Efficient I/O on the Cray XT

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Overview

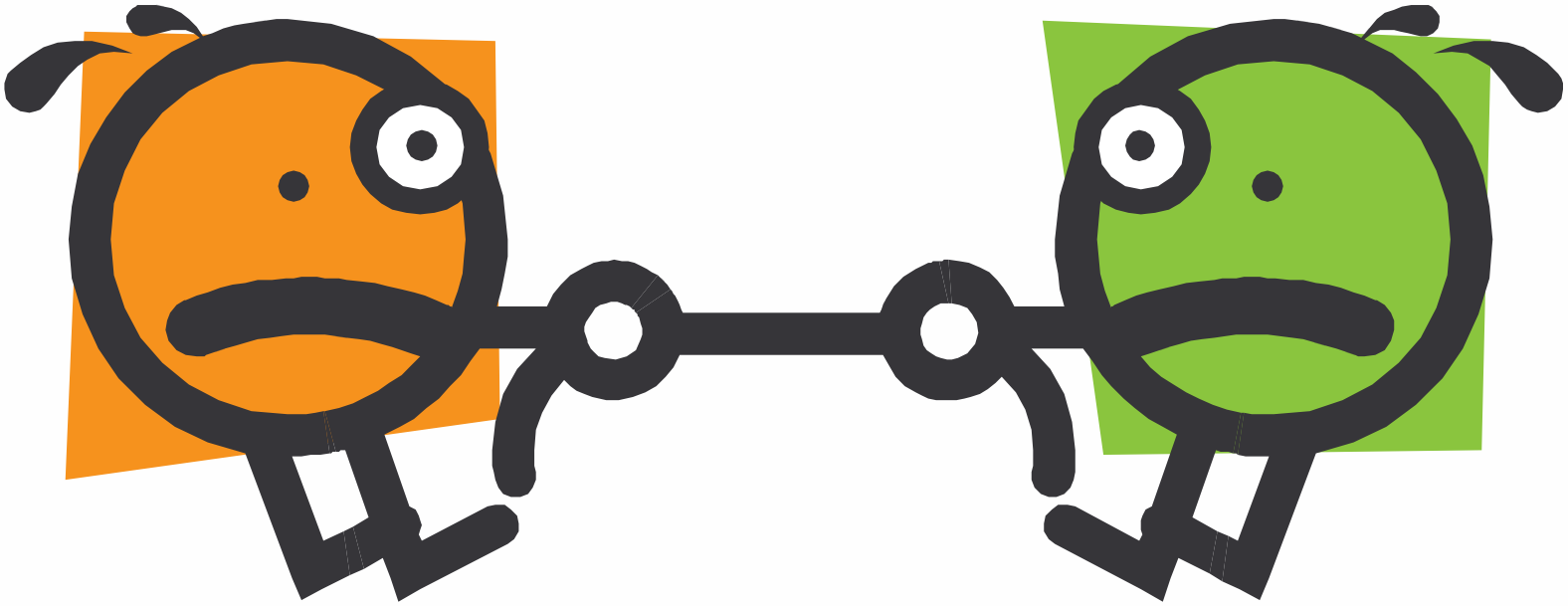
- What's the problem?
- “Typical” Application I/O
- I/O Solutions
- A Solution That Works
- Graphs, so many Graphs
- Take Home Notes

What's The Problem?

- Flops are Cheap, Bandwidth isn’t
- Machines and Applications aren’t getting any smaller
- But...
  - Isn't Lustre enough?
  - Can't I use libraries?
  - Doesn't it just work?
- Without user or programmer intervention, I/O will not perform at peak
- There is no *Silver Bullet*

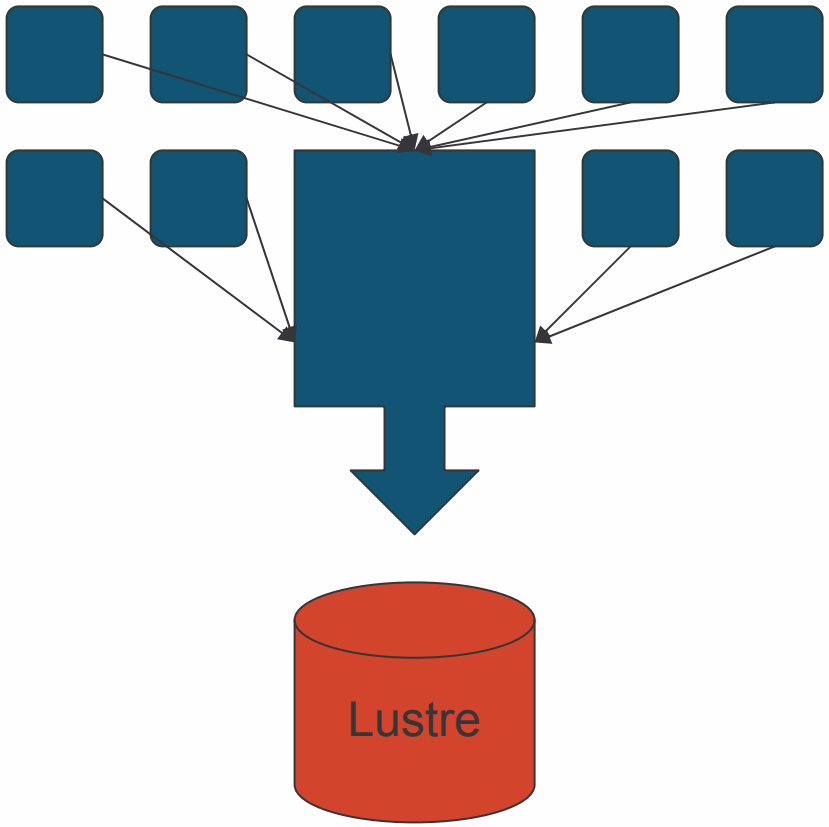
“Typical” Application I/O

- THERE IS NO TYPICAL APPLICATION I/O
- There are several common methods, but 2 are very common and problematic
  - Single-writer reduction
  - N-writer/N-reader to N-files



Simple **Efficient**

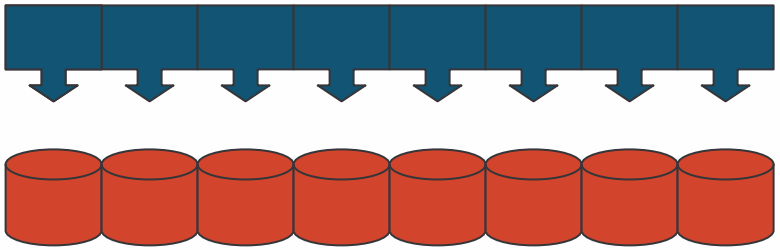
Single-writer Reduction



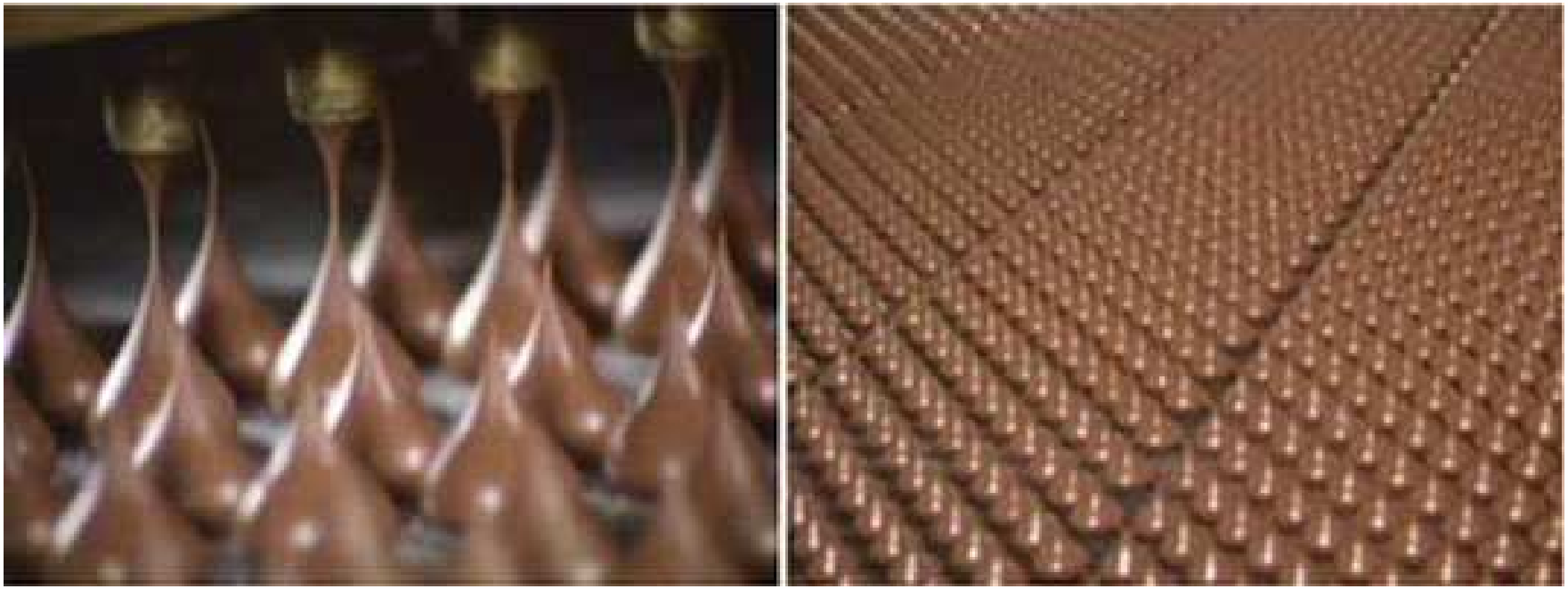
- The Plan
  - All processors send to 1 I/O node for output
  - File striped to maximum OSTs
- The Problem
  - Even with maximum striping, 1 node will never achieve maximum bandwidth
  - single node IO bandwidth is approximately 200 MB/s
  - reading/writing a terabyte would require more than 1 hour at current I/O rates

N-Writer to N-Files

- The Plan
  - Every process opens a file and dumps its data
  - Files striped to 1 OST
- The Problem
  - Can lead to slow opens and general filesystem slowness
  - If the writes are not large, performance will suffer
  - Inconvenient
  - Can only be used as input for same number of nodes
- One Modification
  - Use MPI-I/O for just 1 file
  - Suffers when i/o results in small buffers



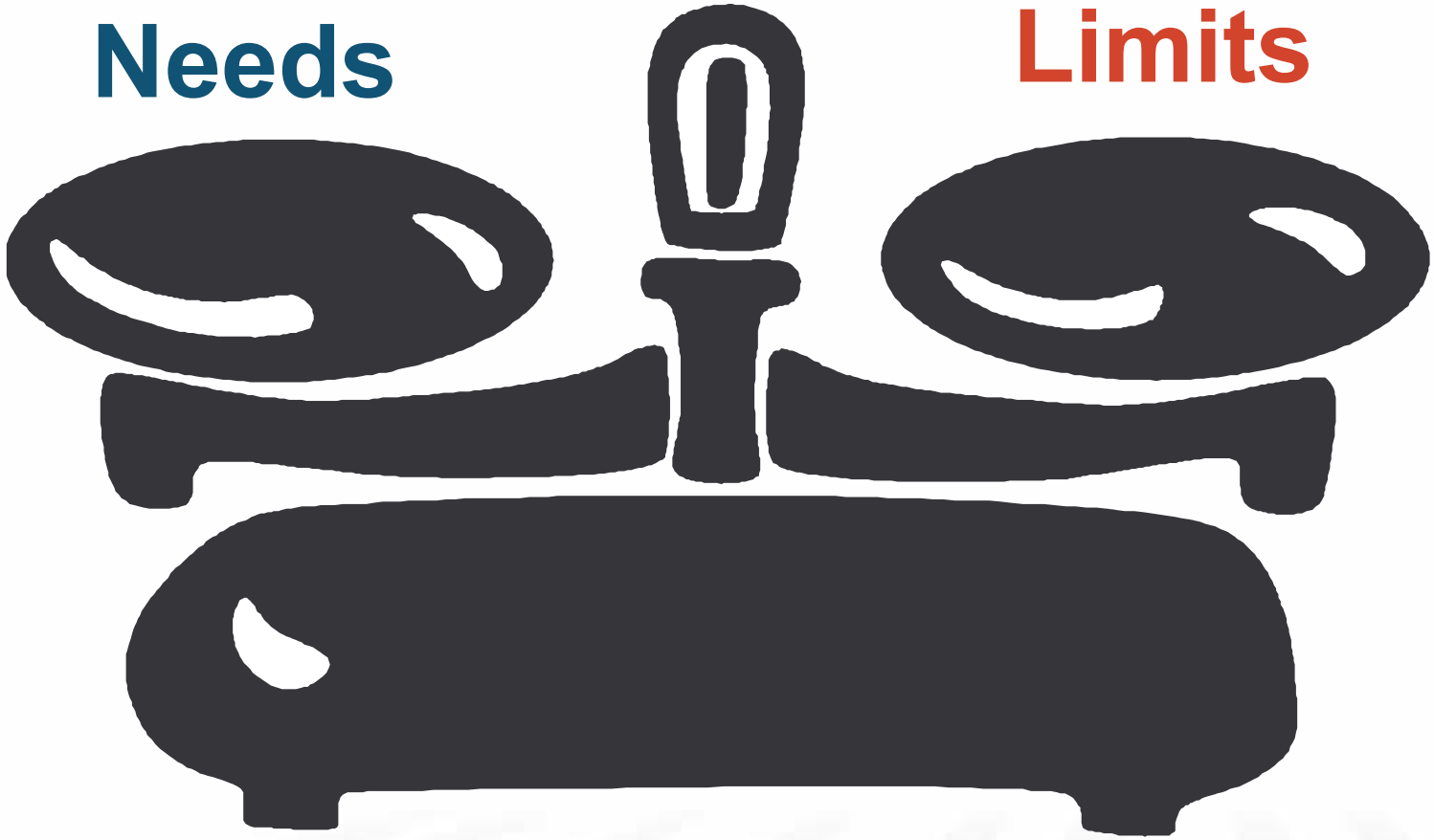
What does efficient I/O look like?



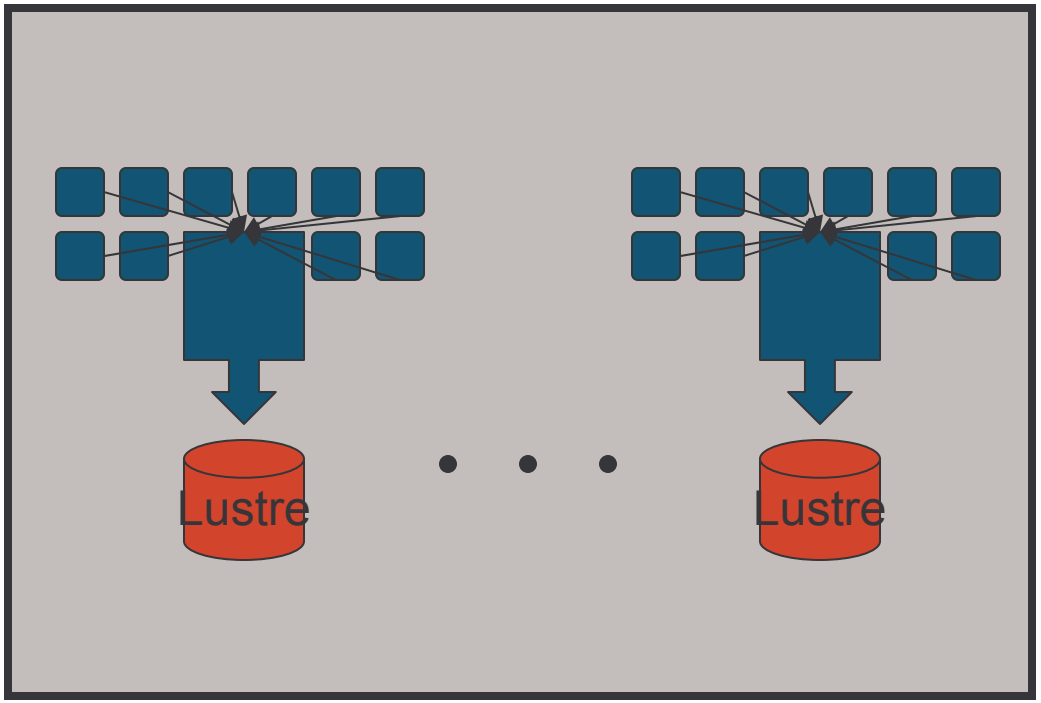
Striking a Balance

Application Needs

Filesystem Limits



Subset of Readers/Writers Approach



- The Plan:
  - Combine the best of our first two I/O methods
  - Choose a subset of nodes to do I/O
  - Send output to or Receive input from 1 node in your subset
- The Benefits
  - I/O Buffering
  - High Bandwidth, Low FS Stress
- The Costs
  - I/O Nodes must sacrifice memory for buffer
  - Requires Code Changes

Subset of Readers/Writers Approach

- Assumes job runs on thousands of nodes
- Assumes job needs to do large I/O
- From data partitioning, identify groups of nodes such that:
  - each node belongs to a single group
  - data in each group is contiguous on disk
  - there are approximately the same number of groups as OSTs
- Pick one node from each group to be the ionode
- Use MPI to transfer data within a group to its ionode
- Each IOnode reads/write shared disk file

Example Code: MPI Subset Communicator

create an MPI communicator that include only ionodes

```
call MPI_COMM_GROUP(MPI_COMM_WORLD,
    WORLD_GROUP,ierr)

call MPI_GROUP_INCL(WORLD_GROUP,niotasks,
  listofiotasks,IO_GROUP,ierr)

call MPI_COMM_CREATE(MPI_COMM_WORLD,IO_GROUP,
  MPI_COMM_IO,ierr)
```

Example Code: MPI I/O

open

```
  call MPI_FILE_OPEN(MPI_COMM_IO,trim(filename),
       filemode,finfo,mpifh,ierr)
```

read/write

```
  call MPI_FILE_WRITE_AT(mpifh, offset, iobuf,
        bufsize, MPI_REAL8,status,ierr)
```

close

```
  call MPI_FILE_CLOSE(mpifh,ierr)
```

Example Code: I/O Code Outline

- IONode:

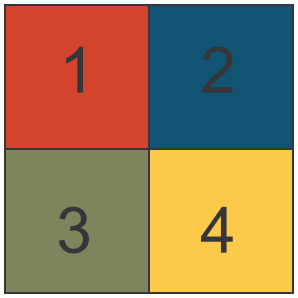
```
copy (scatter) this nodes data to IO buffer
loop over nonIOnodes in this group
mpi_recv data from compute node
copy(scatter) data to IO buffer
write data from IO buffer to disk
```

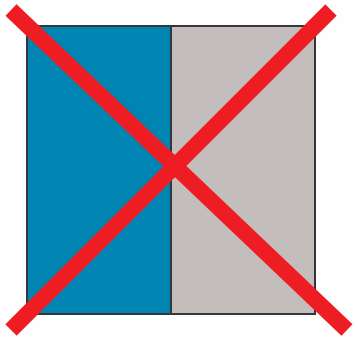
- Non-IONode:

```
copy data to mpi buffer
mpi send data to IO node
```

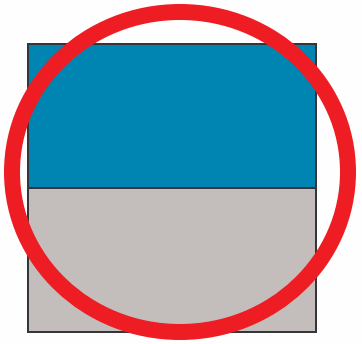
Sample Paritioning: POP

- data is 3d - X, Y, Z
- X and Y dimensions are partitioned in blocks
- sample 4 node partition:
  - Each of the 4 colored blocks represents one node's part of the data
  - Each of the two lighter colored blocks represent 1 I/O Node
  - I/O Groups should be arranged so their data is contiguous on disk





Data from nodes 1 & 3 alternate on disk. This will perform slowly and can't adjust to more processors.



Data from node 1 is contiguous, followed by data from node 2, which is also contiguous.

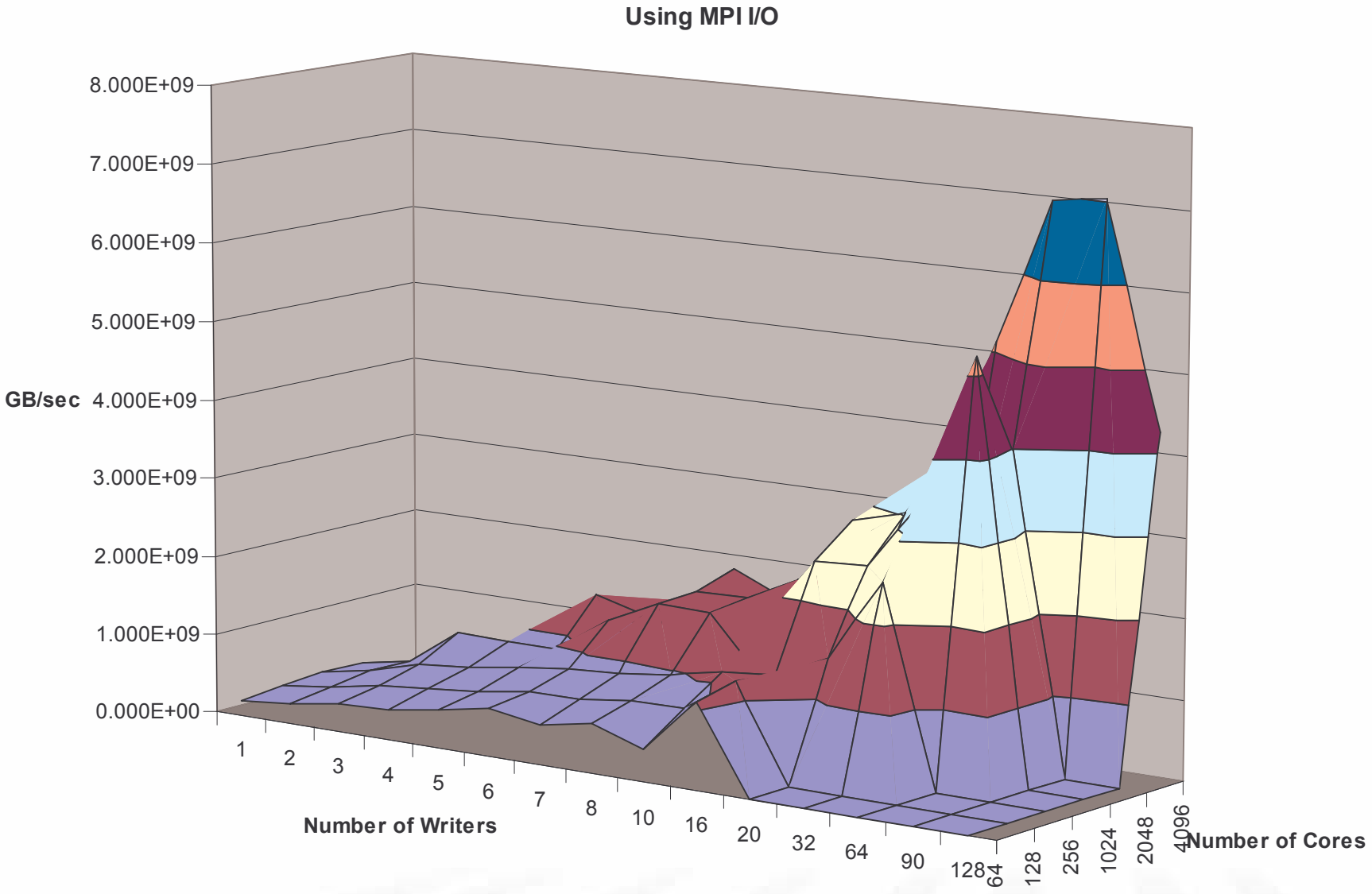
Sample Paritioning: POP

- Given a nearly square partitioning, the number of nodes simultaneously performing IO is approximately the square root of the total number of compute nodes.
  - 2500 compute nodes - 50 IO nodes
  - 10000 compute nodes - 100IO nodes
  - 25600 compute nodes - 160 IO nodes
- Many partitions allow a reasonable assignment of ionodes

For Example:

- An array of 8 byte reals (300, 400, 40) on each of 10000 nodes
  - 4.8 million elements on each node
  - 48 billion elements total
  - 384 gigabytes data
  - 50 - 100 seconds to read or write at 4 - 8 gbyte/sec
  - 100 IO nodes

A Subset of Writers Benchmark



Benchmark Results: Things to Know

- Uses write_at rather than file partitioning
- Only write data...sorry
  - Read data was largely similar
- Initial benchmarking showed MPI transfers to be marginal, so they were excluded in later benchmarking
- Real Application Data in the works, Come to CUG

Benchmark Results: 1 I/O Node - Stripes

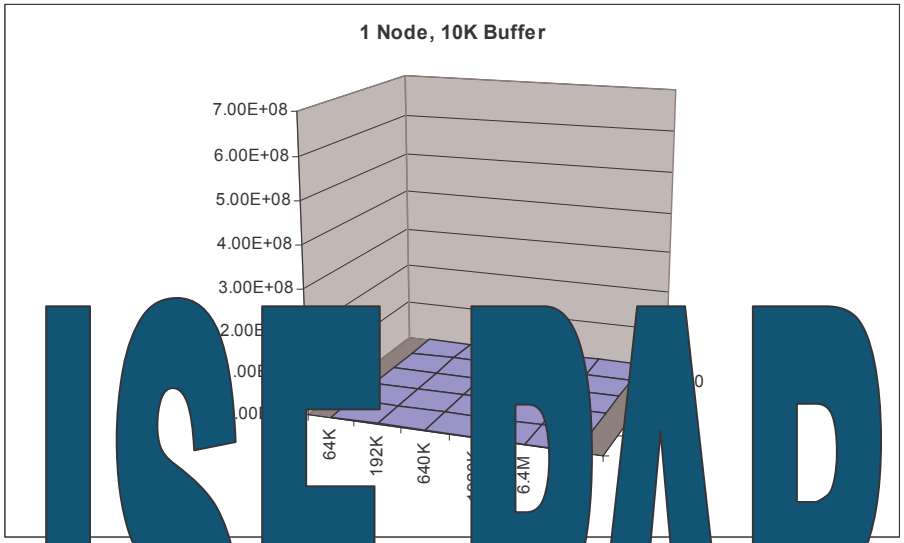
- Single IO node, 10 megabyte buffer, 20 megabyte stripe size: bandwidth of IO write to disk

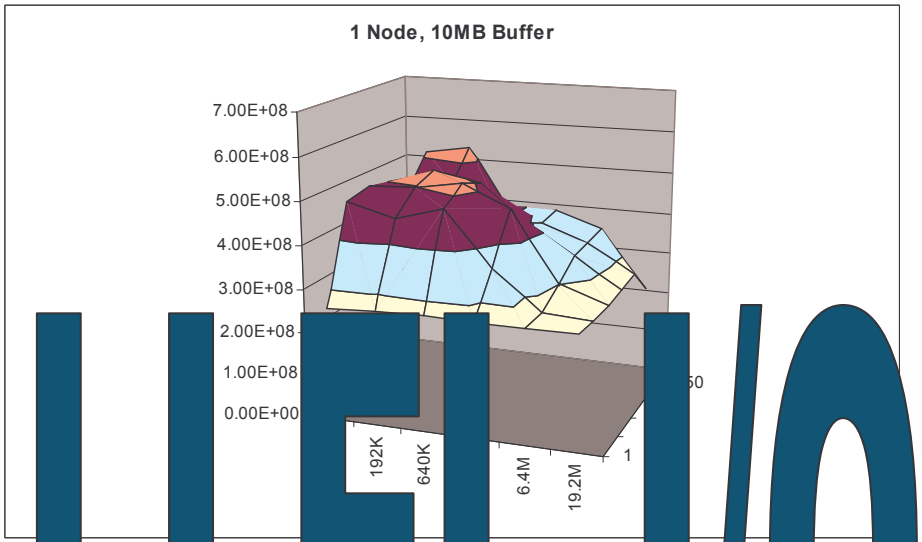
Number of stripes

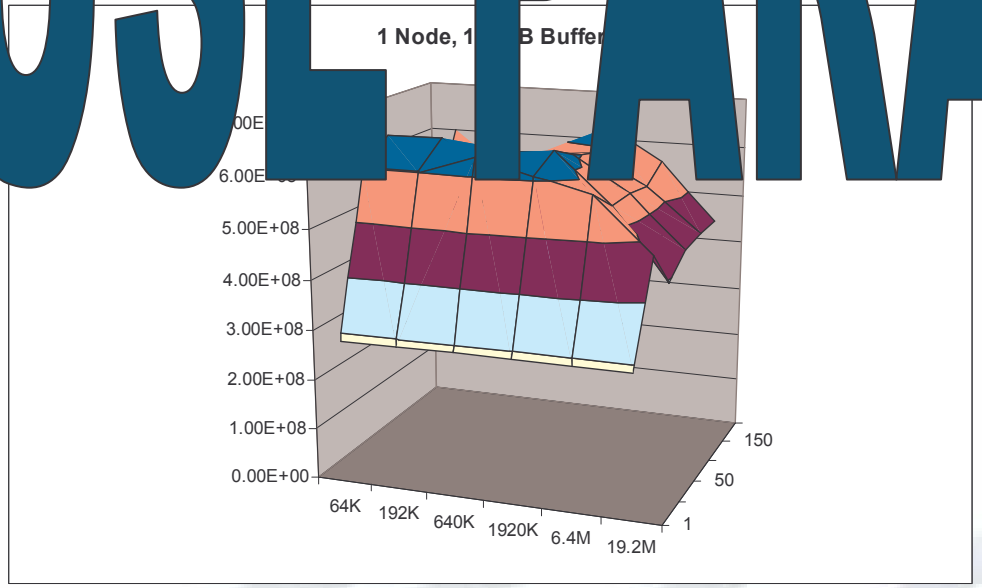
1	10	50	100	150	160
150MB/s	134MB/s	135MB/s	139MB/s	149MB/s	148MB/s

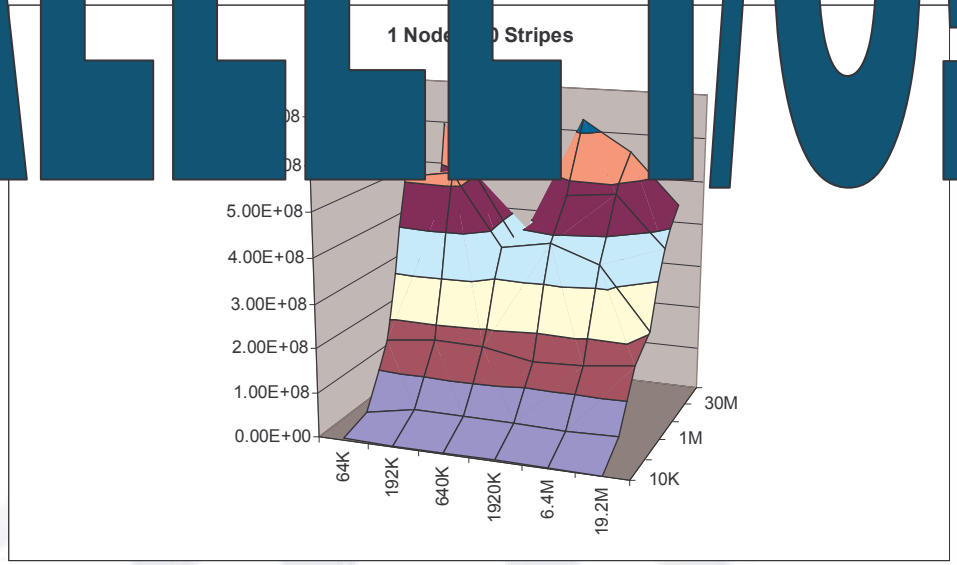
- Using a single IO node:
  - number of stripes doesn't matter
  - stripe size doesn't matter (timings not shown)

Benchmark Results: 1 I/O Node - Stripes





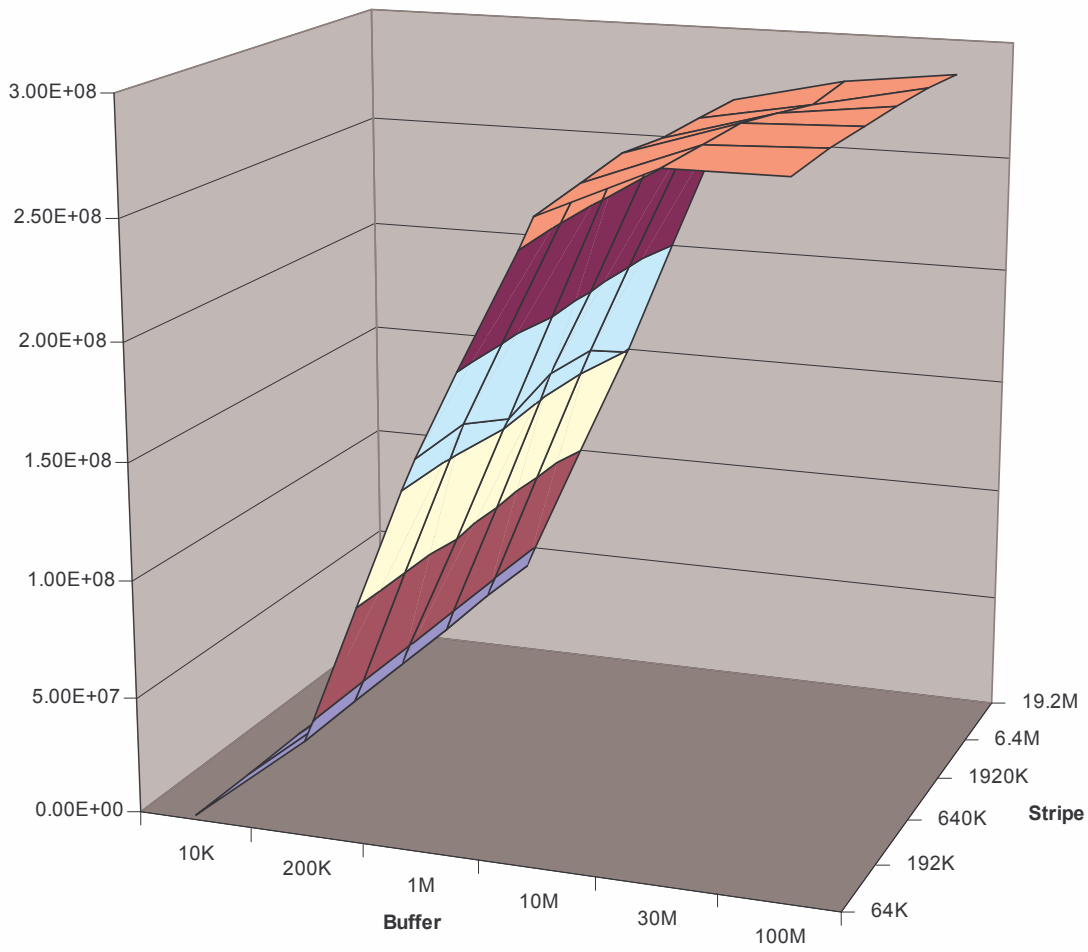




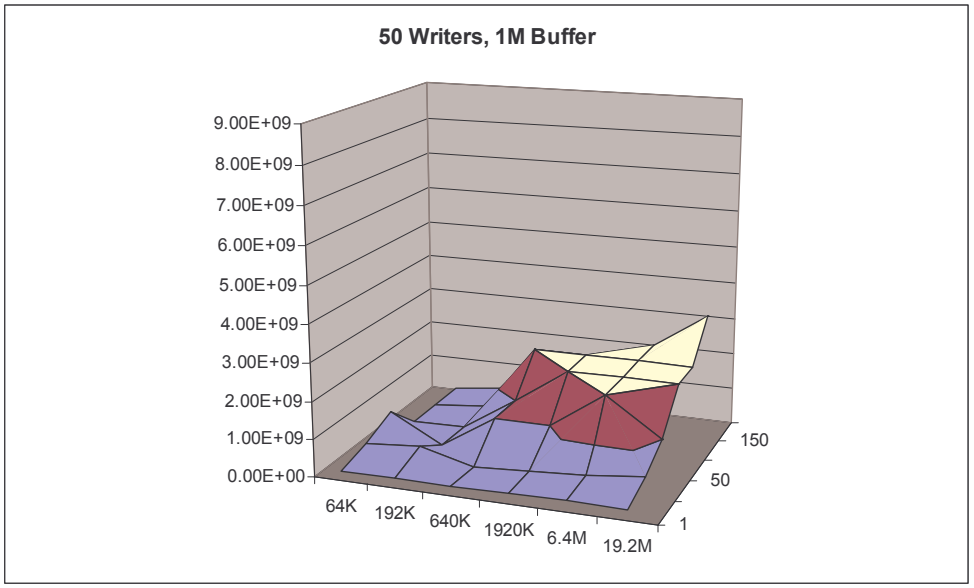
USE PARALLEL I/O!

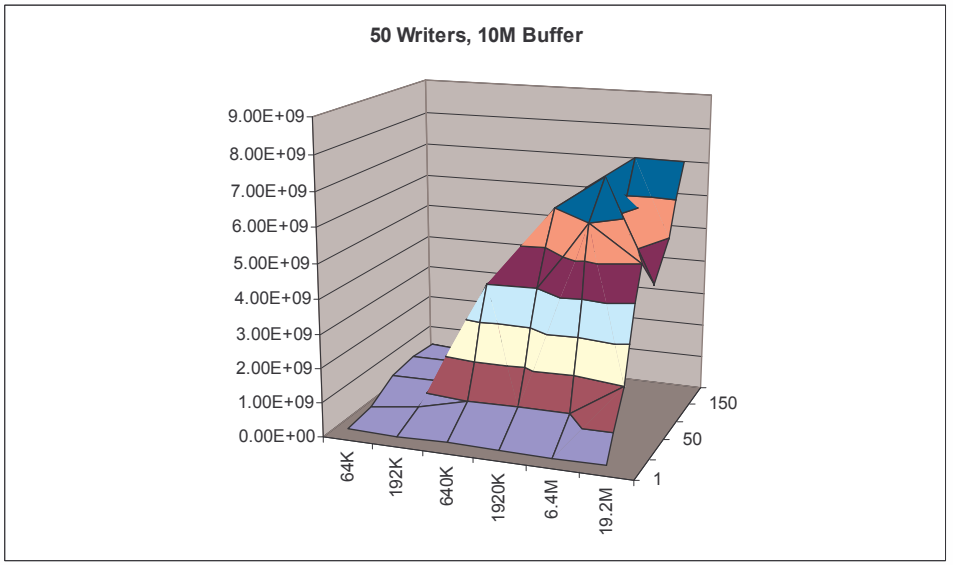
Benchmark Results: 1 I/O Node – Buffer Size

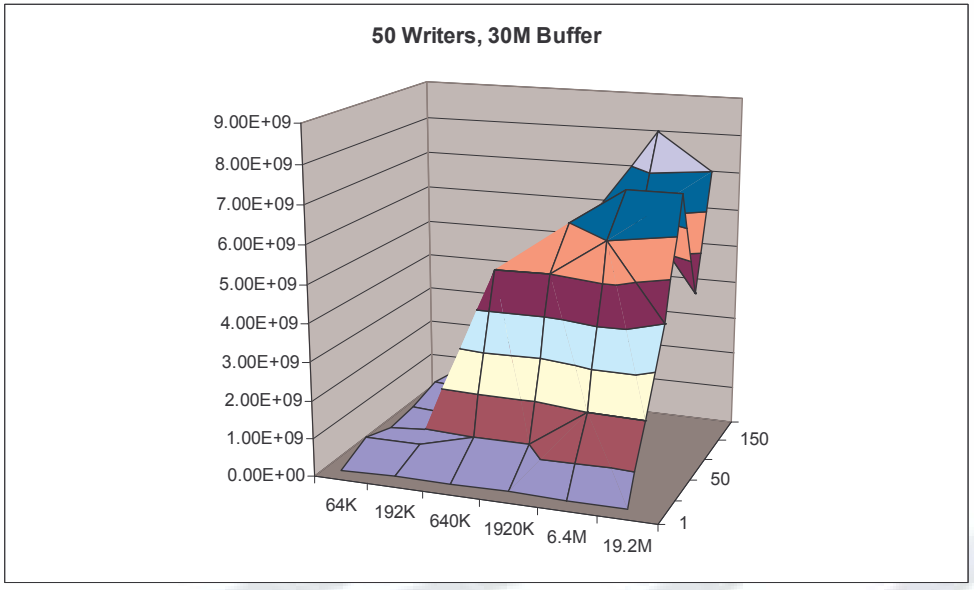
- Single node, single stripe: bandwidth of IO write to disk for different buffer sizes
  - Buffer size is the size of contiguous memory on one IO node written to disk with one write
- Buffer size should be at least 10 megabytes

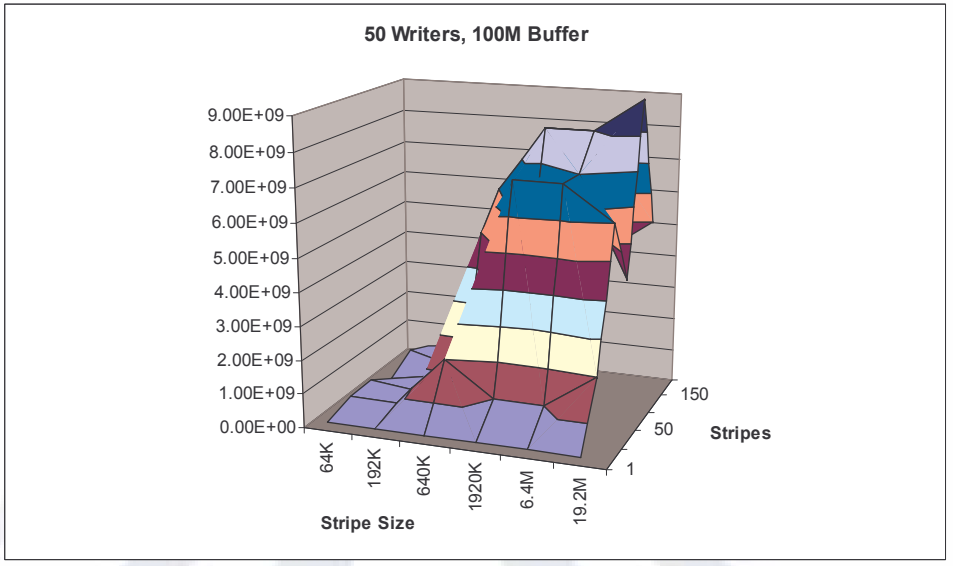


50 Writers, Varying Stripe Count, Size and Buffer Size

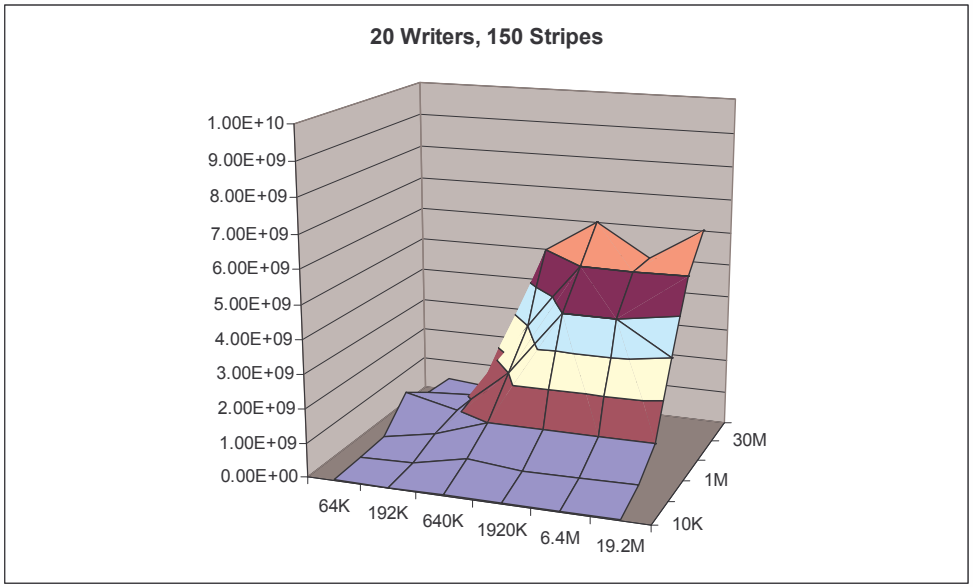


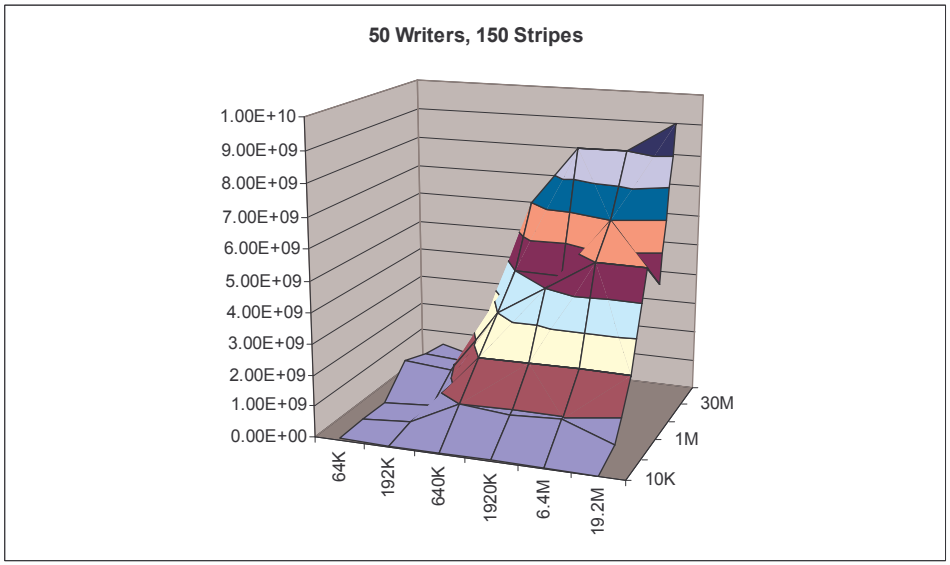


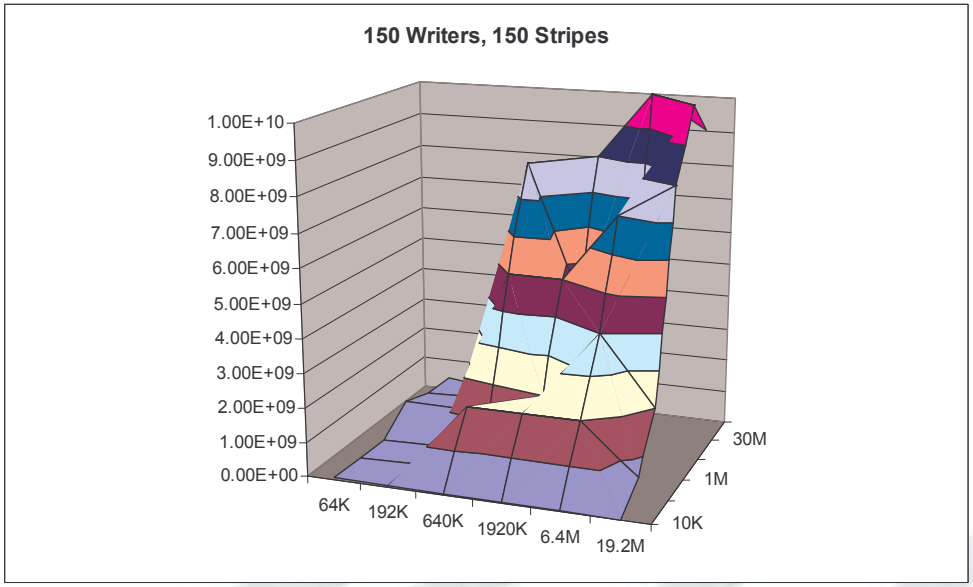


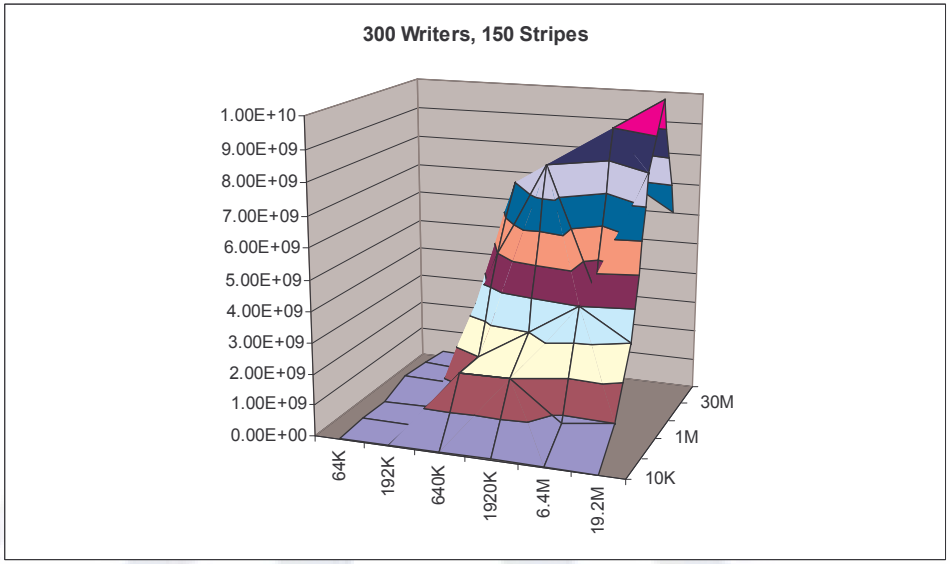


150 Stripes, Varying Writers, Buffer, and Stripe Sizes









Cliff's Take Home Notes

- Do Large I/O Operations in Parallel MPI-IO
- Create a natural partitioning of nodes so that data will go to disk in a way that makes sense
- Stripe as close to the maximum OSTs as possible given your partitioning
- Use buffers of at least 1MB, 10MB if you can afford it
- Make your I/O flexible so that you can tune to the problem and machine
  - One hard-coded solution will meet your some of the time, but not all of the time
- Come to CUG 2007 and see the application results!