PLFS: The Parallel Log-Structured Filesystem

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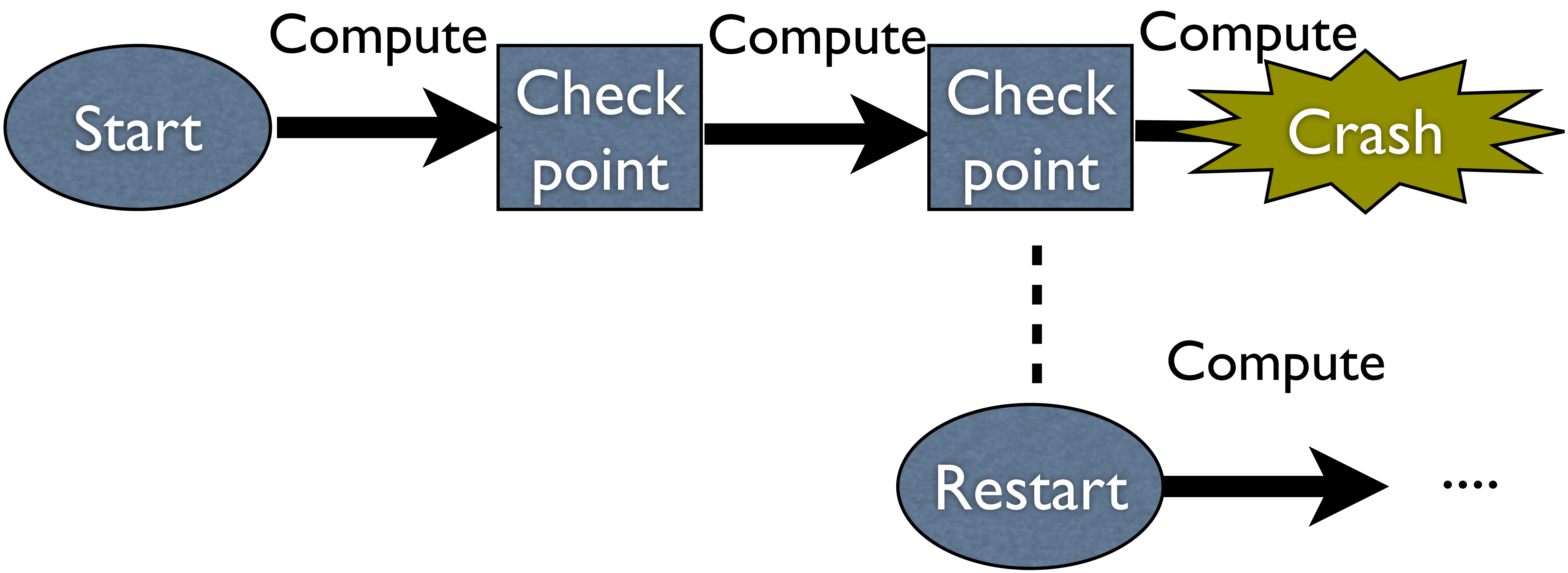
Computational Science = Always Hungry

- LANL's Roadrunner
  - Petaflop machine, tens of thousands of cores
- Building bigger machines isn't free
- Higher processor count
  - More Failures
  - Bigger, more frequent checkpoints
  - Also bigger simulation/visualization output
- Having time to compute requires fast I/O!

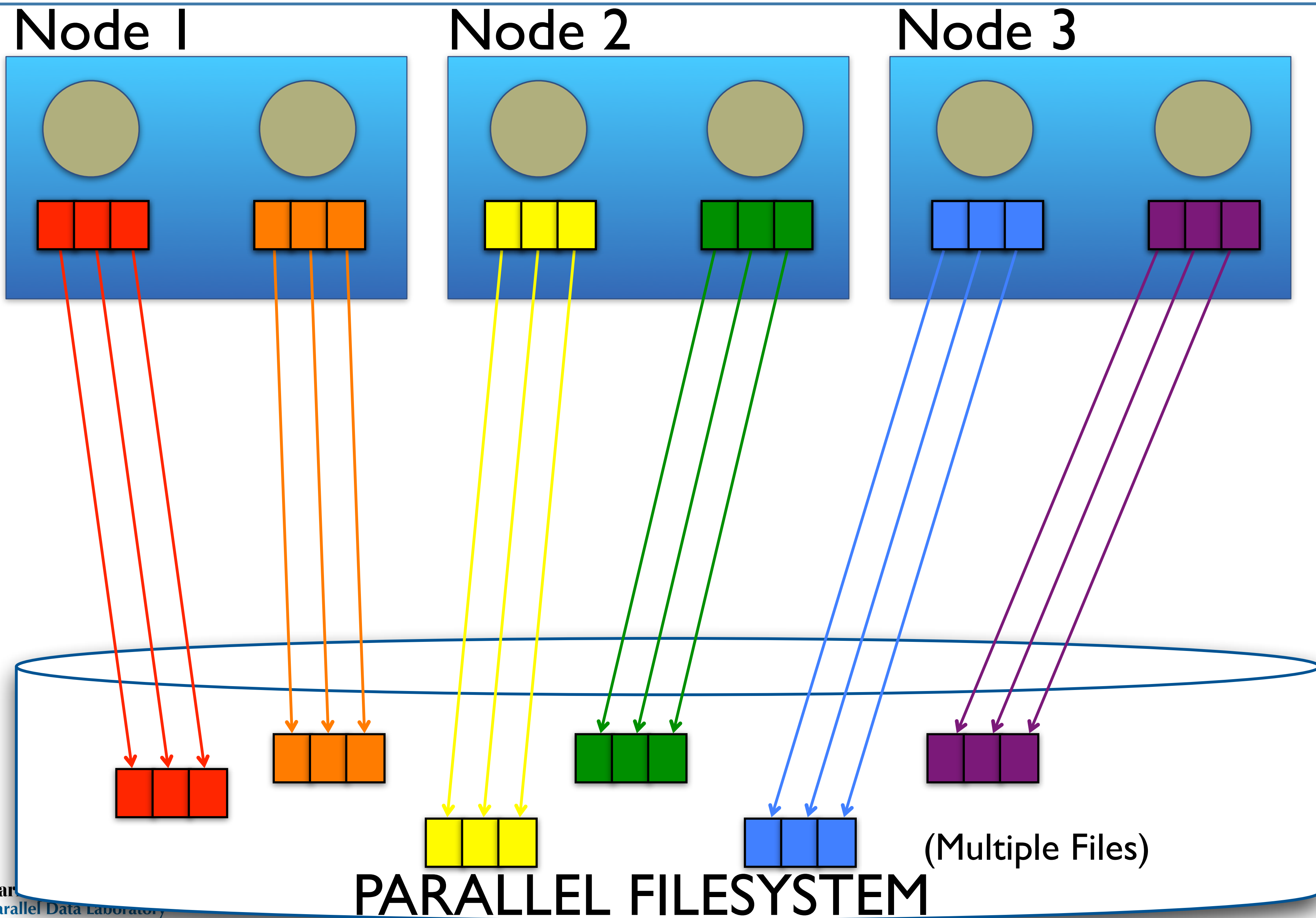
Lifetime of a Scientific App



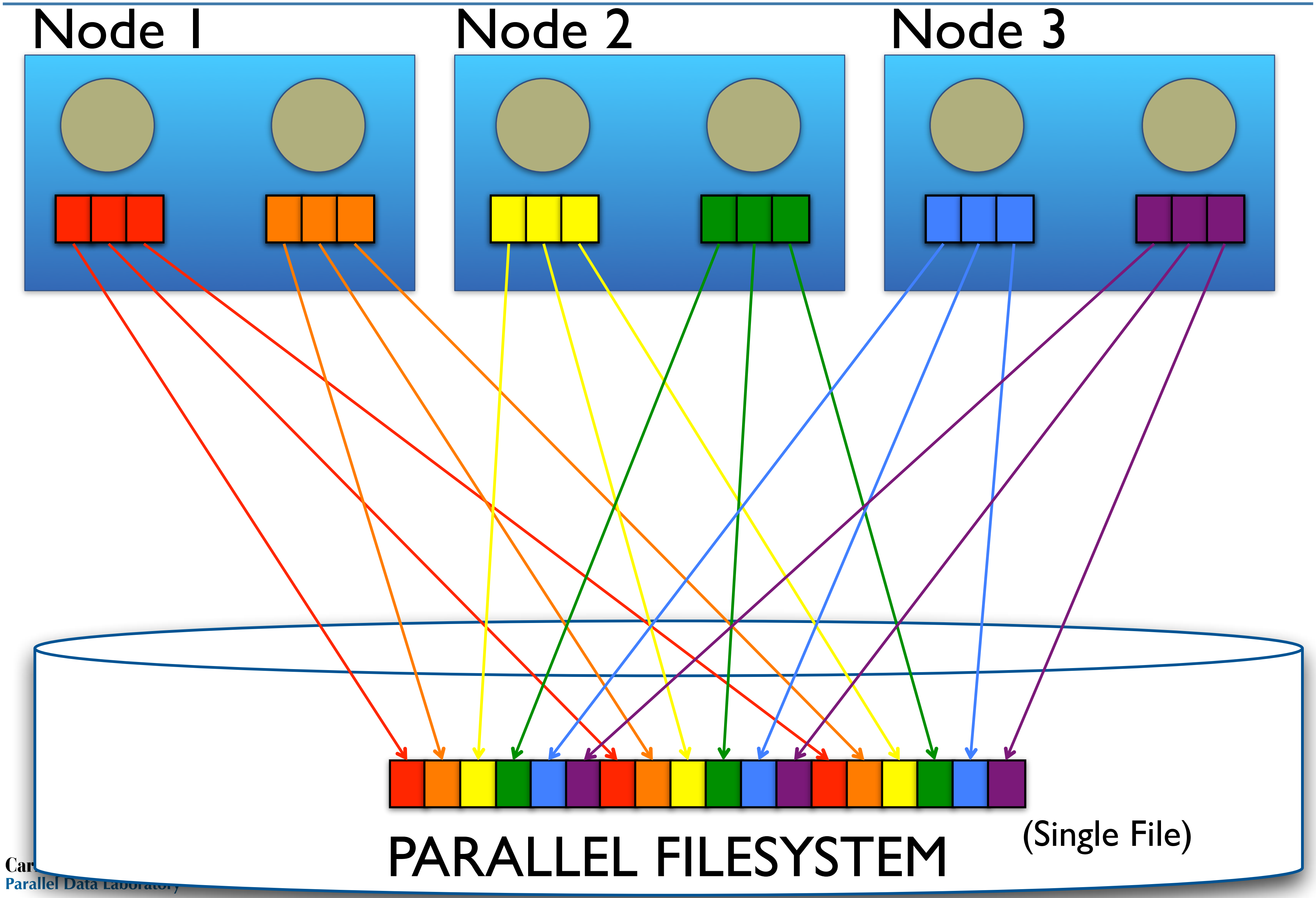
Parallel Apps = Parallel Writes

- Writes are concurrent
- Tens of thousands of concurrent writes
  - Challenge for a filesystem
- Two common write patterns
  - **N-N, N-1**

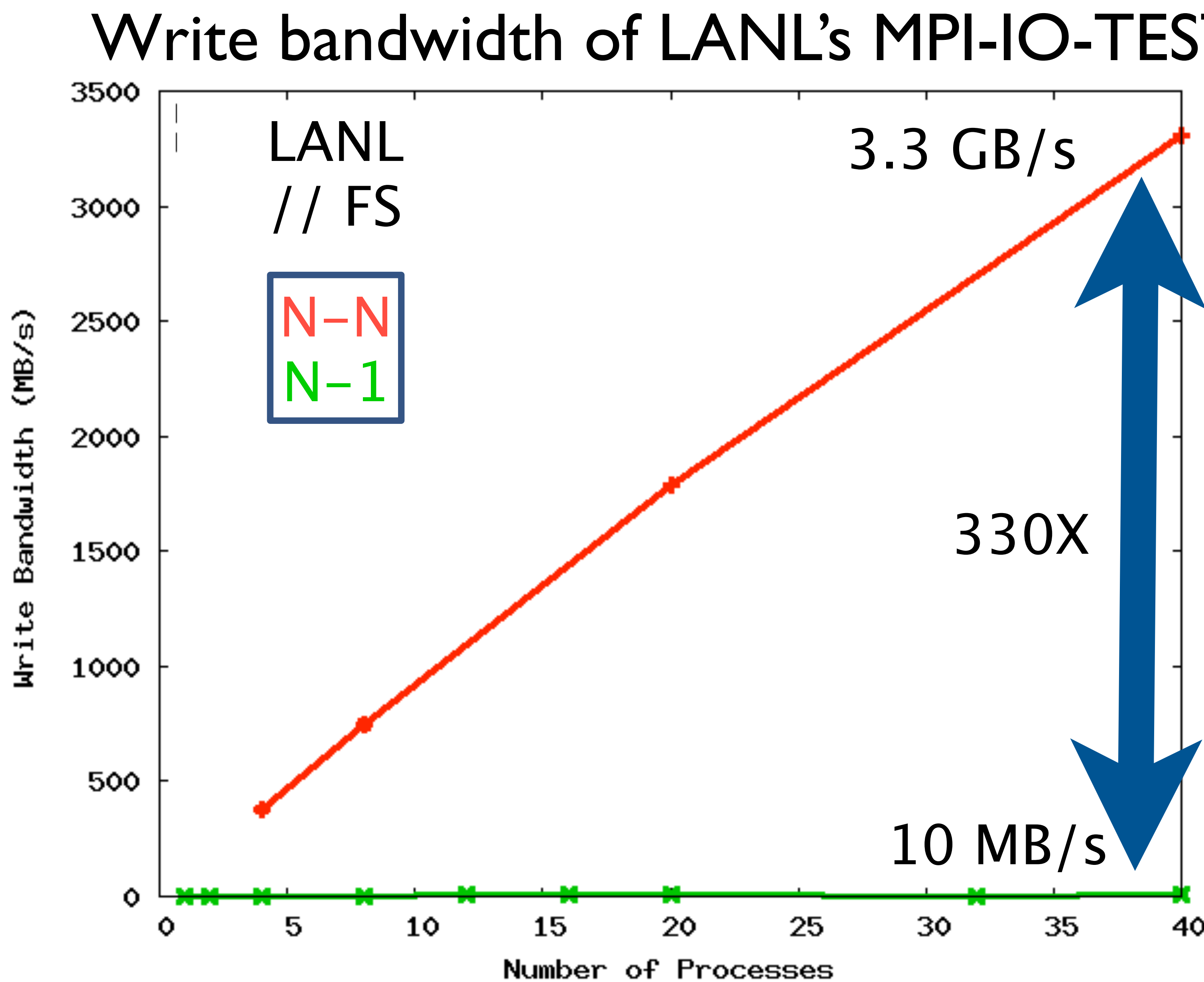
N-N File IO



N-1 File IO



N-1 Concurrent Writing Doesn't Scale



N-1: What's the hold up?

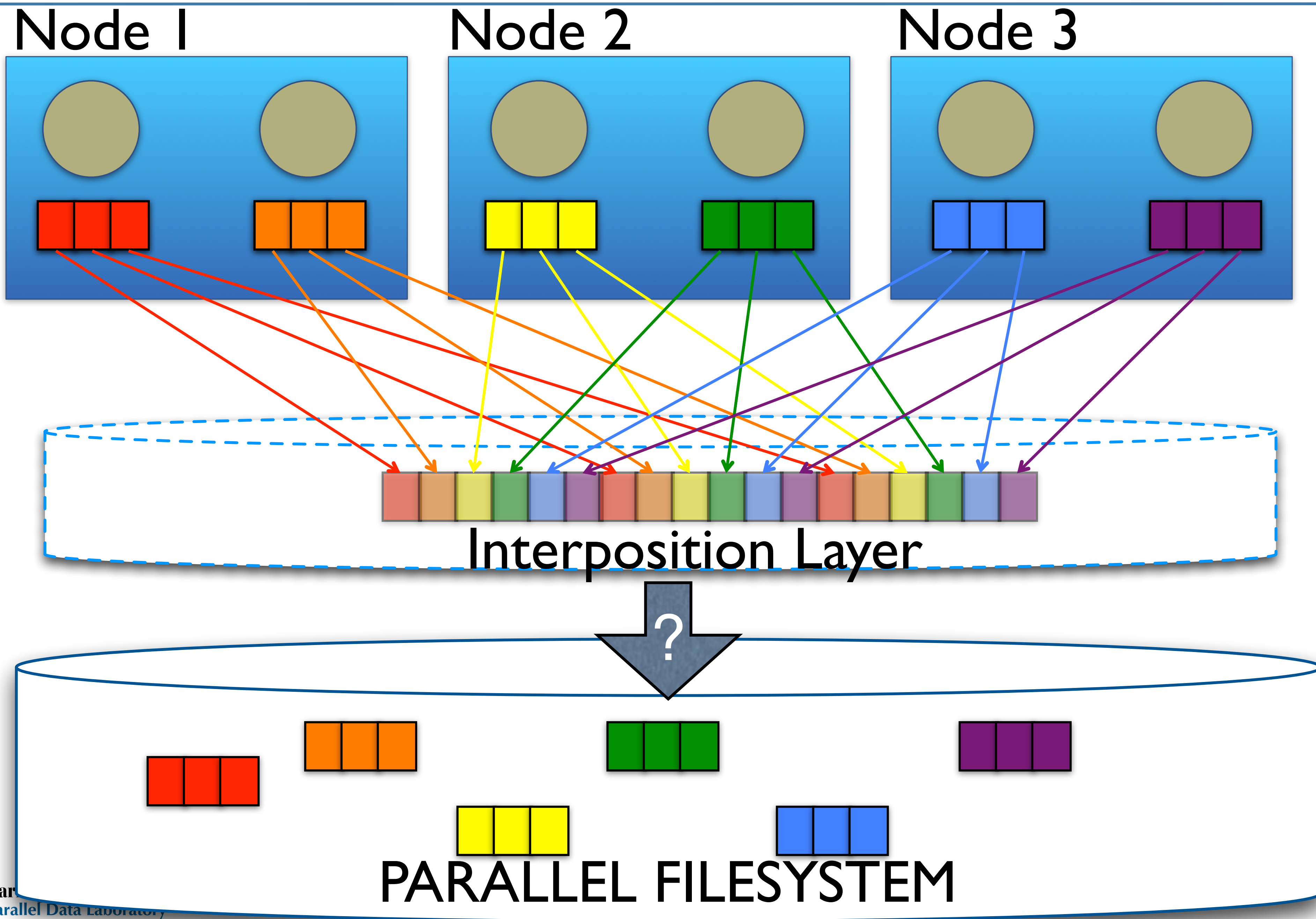
- Contention within a single object
  - Locking, safety
- Small strides, small writes
  - May be misaligned
  - Stripe alignment
  - RAID parity read-modify-write disaster

Ditch N-1? Not so fast....

- At HPC sites (LANL) many old codes use N-1
  - "Untouchables"

- Newly written codes still choosing N-1
  - 2 of 8 open science applications on Roadrunner
  - Common scientific formatting libraries are N-1
- Many benchmarks as well
  - Half the PIO Benchmarking Consortium
  - Designed to represent real apps

How can we convert N-1 to N-N?



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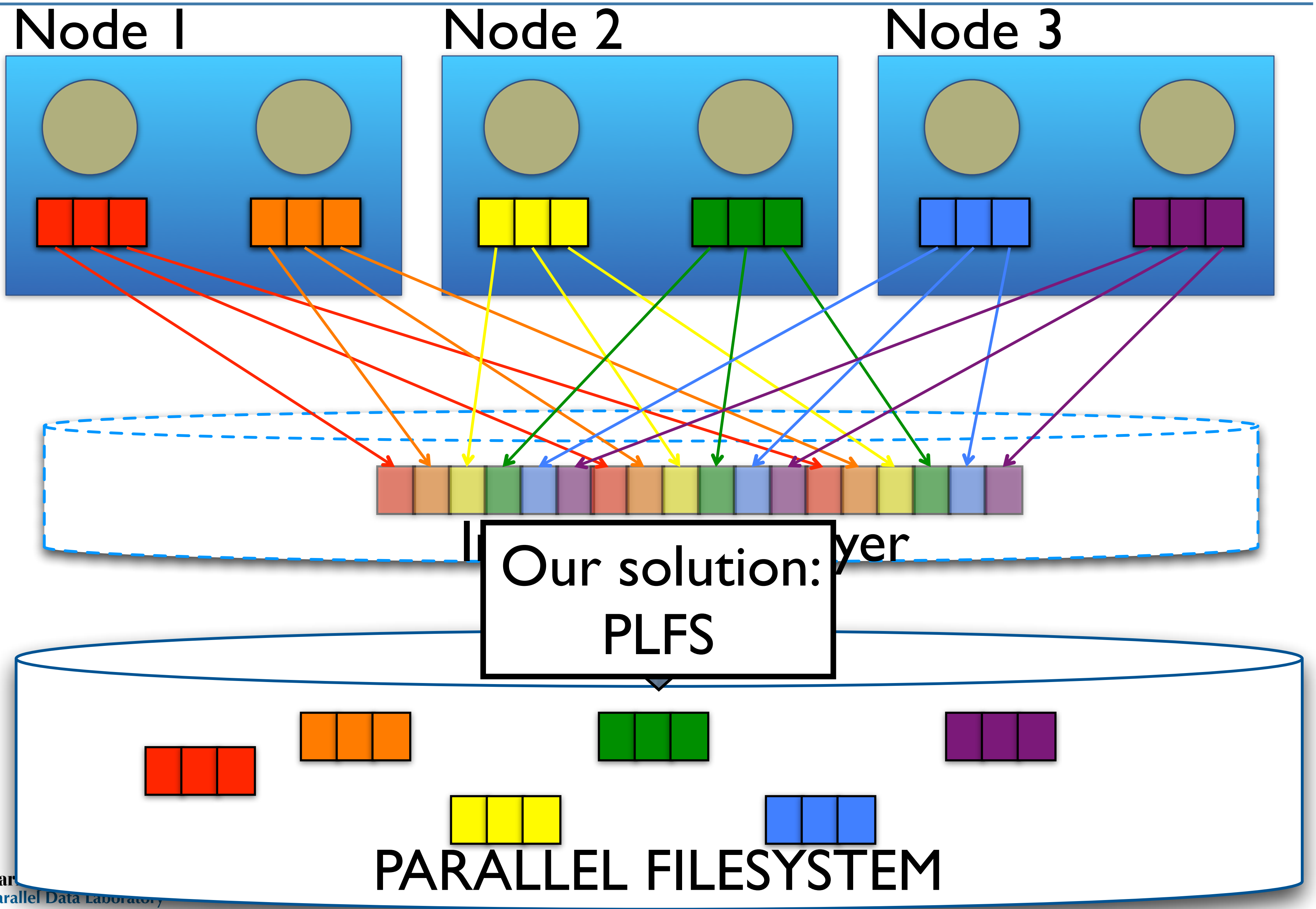


Outline

- Motivation
- PLFS Design
- Evaluation
  - Write Speeds in PLFS
  - Read Speeds in PLFS
  - Metadata Rates in PLFS
- Future Work
- Conclusions

Design of a checkpoint interposition layer

Requirement	Solution
Extreme parallelism	Decouple writers to individual files
Fast, efficient writes	Write in a log structured manner
No application changes	Expose POSIX filesystem interface
Portable across filesystems	Implement as a 'stackable' filesystem
Low comp. node footprint	Use existing parallel FS storage

Using PLFS

- PLFS is implemented as a FUSE filesystem
- Mounted on top of an existing parallel filesystem
- Example: On every node, mount as

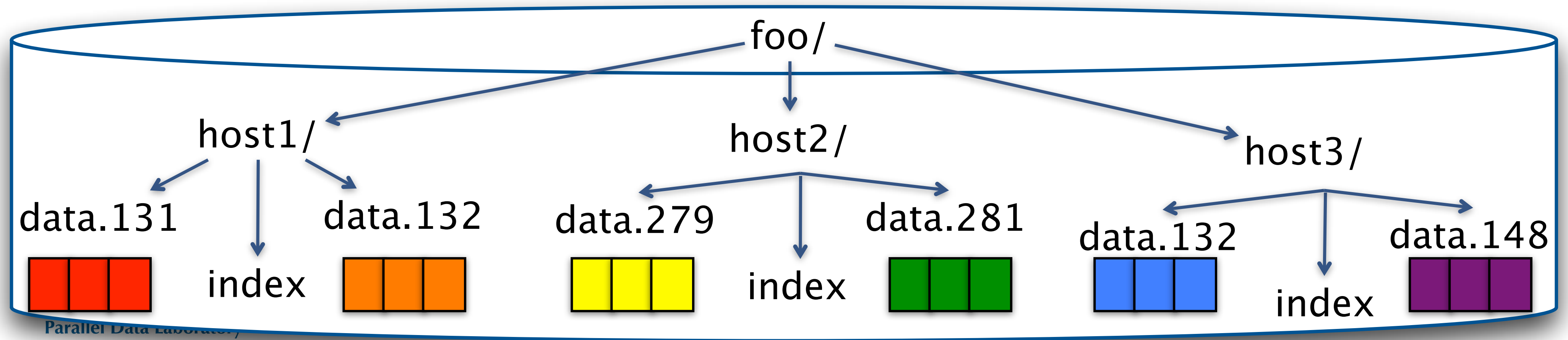
```
$ plfs ~/mnt/plfs -plfs_backend=/mnt/scratch
```

  - Checkpoints write to `~/mnt/plfs`
  - PLFS stores data in parallel filesystem `/mnt/scratch`

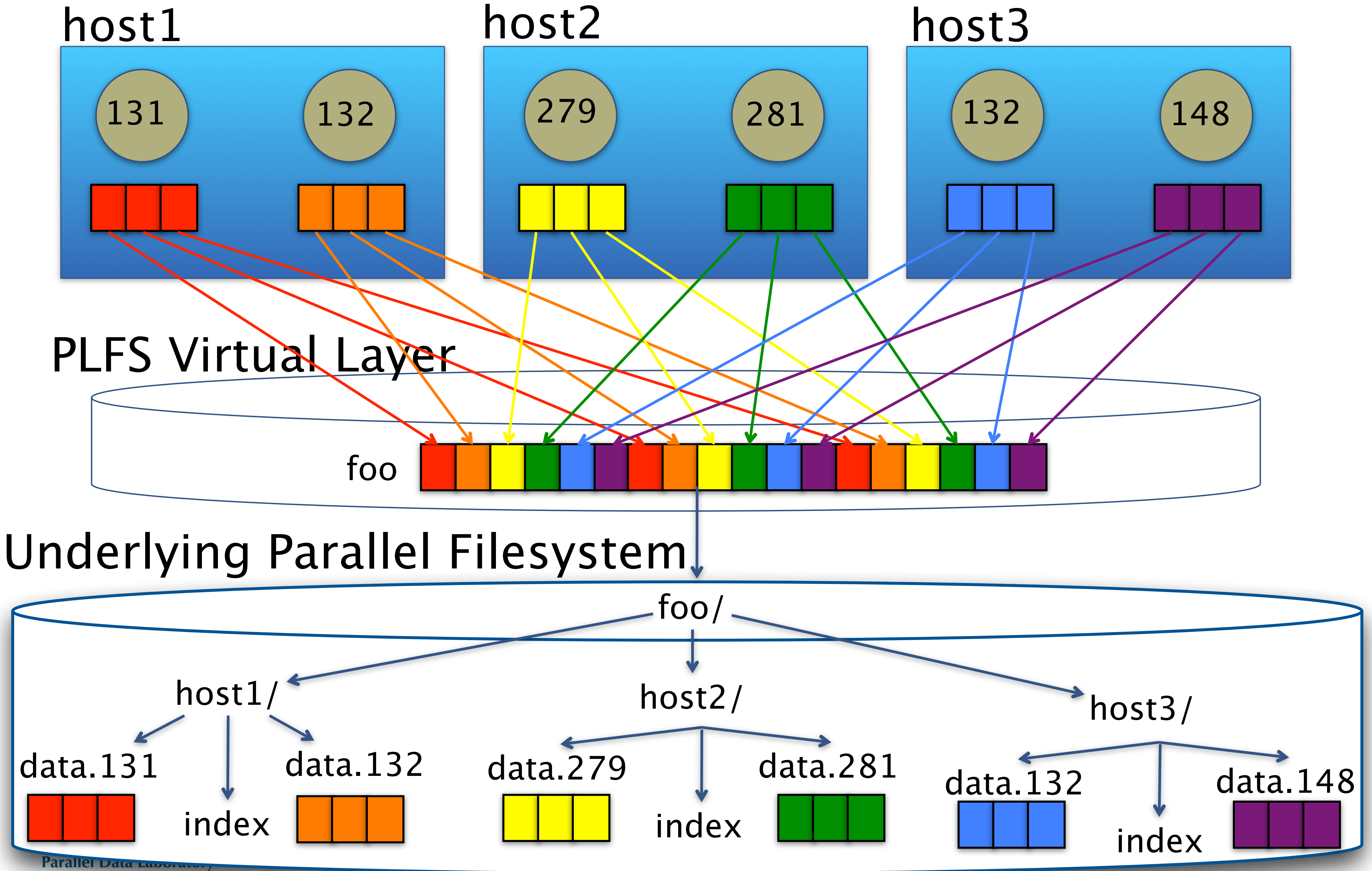
Applications write checkpoints to PLFS the same as they wrote to the parallel filesystem

PLFS Decoupling

- Processes open a file ‘foo’ in PLFS mount point
  - PLFS mkdir’s directory ‘foo/’ in underlying filesystem
  - PLFS mkdir’s ‘foo/<hostname>/’ in underlying filesystem
- Processes start writing to ‘foo’ in PLFS
  - PLFS opens a data log per writer, begins appending
  - PLFS writes a index file per host



Review: Decoupled Layout



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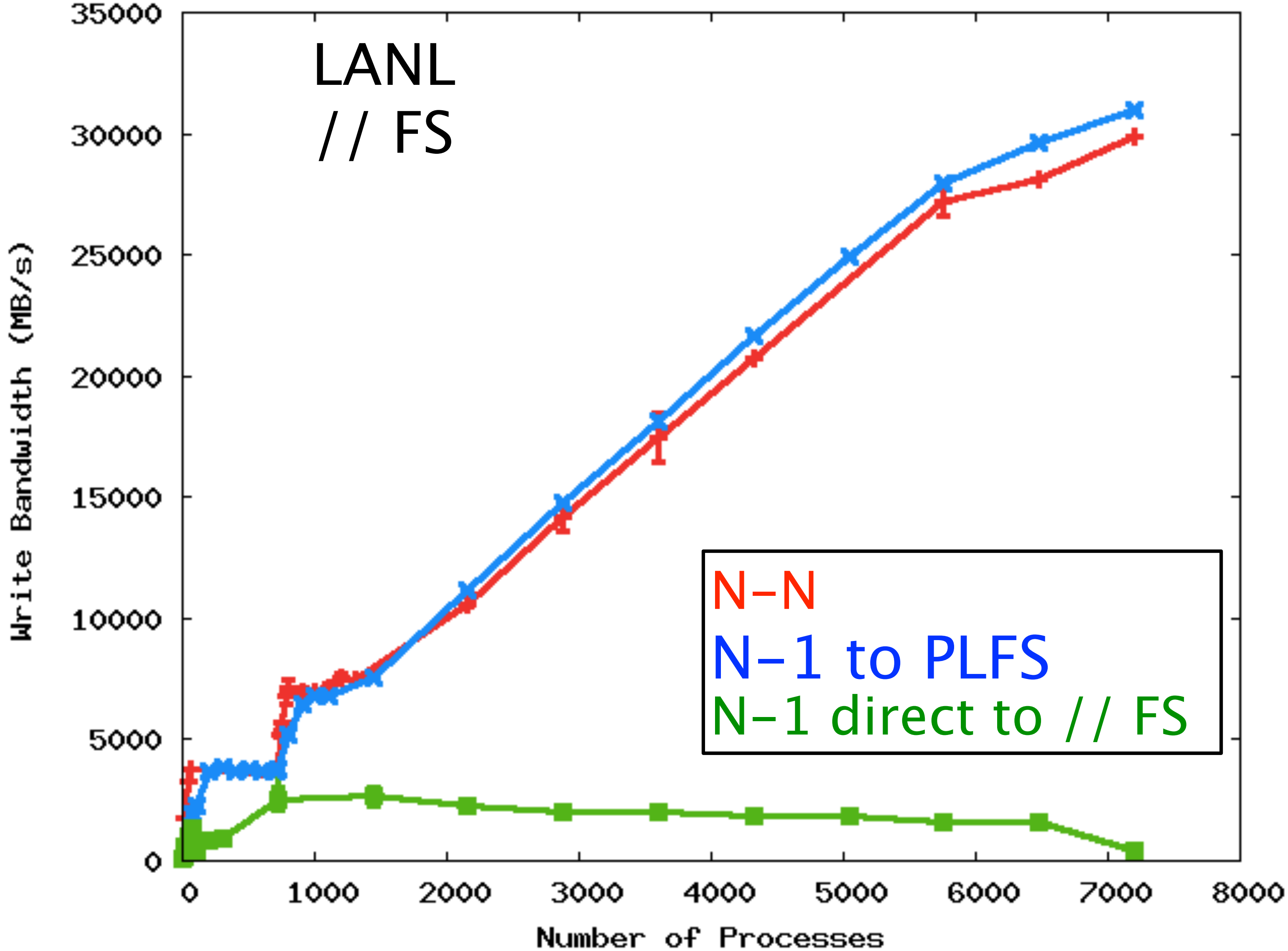
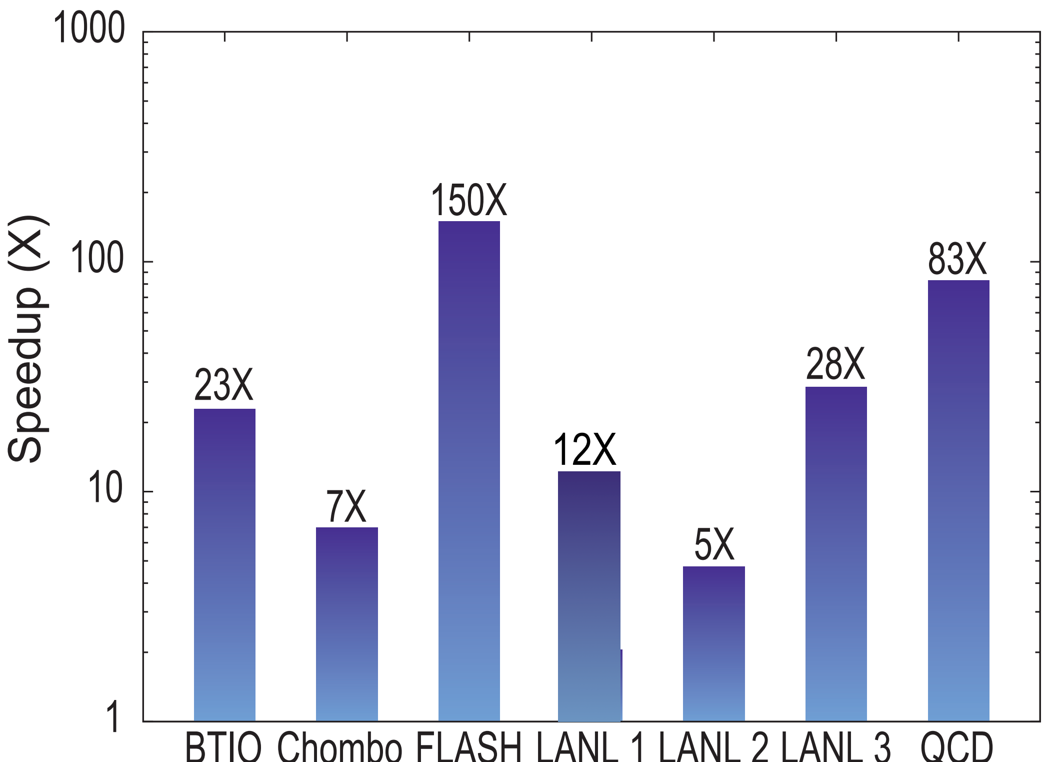
PLFS converts N-1 to N-N speeds

Write bandwidth of LANL's MPI-IO-TEST



Writes Evaluated Extensively

- GPFS, Lustre, Panfs filesystems
- Applications and IO Kernels
- Synthetic Checkpoint Benchmarks



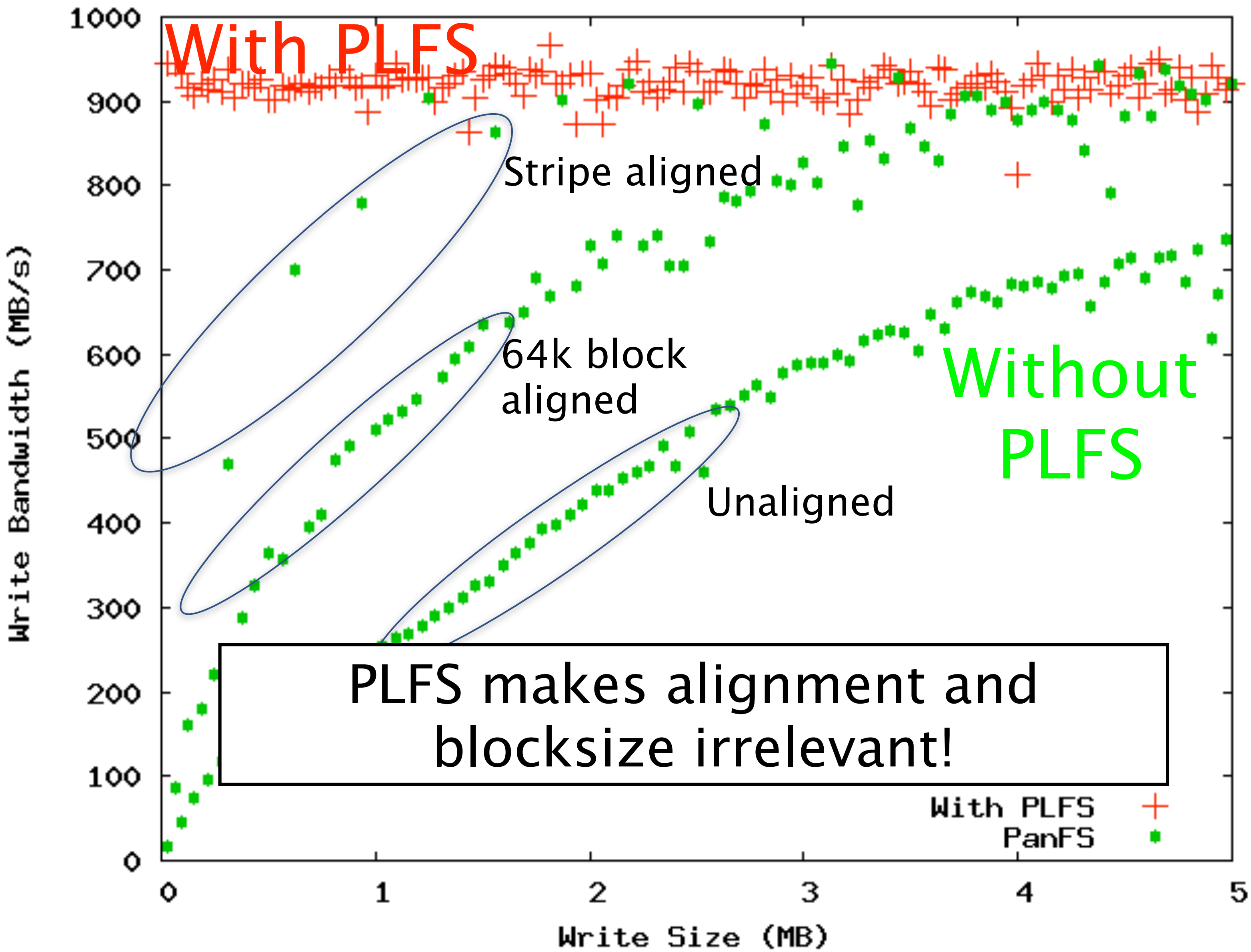
5-150x improvements

Bigger improvements with more writers

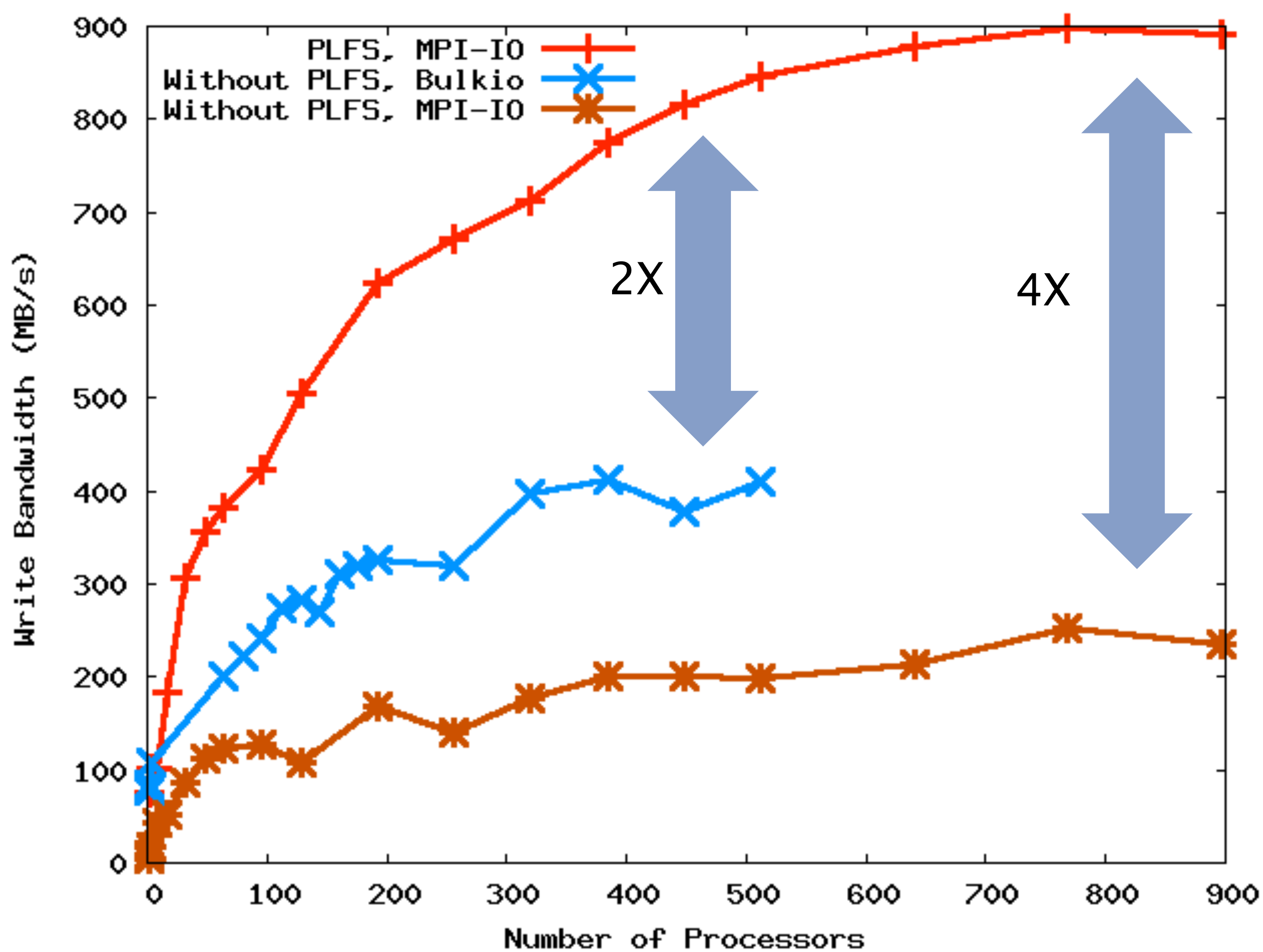
Alignment and Write Size

- Small strided writes induce contention
  - Hurt caching, buffering
- Misaligned writes use resources inefficiently
  - False sharing
  - RAID parity read-modify-write problem

LBNL's PatternIO



"Zero-Effort" Improvement For Real Apps



LANL App that simulates wiping out the dinosaurs with a meteor

Bulkio was a 10k line library written just to improve this app

PLFS is 3k lines, benefits from the FUSE approach

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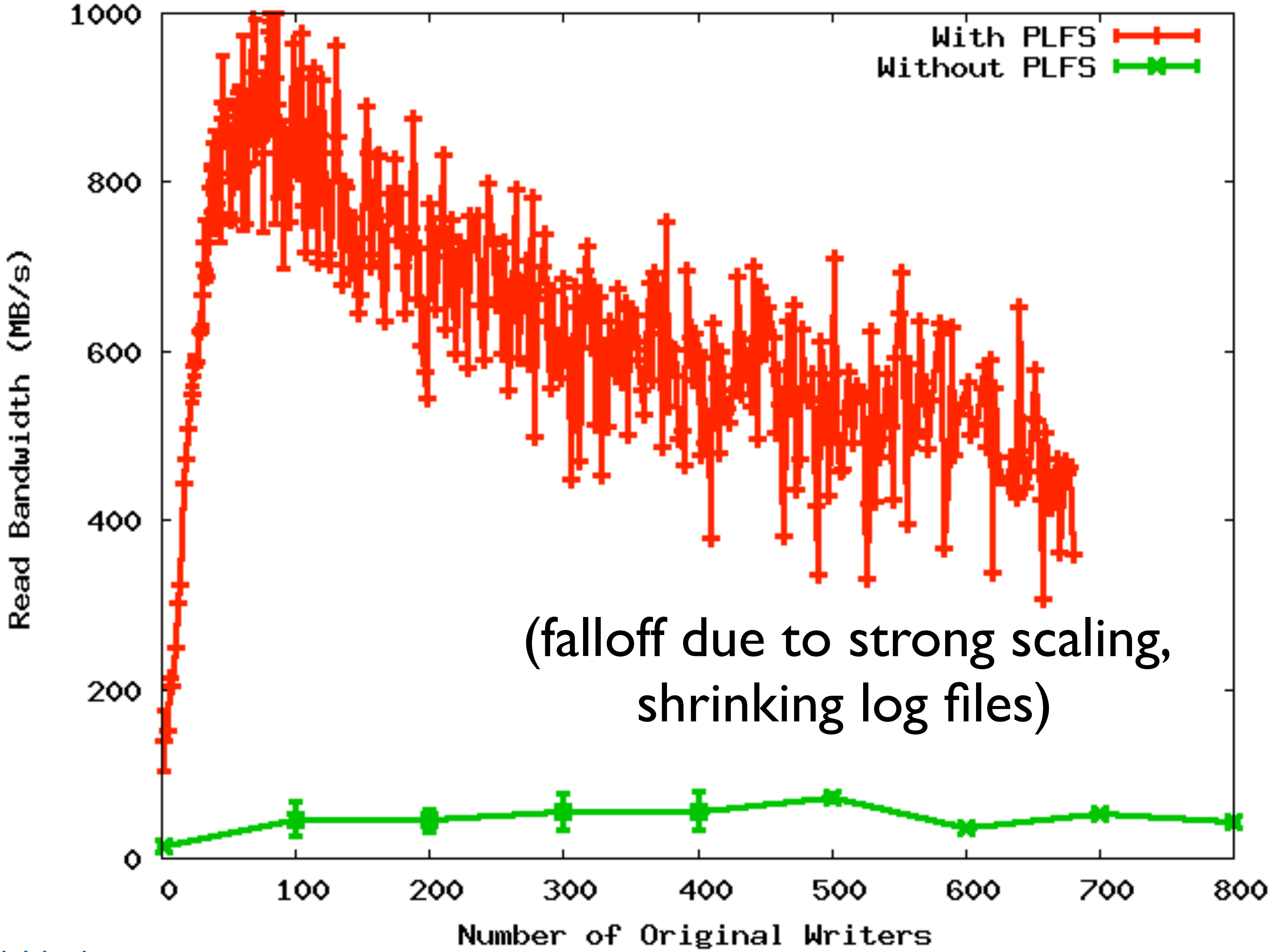
What about the read path?

- Checkpoint is 'write once, read maybe'
- PLFS readers read in indices, remap requests
- We're writing in a log structured way
  - Can't this hurt reads?

Read Speed Improved by PLFS?

Read bandwidth of LANL's MPI-IO-TEST

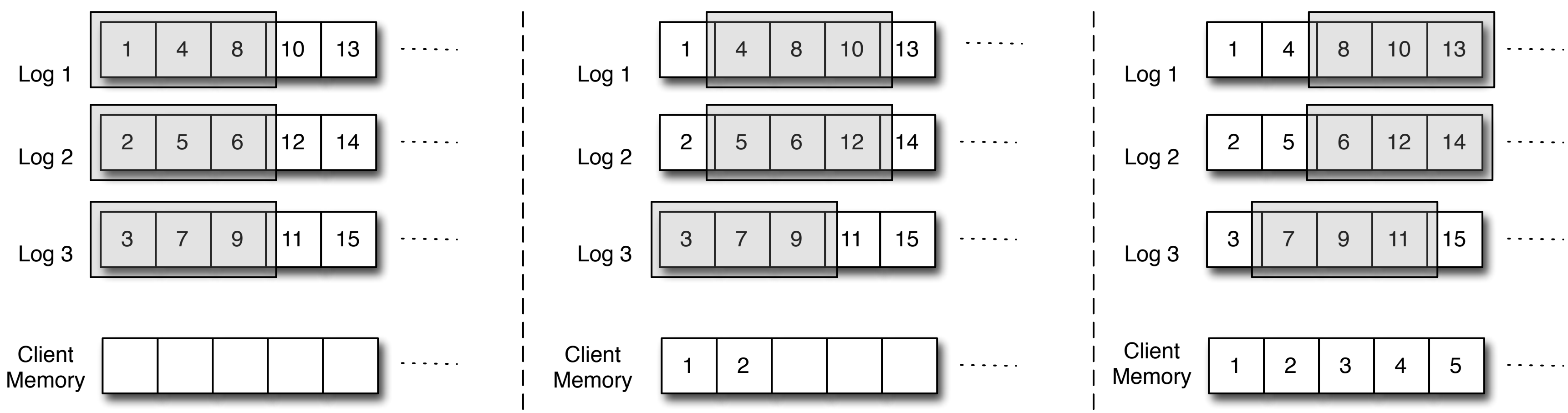


Read Speed Explanation (I)

- Checkpoints don't write randomly
- Examined write traces of evaluated applications
- In every case, processes wrote to monotonically increasing logical offsets
- Creates offset-sorted logs

Read Speed Explanation (II)

- Checkpoints aren't read randomly either
  - Restart and archive read sequentially
- PLFS reads from many files at once
- Gets more filesystem resources than N-1
- Next byte always in read-ahead buffer of some file



A client reading sequentially from offset-sorted logs

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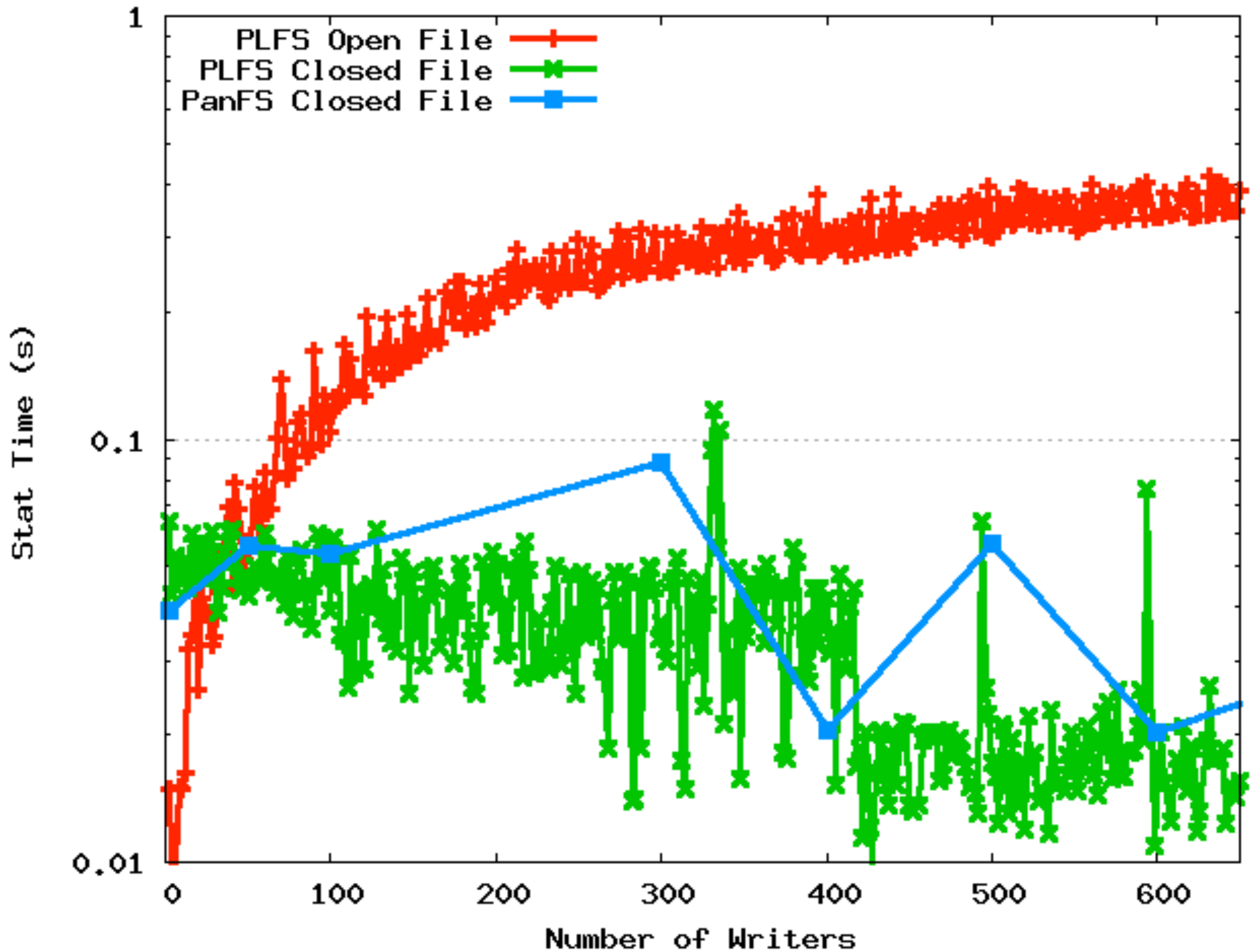
Metadata operations performance

- Recall: A PLFS file is really a directory
- Chmods, Chowns, Chgrps, Utimes, etc.
  - Use the container or a special access file
- Stat can use access file for permissions, ownership
- What about size? Modified time?
- Have to stat every data log?
- Expensive with thousands of independent logs!

Stat Optimization

- Containers have special metadata subdirectory
- On close, writers make `metadata/host.B.L.T`
  - B = blocks of capacity
  - L = last offset (i.e. file size)
  - T = timestamp of last write (mtime)
- Stat can now be implemented with a readdir
- If writers are still open, have to use slow path

Stat Rates



PLFS Open File
PLFS Closed File
PanFS Closed File
Stat Time (s)
1
0.1
0.01
0
100
200
300
400
500
600
Number of Writers

Remaining Challenges and Future Work

- First open invokes thousands of sub-file creates
- Index reprocessing overhead in read-write mode
- Odd read patterns? Data analysis?
- Faster stat of open files
  - `ls -l` of growing file

Future Work: PLFS + HDFS

- ‘Cloud’ filesystems gaining prevalence
- High resilience but often lack important semantics
- HDFS:
  - No concurrent writers
  - No reopen for write
  - Could be achieved by ‘decoupling’ every open
- Use PLFS to add semantics to Cloud Filesystems
- See me at poster

Conclusions

- Drastically improves performance of N-1 checkpointing
- Works on multiple parallel filesystems
- No application, filesystem modifications
- Does not penalize checkpoint reading
- Potential to enrich semantics of cloud filesystems
- Downloadable at: http://sourceforge.net/projects/plfs/