Scalable Approaches for Supporting MPI-IO Atomicity

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Data Integrity in Large-Scale Applications

- Programmatic methods:
  - MPI_Barrier()
  - MPI_File_set_atomicity()
- Guarantees atomicity, but tends to be inefficient and more effort-intensive

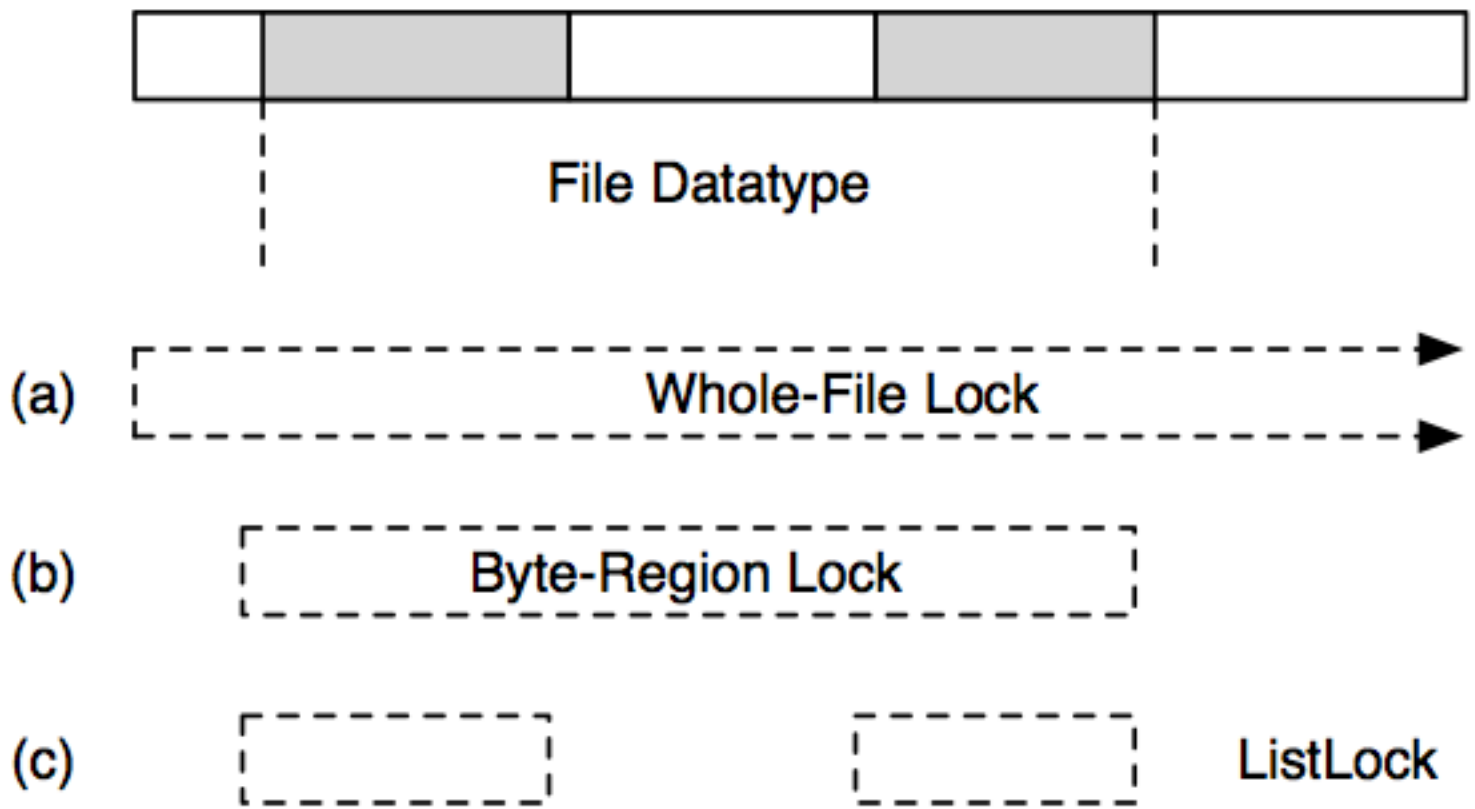
File Locking

- Used by many popular distributed/parallel file systems:
  - GPFS (Schmuck et al, 2002)
  - Petal (Lee et al, 1996)
  - NFS versions 3 (RFC 1813) and 4 (RFC 3530)
- Main strategies: Whole-File Locking and Byte-Range Locking

A Better Way to Lock: List Locks

- Other methods: Easy to implement, but cause a great deal of false sharing
- Our approach: Lock only what you need in the file
- Bottom line: Outperforms simplistic (whole-file and byte-range) locking by a factor of up to 8, and generally performs almost as well as non-atomic I/O access

Summary of Locking Approaches



Whole-file Locking

- One process requests a lock on a file; if available, it gains exclusive access to the entire file
- Another process that needs access to the file will block until the file is unlocked
- Concurrent access to the file is prohibited, but this prevents different processes from accessing different portions of the file

Byte-Range Locking

- Locks granted on a file are now a single byte range - the extent of the datatype being used by the process
- More efficient than whole-file locking; multiple processes can now access the file if their datatypes do not overlap
- Still not ideal: if there are “holes” in the datatype, the lock covers portions of the file not being accessed by the process

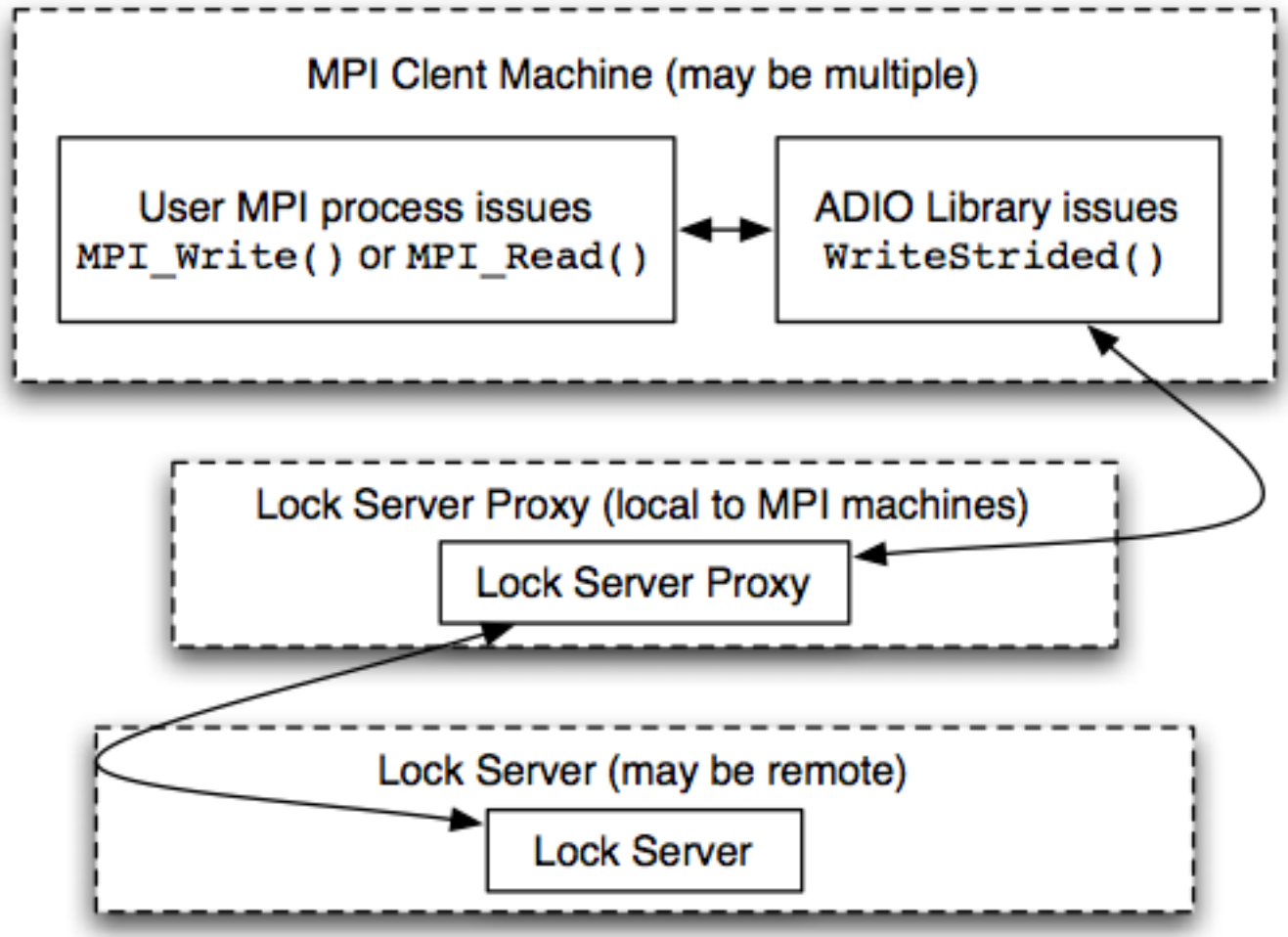
List Locking

- Lock only those parts you need
- How?
  - Examine the data types' offsets and lengths
  - Compute the exact byte ranges you need, consolidating as necessary
  - Send the results to the lock server to be processed in ascending order (to avoid deadlock)

List Locking

- Complications:
  - Computation of the locks - nontrivial, though not too expensive
  - Transmission of the offset-length pairs to the server - potentially thousands of these for a complex data type, so transmission must be efficient

The List Lock Server



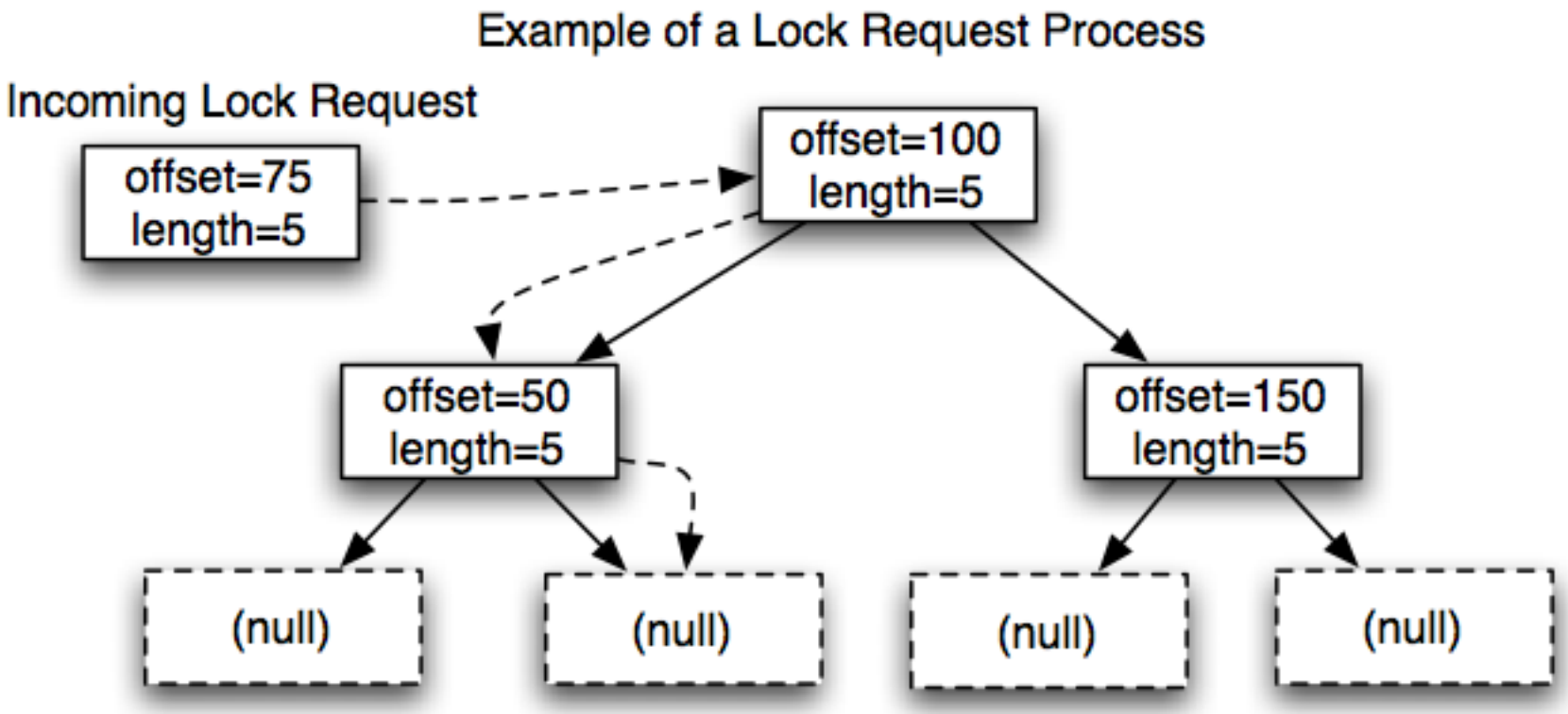
Software Architecture

- Java 1.4.2 (Sun Microsystems, http://java.sun.com)
  - Chosen for implementation speed and simplicity of code; JIT compiler makes simple computations very close in speed to compiled machine-language code
  - Efficient network implementation; important since most of the "think time" is spent transmitting the lock information

Software Architecture

- Locks stored in red-black tree (Guibas et al 1978)
- Time complexity of operations (m = number of lock requests for a file; n = number of existing locks for that file)
  - Insertion: O(m log n)
  - Deletion: O(m log n) worst-case

Software Architecture



Client-Server Communication

- JHPC class library (Thiruvathukal and Christopher, 2000; http://www.jhpc.info)
- Object-oriented transmission protocol
- Modified to send arrays of integers efficiently
- Interface code written to allow communication between clients written in C and servers written in Java

Lock Server API

- MPI-based API
- Client calls lock_datatype() on a datatype instance, which:
  - computes offset-length pairs
  - communicates them to the server
  - waits for affirmative response that locks were acquired

Testbed

- Jazz cluster at Argonne National Laboratory (http://www.lcrc.anl.gov/jazz):
  - 350 nodes, each with single 2.4 GHz Pentium Xeon processor
  - 175 have 2 GB RAM, 175 have 1 GB RAM
  - 80 GB scratch disk, Myrinet 2000 connection, Fast Ethernet connection
  - 10 TB global disk with NFS and PVFS
  - Linux 2.4.29-rc2

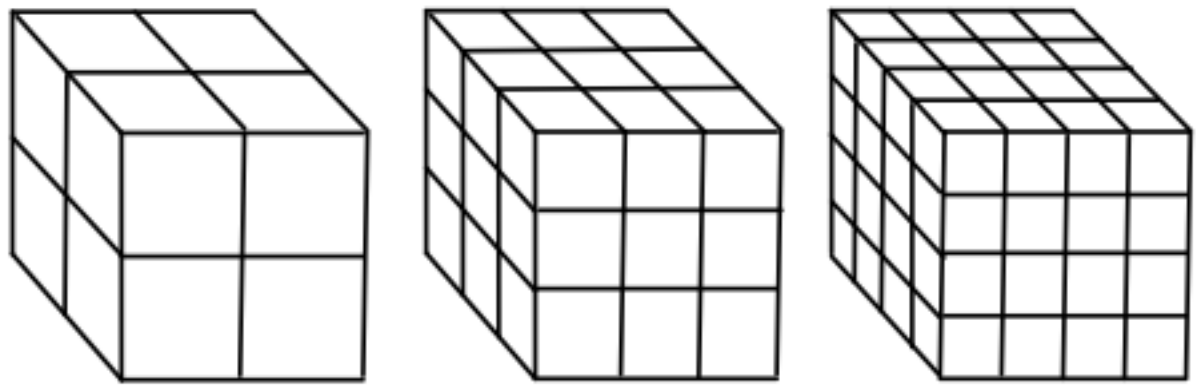
Testbed

- For our tests:
  - MPICH2 version 1.0.2p1
  - PVFS shared disk space
  - Fast Ethernet connections used (MPICH did not recognize the Myrinet host names)

ROMIO 3-D Block Test

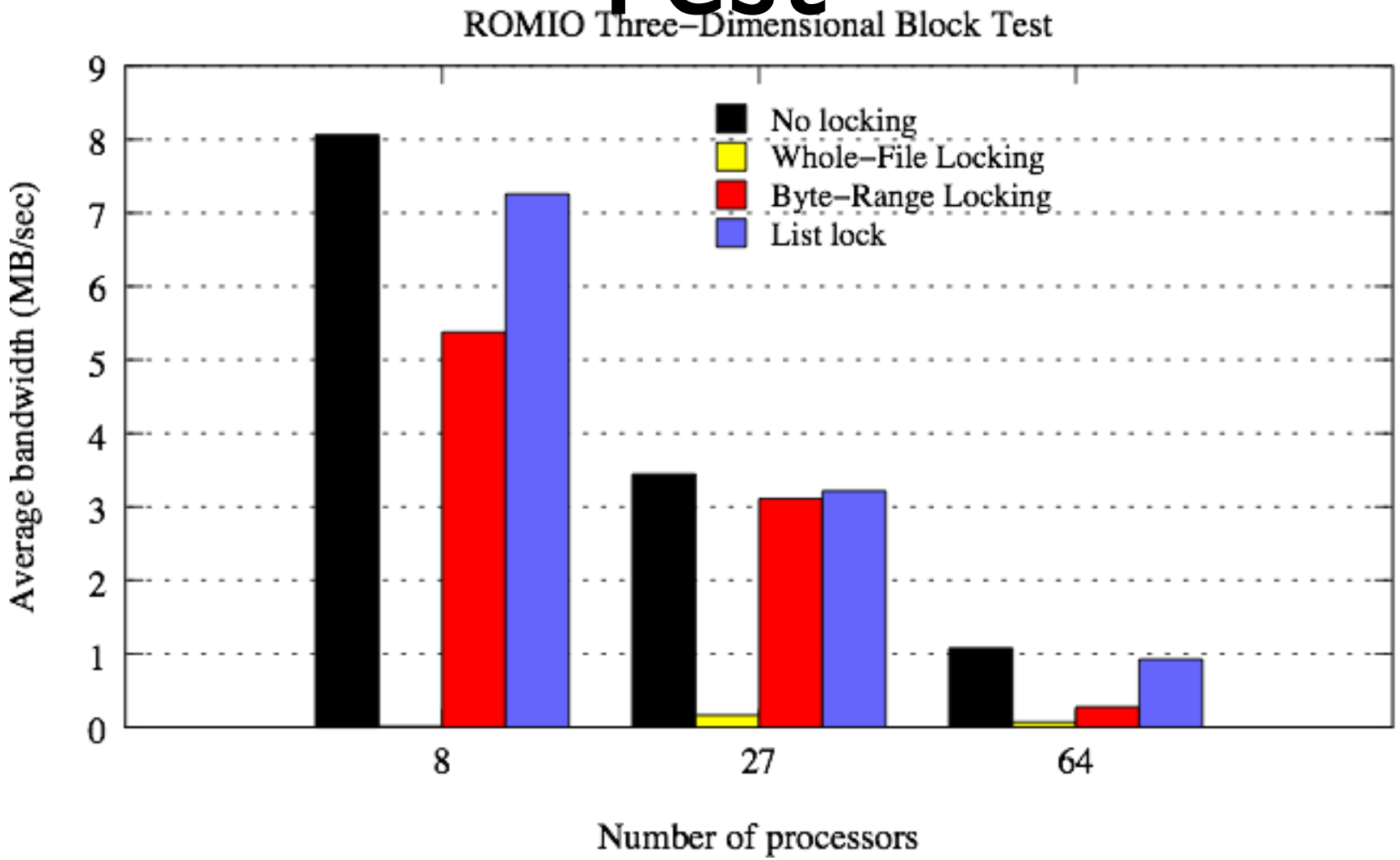
- coll_perf.c test from the ROMIO test suite
- Measures bandwidth writing to a cube of data of size 100 integers
- 8, 27, and 64 processors used

ROMIO 3-D Block Test



	Number of Processors	Number of Locks per Client	Maximum Concurrent Processes
Whole-File Locking	8	1	1
	27	1	1
	64	1	1
Byte-Range Locking	8	1	4
	27	1	9
	64	1	16
List Lock	8	25	8
	27	12	27
	64	64	64

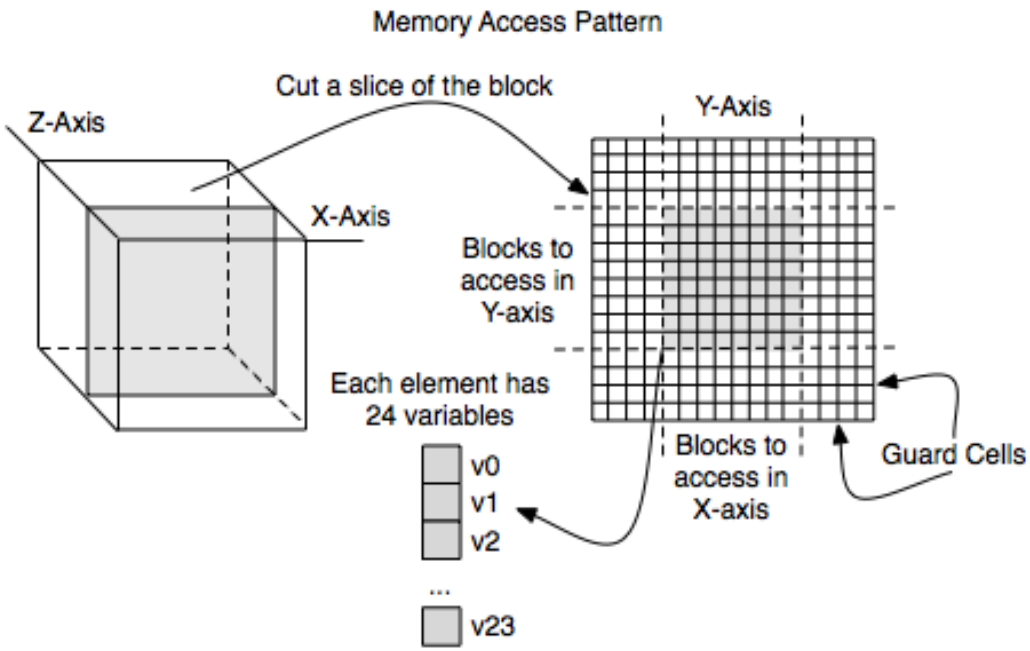
ROMIO 3-D Block Test

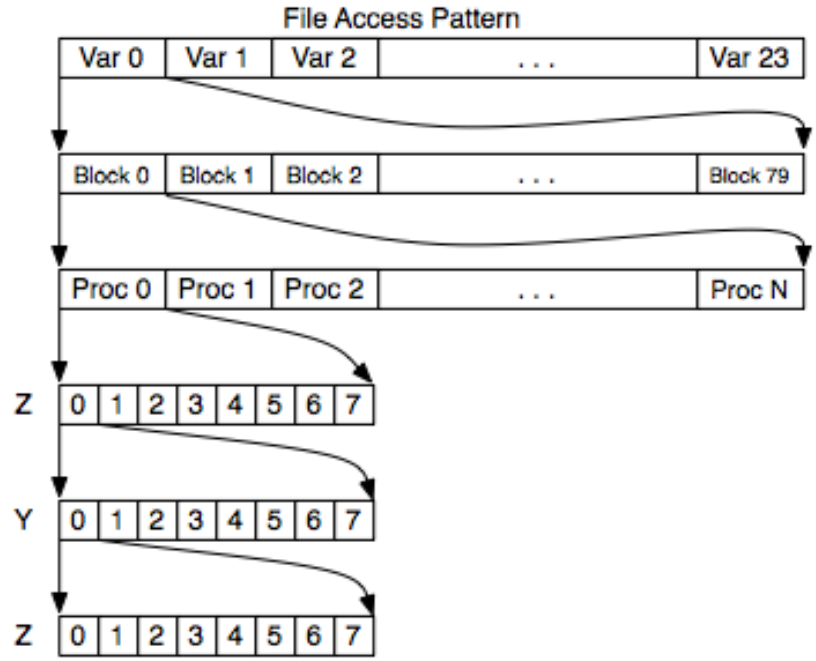


FLASH I/O Simulation

- Mesh refinement application used to study astrophysics
- HDF5 used for writing checkpoints
- Non-contiguous datatypes used, which is useful for exercising novel non-contig I/O systems

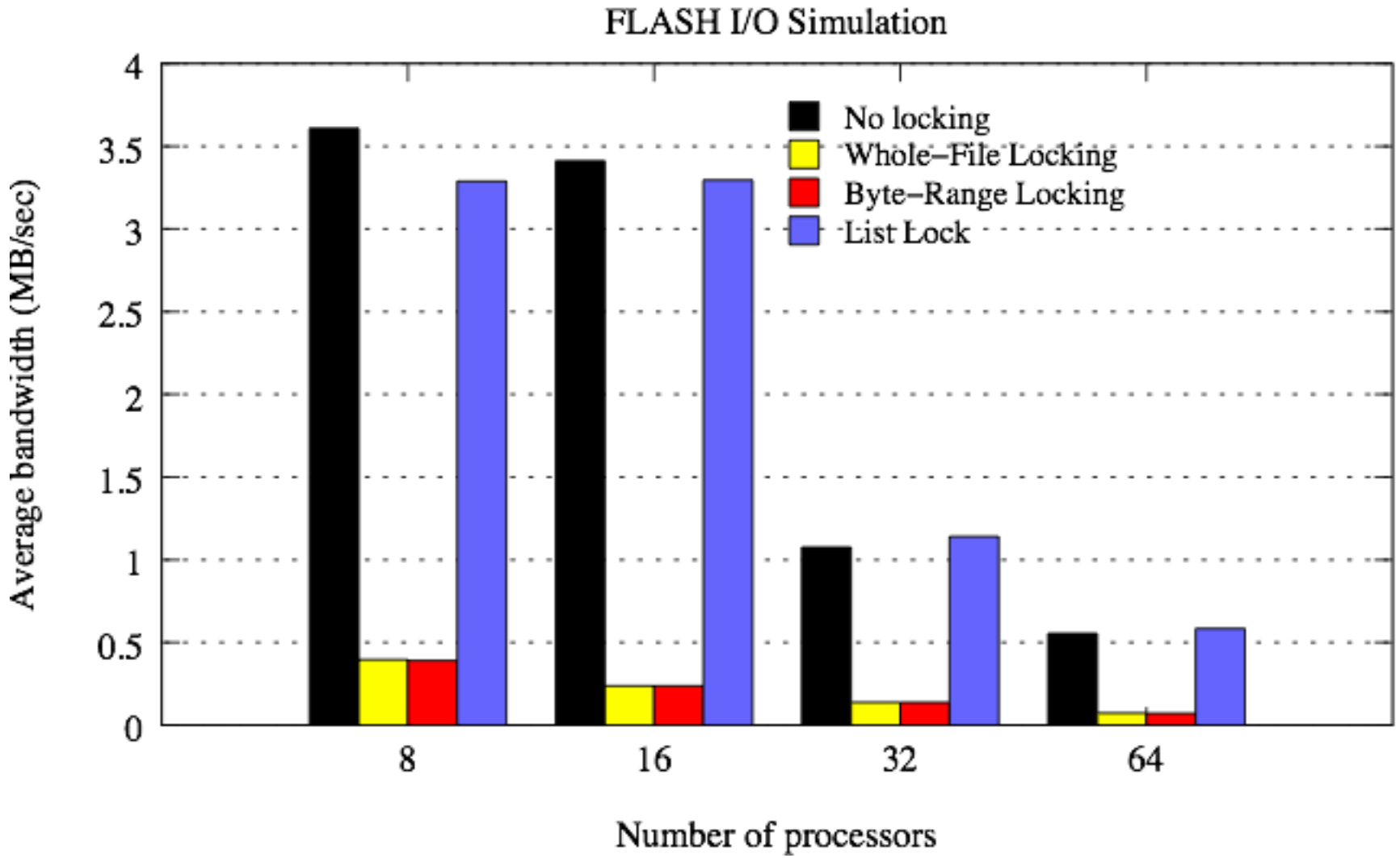
FLASH I/O Simulation





	Number of Processors	Number of Locks per Client	Maximum Concurrent Processes
Whole-File Locking	8	1	1
	16	1	1
	32	1	1
	64	1	1
Byte-Range Locking	8	1	1
	16	1	1
	32	1	1
	64	1	1
List Lock	8	64	8
	16	64	16
	32	64	64
	64	64	64

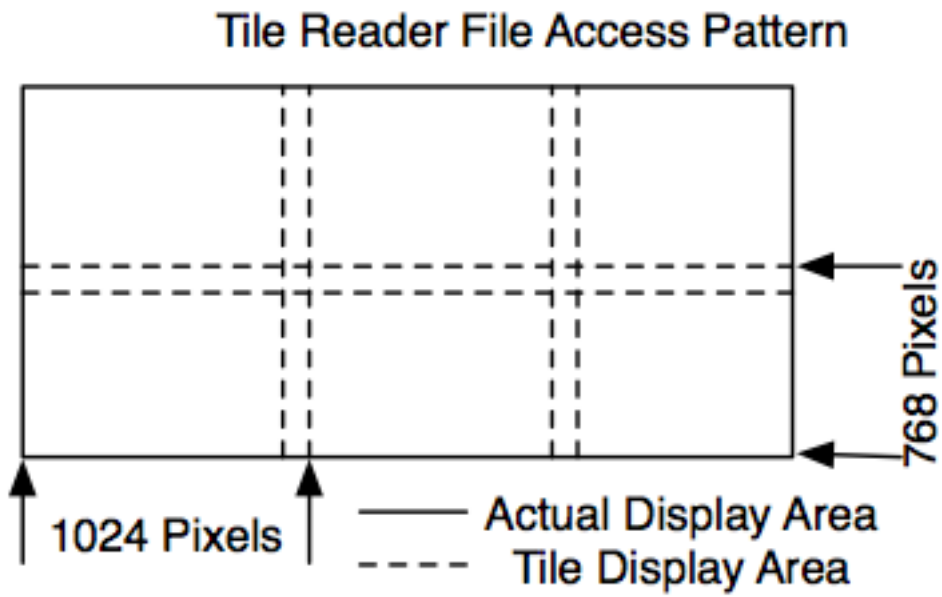
FLASH I/O Simulation



Tile Reader Benchmark

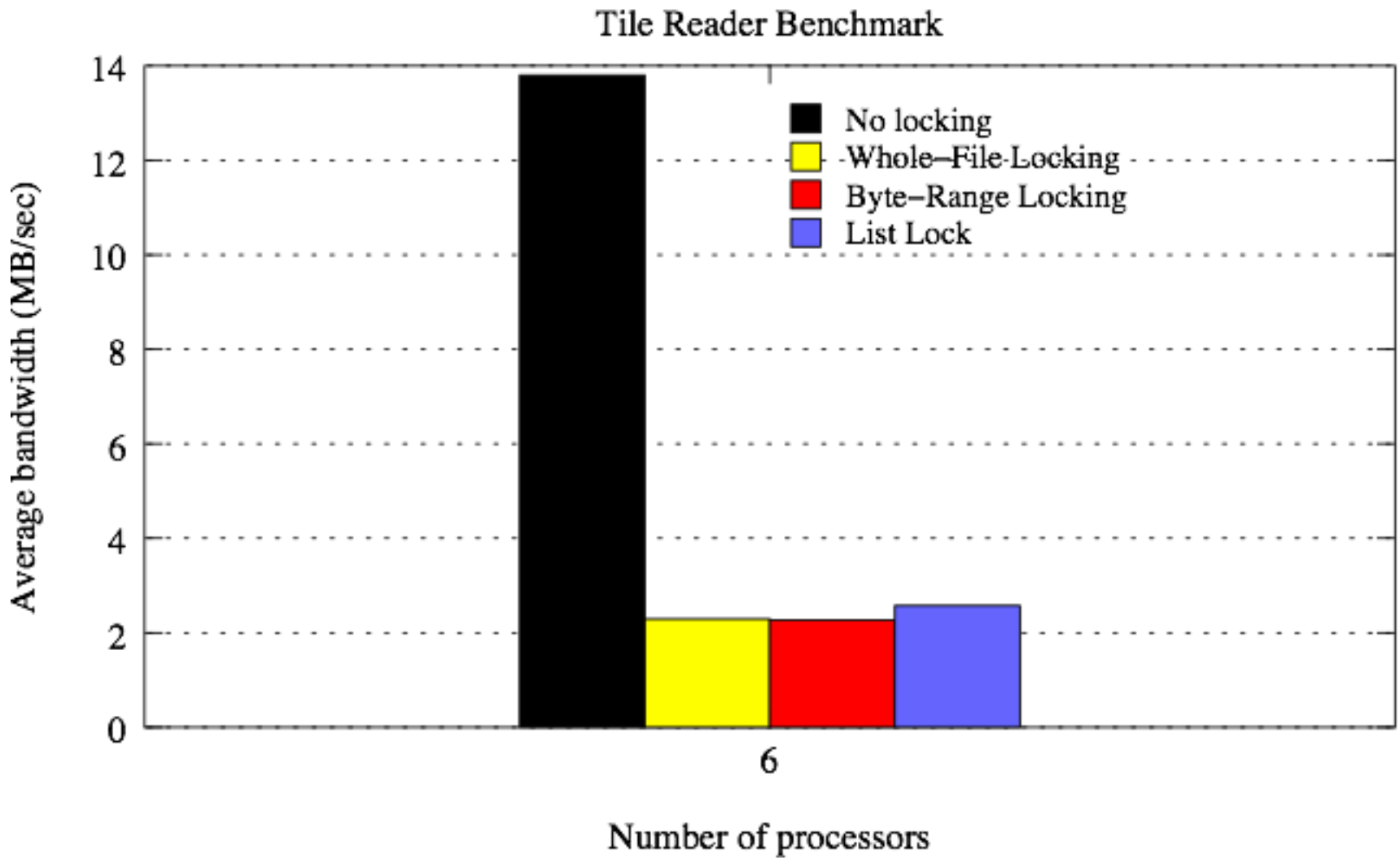
- Used to test performance of commodity-based graphics systems
- Each node simulates reading 1024x768 blocks for displaying to its own display
- 270-pixel horizontal overlap and 128-pixel vertical overlap to hide merging of edges
- 6 processes running simultaneously

Tile Reader Benchmark



	Number of Locks per Client	Maximum Concurrent Processes
Whole-File Locking	1 per file	1
Byte-Range Locking	1 per file	2
List Lock	64 per file	2

Tile Reader Benchmark



Conclusions

- Tests show a fair comparison of locking strategies; list locking is far superior to naïve locking methods in realistic tests
- Demonstration of feasibility of using Java in a high-performance computing application

Future Work

- Handling stale locks - important for a robust production environment
- Compression of lock requests to further optimize lock request transmission time
- Block-oriented lock approach using bit vectors on the server side

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