ATPESC 2016

UNDERSTANDING I/O

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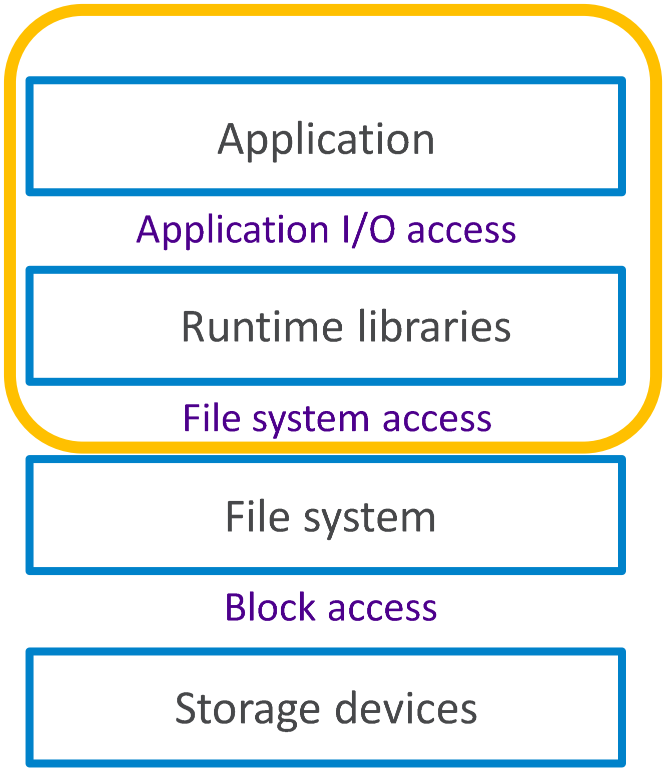
St. Charles IL

CHARACTERIZING APPLICATION I/O

How is your application using the I/O system, and how successful is it at attaining high performance?

- The best way to answer these questions is by observing behavior at the application and library level
- In this portion of the training course we will focus on ***Darshan***, a scalable tool for characterizing application I/O activity.

Simplified HPC I/O stack



DARSHAN: CONCEPT

Goal: to observe I/O patterns of the majority of applications running on production HPC platforms, without perturbing their execution, with enough detail to gain insight and aid in performance debugging.

- Majority of applications – transparent integration with system build environment
- Without perturbation – bounded use of resources (memory, network, storage); no communication or I/O prior to job termination; compression.
- Adequate detail:
  - basic job statistics
  - file access information from multiple APIs

THE TECHNOLOGY BEHIND DARSHAN

- Intercepts I/O functions using link-time wrappers
  - No code modification
  - Can be transparently enabled in MPI compiler scripts
  - Compatible with all major C, C++, and Fortran compilers
- Record statistics independently at each process, for each file
  - Bounded memory consumption
  - Compact summary rather than verbatim record
- Collect, compress, and store results at shutdown time
  - Aggregate shared file data using custom MPI reduction operator
  - Compress remaining data in parallel with zlib
  - Write results with collective MPI-IO
  - Result is a single gzip-compatible file containing characterization information
- Works for Linux clusters, Blue Gene, and Cray systems

DARSHAN: ANALYSIS EXAMPLE

The **darshan-job-summary** tool produces a 3-page PDF file that summarizes job I/O behavior

Run time

Performance estimate

Percentage of runtime in I/O

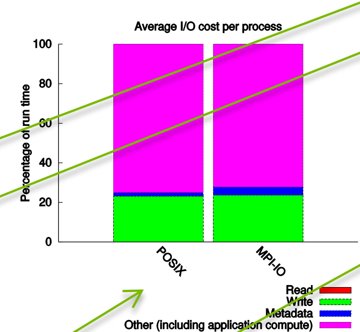
Access type histograms

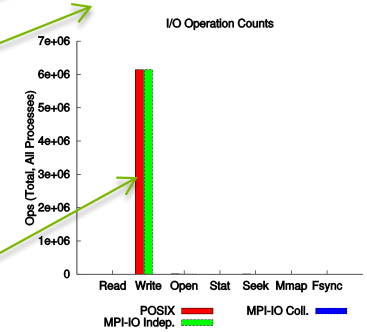
Access size histogram

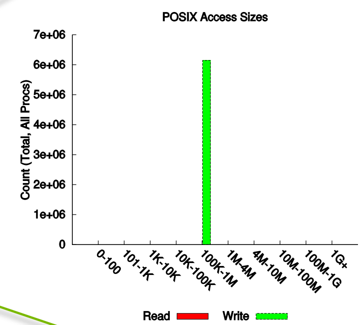
File usage

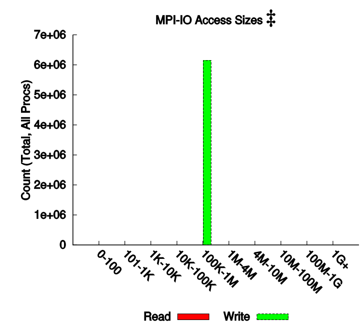
jobid: 1723213	uid: 69628	nprocs: 6000	runtime: 71 seconds

I/O performance *estimate* (at the MPI-IO layer): transferred 3072000.0 MiB at 48781.92 MiB/s









Most Common Access Sizes

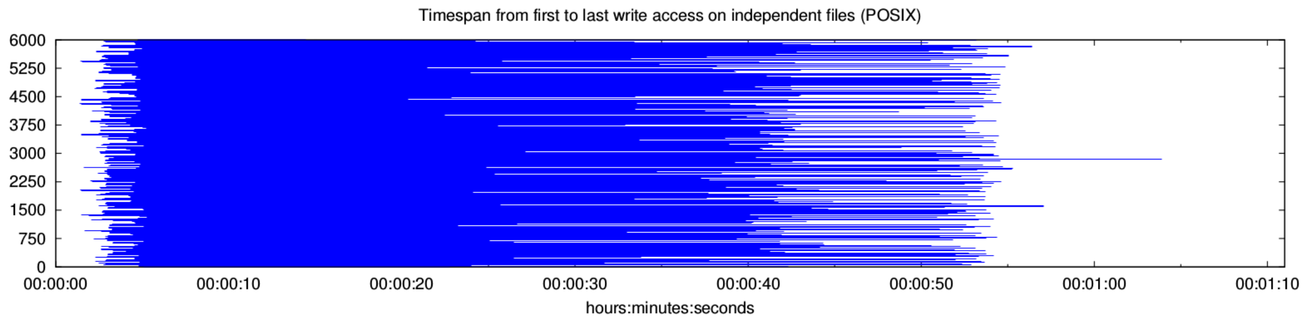
	access size	count
POSIX	524288	6144000
MPI-IO ‡	524288	6144000

‡ NOTE: MPI-IO accesses are given in terms of aggregate datatype size.

File Count Summary
(estimated by POSIX I/O access offsets)

type	number of files	avg. size	max size
total opened	6000	512M	512M
read-only files	0	0	0
write-only files	6000	512M	512M
read/write files	0	0	0
created files	6000	512M	512M

Darshan analysis example (page 2)



Time

This graph (and others like it) are on the second page of the darshan-job-summary.pl output. This example shows intervals of I/O activity from each MPI process. In this case we see that different ranks completed I/O at very different times.

HOW TO USE DARSHAN

- Compile a C, C++, or FORTRAN program that uses MPI
- Run the application
- Look for the Darshan log file
- This will be in a particular directory (depending on your system's configuration)
  - <dir>/<year>/<month>/<day>/<username>_<appname>*.darshan*
    - Mira: see /projects/logs/darshan/
    - Edison: see /scratch1/scratchdirs/darshanlogs/
    - Cori: see /global/cscratch1/sd/darshanlogs/
- Use Darshan command line tools to analyze the log file

- Application must run to completion and call MPI_Finalize() to generate a log file
- Warning/disclaimer: Darshan does not currently work for *F90* programs on Mira
- Opt in (i.e., by loading module or software key) at OLCF, LANL, LLNL and others: see site-specific documentation

AVAILABLE DARSHAN ANALYSIS TOOLS

- http://www.mcs.anl.gov/research/projects/darshan/docs/darshan-util.html
- Key tools:
  - **Darshan-job-summary.pl**: creates pdf with graphs for initial analysis
  - **Darshan-summary-per-file.sh**: similar to above, but produces a separate pdf summary for every file opened by application
  - **Darshan-parser**: dumps all information into text format

Darshan-parser example (see all counters related to write operations):

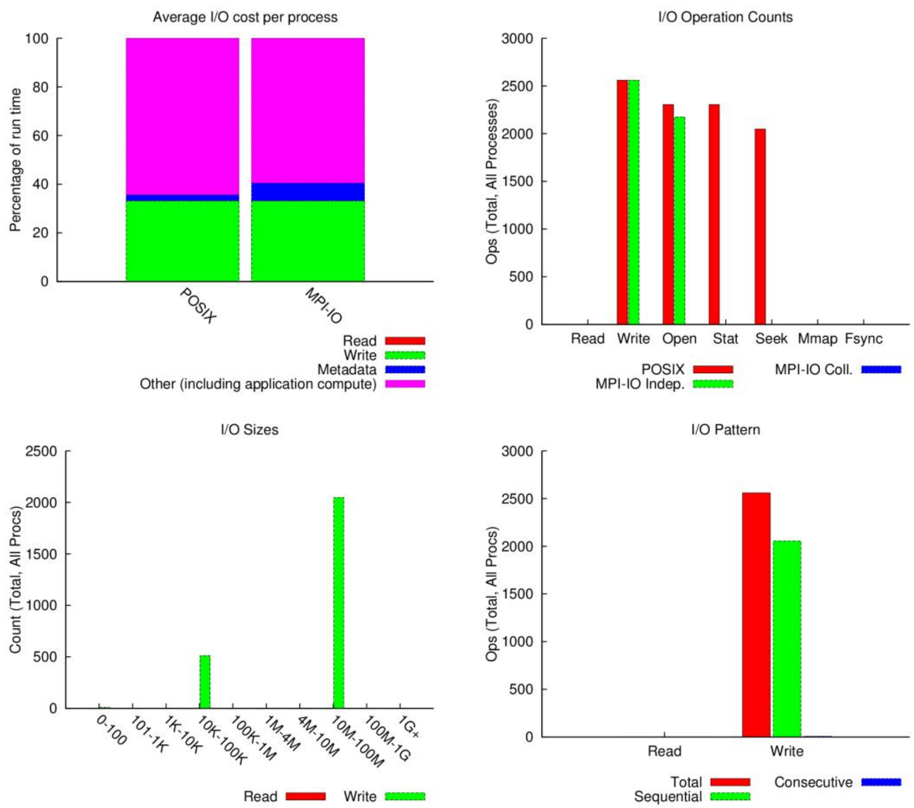
“darshan-parser user_app_numbers.darshan.gz |grep WRITE”

See documentation above for definition of output fields

DARSHAN: EXAMPLES OF FINDING AND ISOLATING I/O PERFORMANCE PROBLEMS

EXAMPLE: CHECKING USER EXPECTATIONS

jobid:	uid: (	nprocs: 4096	runtime: 175 seconds



Most Common Access Sizes

access size	count
67108864	2048
41120	512
8	4
4	3

File Count Summary

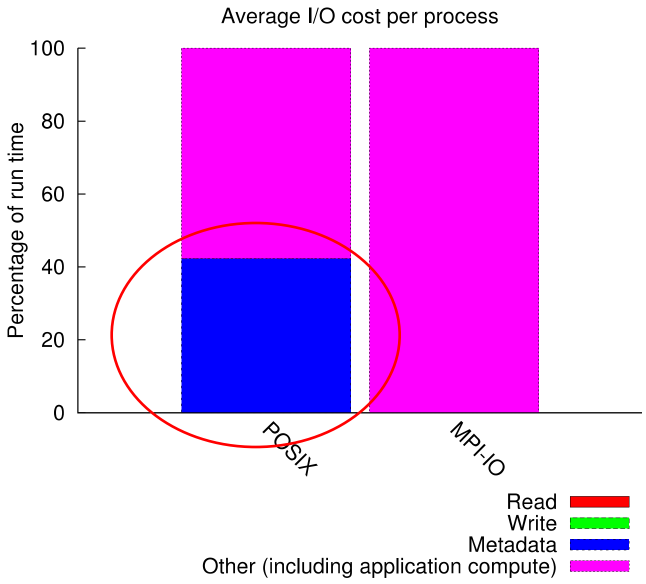
type	number of files	avg. size	max size
total opened	129	1017M	1.1G
read-only files	0	0	0
write-only files	129	1017M	1.1G
read/write files	0	0	0
created files	129	1017M	1.1G

- User opened 129 files (one “control” file, and 128 data files)
- Should be one header, about 40 KiB, per data file
- This example shows 512 headers being written
  - Code bug: header was written 4x per file

PERFORMANCE DEBUGGING OUTPUT

- Combustion physics application
  - Was writing 2-3 files per process with up to 32,768 cores
  - Darshan attributed 99% of the I/O time to metadata (on Intrepid BG/P)

jobid: 0	uid: 1817	nprocs: 8192	runtime: 863 seconds



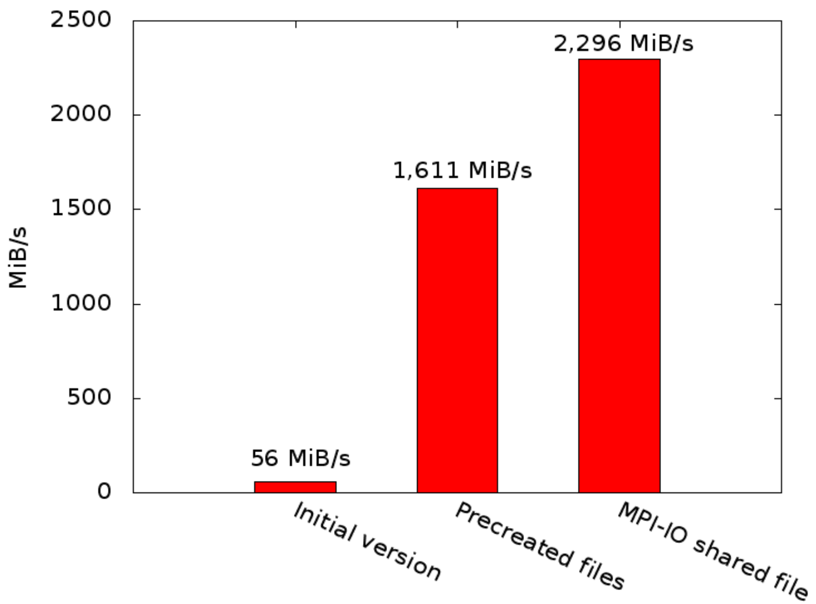
File Count Summary

type	number of files	avg. size	max size
total opened	16388	2.5M	8.1M
read-only files	0	0	0
write-only files	16388	2.5M	8.1M
read/write files	0	0	0
created files	16388	2.5M	8.1M

SIMULATION OUTPUT (CONTINUED)

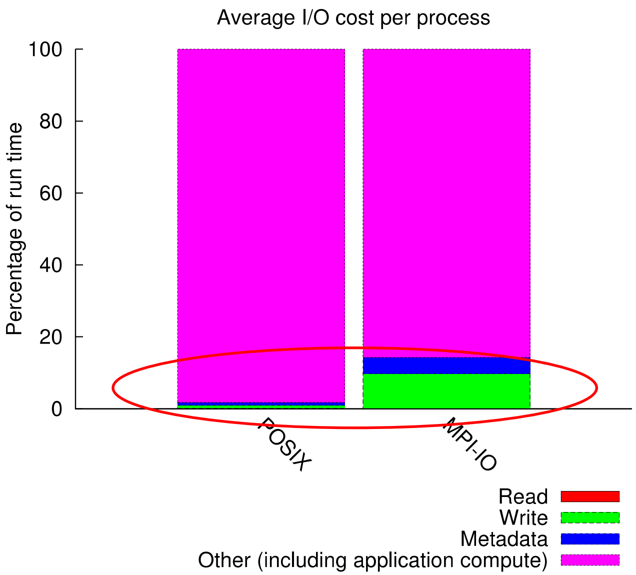
- With help from ALCF catalysts and Darshan instrumentation, we developed an I/O strategy that used MPI-IO collectives and a new file layout to reduce metadata overhead
- **Impact: 41X improvement in I/O throughput for production application**

I/O performance with 32,768 cores

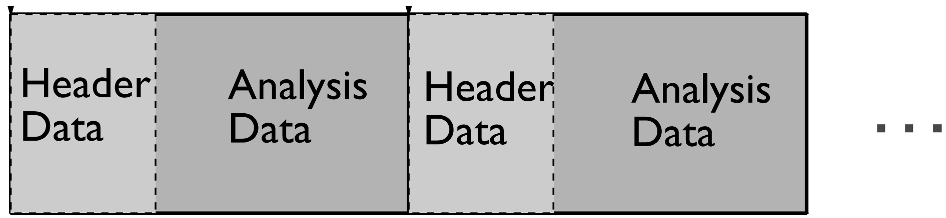


File Count Summary

type	number of files	avg. size	max size
total opened	8	515M	2.0G
read-only files	2	2.2K	3.7K
write-only files	6	686M	2.0G
read/write files	0	0	0
created files	6	686M	2.0G



PERFORMANCE DEBUGGING: AN ANALYSIS I/O EXAMPLE

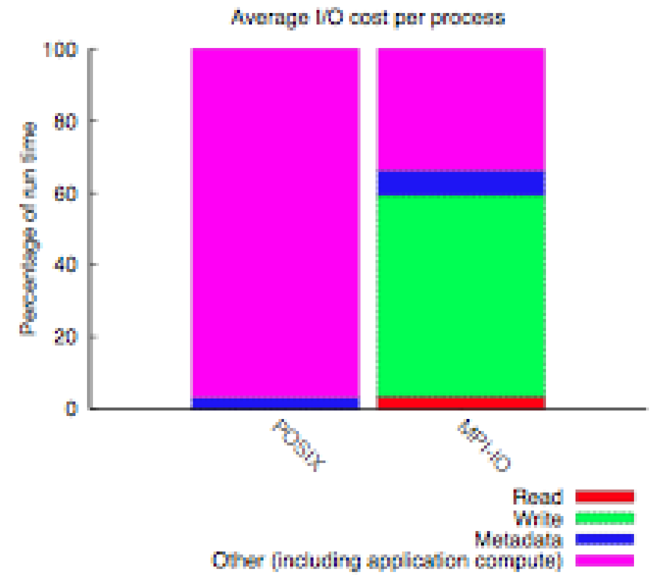


- Variable-size analysis data requires headers to contain size information
- Original idea: all processes collectively write headers, followed by all processes collectively write analysis data
- Use MPI-IO, collective I/O, all optimizations
- 4 GB output file (not very large)
- Why does the I/O take so long in this case?

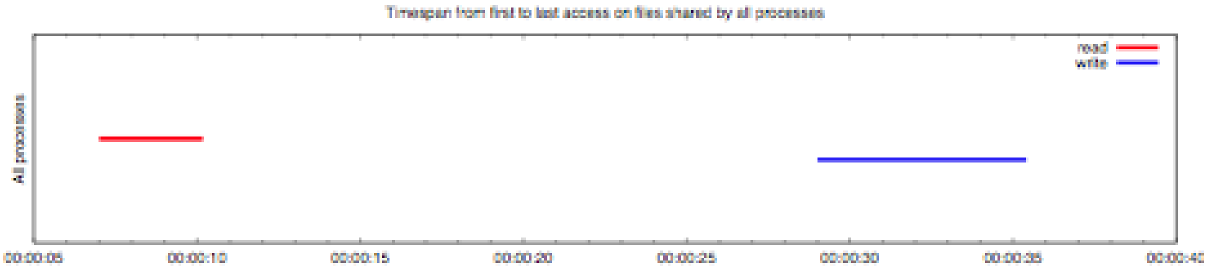
Processes	I/O Time (s)	Total Time (s)
8,192	8	60
16,384	16	47
32,768	32	57

AN ANALYSIS I/O EXAMPLE (CONTINUED)

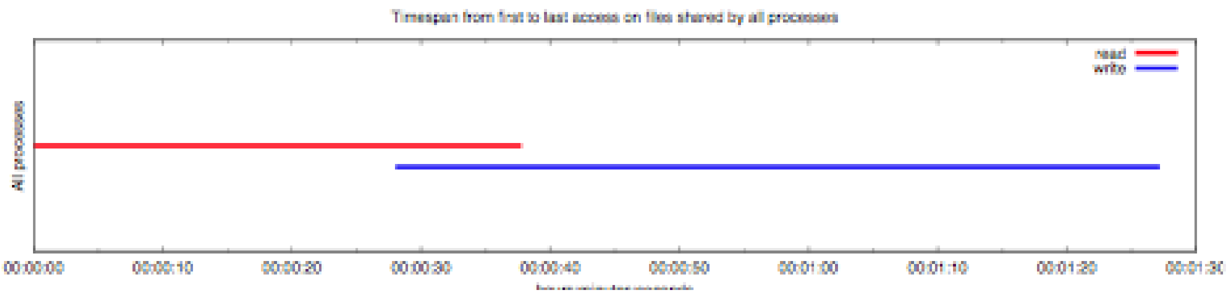
- **Problem**: More than 50% of time spent writing output at 32K processes. Cause: Unexpected RMW pattern, difficult to see at the application code level, was identified from Darshan summaries.



- What we expected to see, read data followed by write analysis:

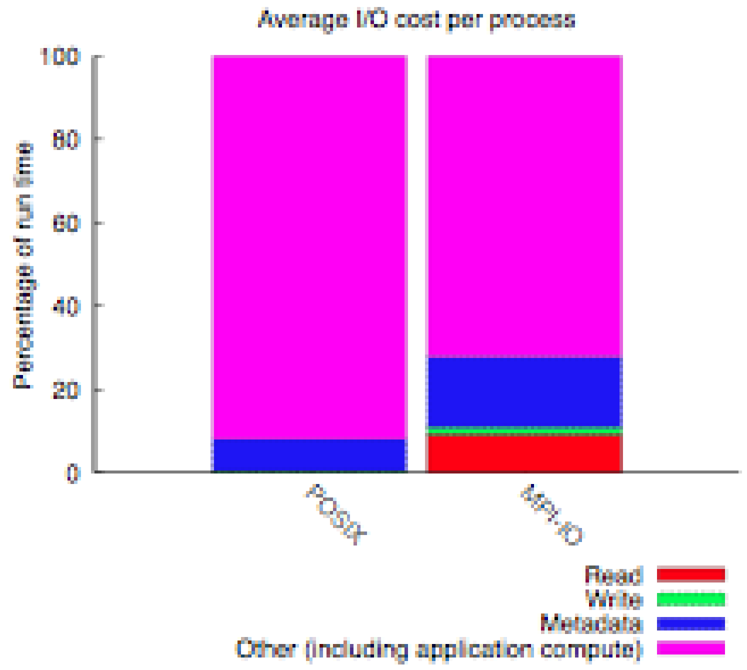


- What we saw instead: RMW during the writing shown by overlapping red (read) and blue (write), and a very long write as well.



AN ANALYSIS I/O EXAMPLE (CONTINUED)

- **Solution**: Reorder operations to combine writing block headers with block payloads, so that "holes" are not written into the file during the writing of block headers, to be filled when writing block payloads
- **Result**: Less than 25% of time spent writing output, output time 4X shorter, overall run time 1.7X shorter
- **Impact**: Enabled parallel Morse-Smale computation to scale to 32K processes on Rayleigh-Taylor instability data



Processes	I/O Time (s)	Total Time (s)
8,192	7	60
16,384	6	40
32,768	7	33

EXAMPLE: REDUNDANT READ TRAFFIC

- Scenario: Applications that read more bytes of data from the file system than were present in the file
  - Even with caching effects, this type of job can cause disruptive I/O network traffic
  - Candidates for aggregation or collective I/O
- Example:
  - Scale: 6,138 processes
  - Run time: 6.5 hours
  - Avg. I/O time per process: 27 minutes
- 1.3 TiB of file data
- 500+ TiB read!

File Count Summary
(estimated by I/O access offsets)

type	number of files	avg. size	max size
total opened	1299	1.1G	8.0G
read-only files	1187	1.1G	8.0G
write-only files	112	418M	2.6G
read/write files	0	0	0
created files	112	418M	2.6G

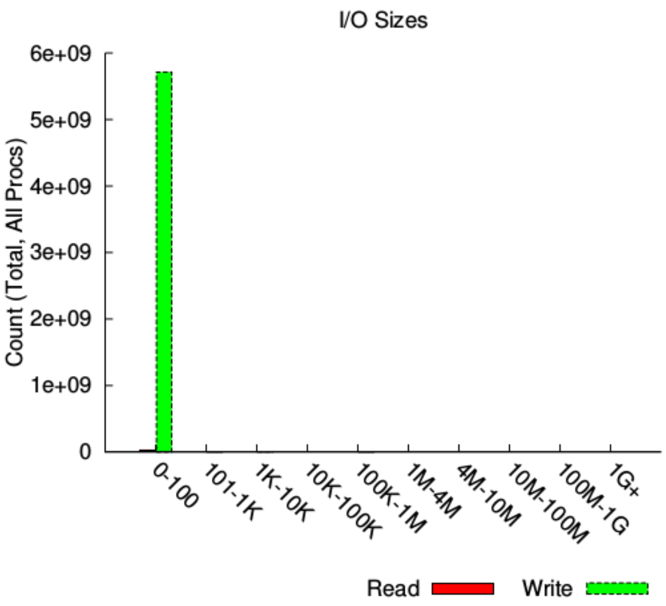
Data Transfer Per Filesystem

File System	Write		Read	
	MiB	Ratio	MiB	Ratio
/	47161.47354	1.00000	575224145.24837	1.00000

EXAMPLE: SMALL WRITES TO SHARED FILES

- Scenario: Small writes can contribute to poor performance
  - Particularly when writing to shared files
  - Candidates for collective I/O or batching/buffering of write operations

- Example:
  - Issued 5.7 billion writes to shared files, each less than 100 bytes in size
  - Averaged just over 1 MiB/s per process during shared write phase

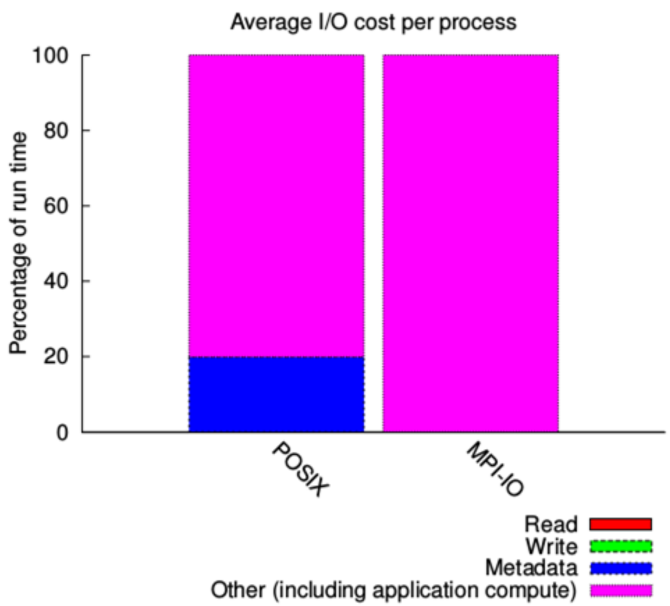


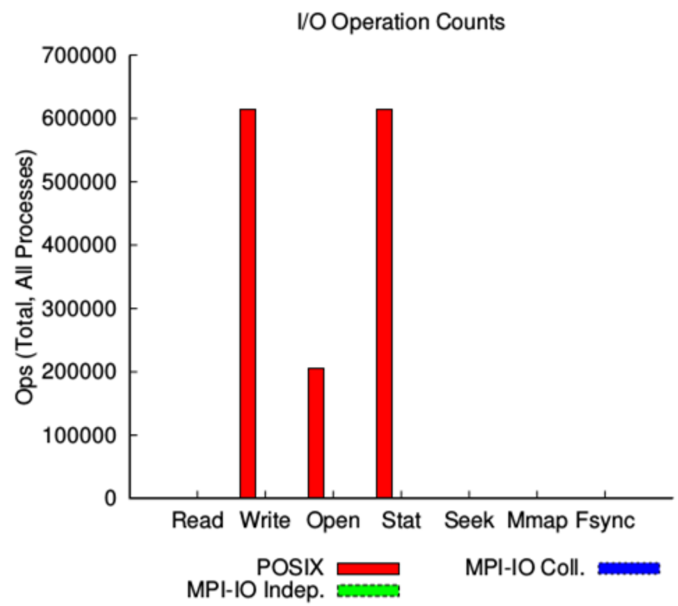
Most Common Access Sizes

access size	count
1	3418409696
15	2275400442
24	42289948
12	14725053

EXAMPLE: EXCESSIVE METDATA OVERHEAD

- Scenario: Very high percentage of I/O time spent performing metadata operations such as open(), close(), stat(), and seek()
  - Close() cost can be misleading due to write-behind cache flushing
  - Candidates for coalescing files and eliminating extra metadata calls
- Example:
  - Scale: 40,960 processes for 229 seconds, 103 seconds of I/O
  - 99% of I/O time in metadata operations
  - Generated 200,000+ files with 600,000+ write() and 600,000+ stat() calls





METADATA SIDE TOPIC: WHAT'S SO BAD ABOUT STAT()?

- stat() is actually quite cheap on most file systems (and practically free on a laptop)
- But not a large-scale HPC I/O system!

- The usual problem is that stat() requires a consistent size calculation for the file
- To do this, a PFS has two options:
  - Store a precalculated size on the metadata server, which becomes a source of contention
  - Calculate size on demand, which might cause a storm of requests to *all* servers
- No present-day PFS deployments respond very well when thousands of processes stat() the same file at once

I/O UNDERSTANDING TAKEAWAY

- Scalable tools like Darshan can yield useful insight
  - Identify characteristics that make applications successful
    …and those that cause problems.
  - It's easy to use, in fact the technically hard part (instrumenting your application) may already be done

- Scalable performance tools require special considerations
  - Target the problem domain carefully to minimize amount of data
  - Avoid shared resources
  - Use collectives where possible

- For more information, see:
  http://www.mcs.anl.gov/research/projects/darshan

I/O PERFORMANCE TUNING “RULES OF THUMB”

- Make sure you are using the right file system
  - Burst buffers if you have them
  - *Not your home directory*
- Use collectives when possible
- Use high-level libraries (e.g. HDF5 or PnetCDF) when possible
- A few large I/O operations are better than many small I/O operations
- Avoid unnecessary metadata operations, especially *stat()*
- Avoid writing to shared files with POSIX
- Avoid leaving gaps/holes in files to be written later
- Use tools like Darshan to check assumptions about behavior
  - It’s probably already instrumenting your code

THANK YOU!

THIS CONCLUDES “UNDERSTANDING I/O”

NEXT UP: “FUTURE OF I/O”