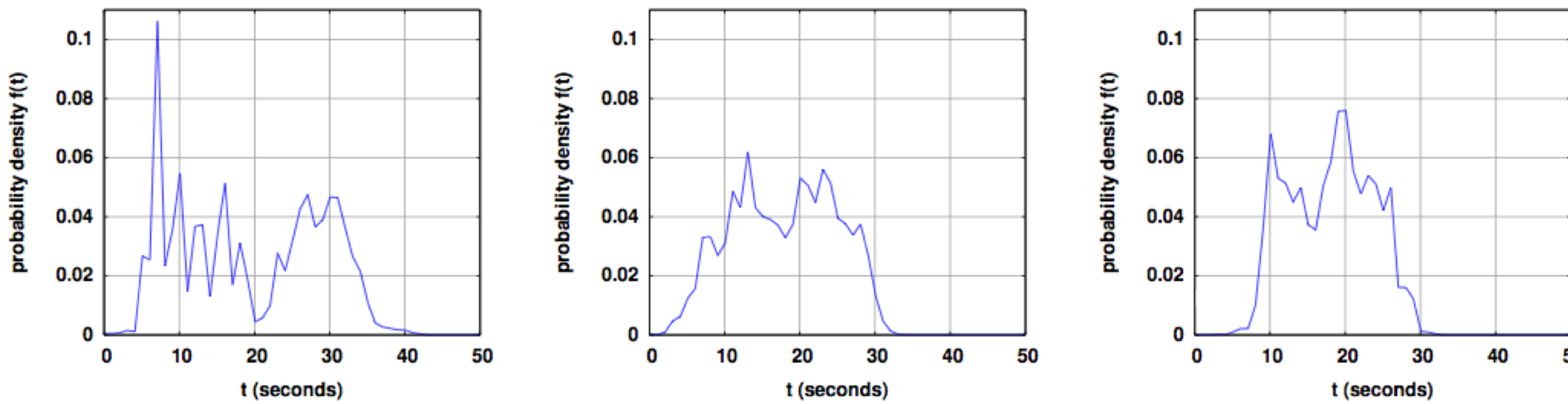
Statistical Observations

- Order statistics
  - Fancy way of saying, the longest operation dominates overall performance
- Law of large numbers
  - I don't think that they make this analysis cogent
  - It's right, but Gaussian distribution is not what matters
  - A better, intuitive conclusion is
- (RB interprets) smaller files are better
  - The worst case slow down on a smaller transfer takes less absolute time than on a large transfer
  - As long as transfers are "big enough" to amortize startups costs

Smaller Files Improve Performance

- Non-intuitive
  - Smaller operations seems like more overhead
  - But, a property of statistical analysis
- Smaller better as long as fixed costs are amortized
  - Obviously, 1 byte is too small



(a) two 256 MB transfers (b) four 128 MB buffers (c) eight 64 MB transfers

Figure 2: **IOR 512 MB transfer using 1024 processors where: a) 512 MB written via two 256MB `write()` calls. b) Four calls (128MB). c) Eight calls (64MB). Note that the distributions become progressively narrower and more Gaussian.**

The Checkpoint Crisis

As HPC codes get larger, I/O becomes more critical

- Some observations
  - Checkpoint to protect against failure
  - More components increase failure probability
  - FLOPs grows faster than bandwidth
- Conclusion
  - Must take slower checkpoints more often
  - Eventually you will get no constructive work done between checkpoints
- Mitigation (just delaying the problem)
  - Burst buffers: fast (SSD) storage in high-speed network
  - Observe the checkpoint persistence is shorter than needed for output/analysis data