OMNIO: A Tool for I/O Recording, Analysis and Replay

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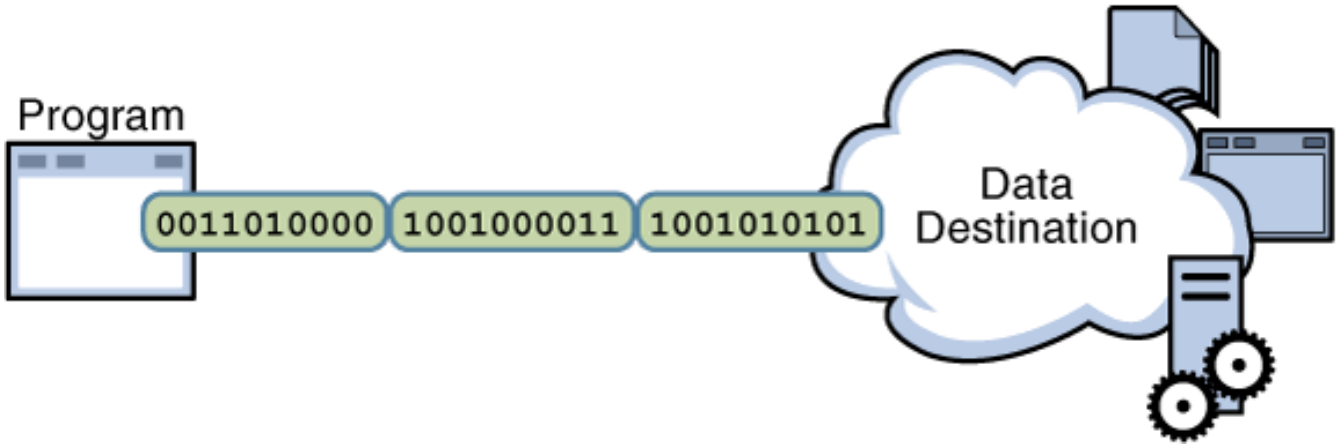
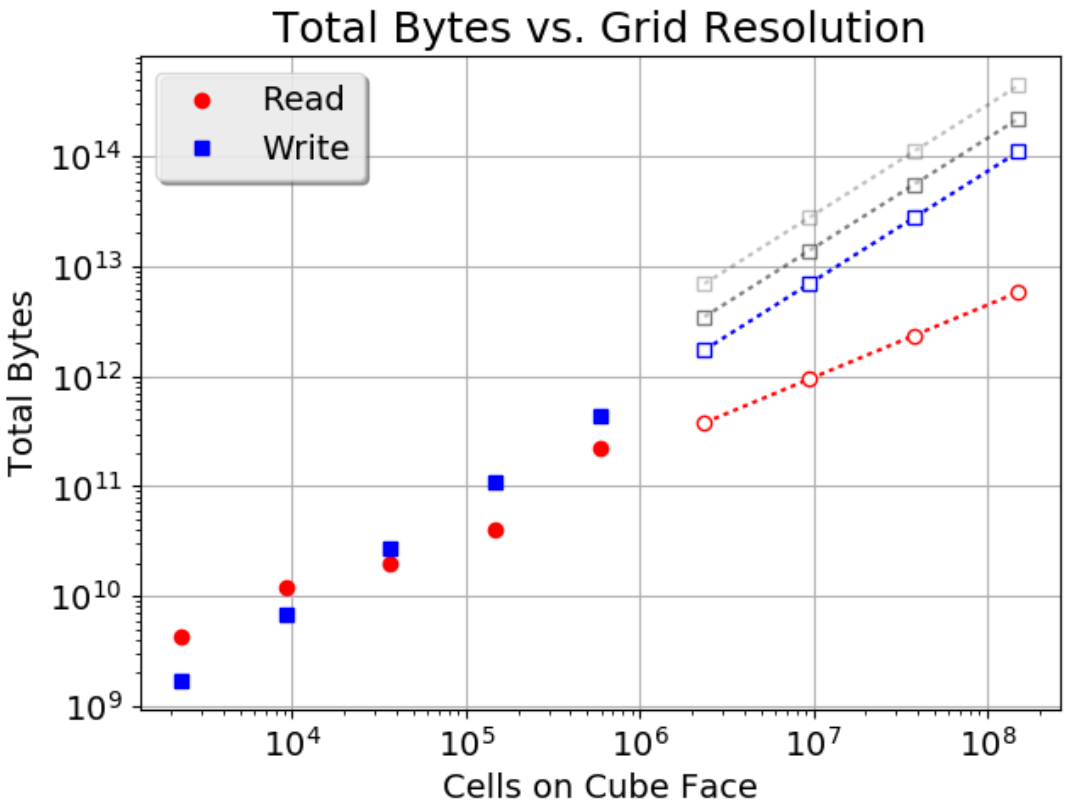
Introduction

- Motivation
- OMNIO Tool
  - Trace
  - Statistics
  - Preprocess
  - Replay
- Current Status
  - Architecture
  - Trace + Statistics
- Future
  - Preprocess + Replay
- Development



Motivation

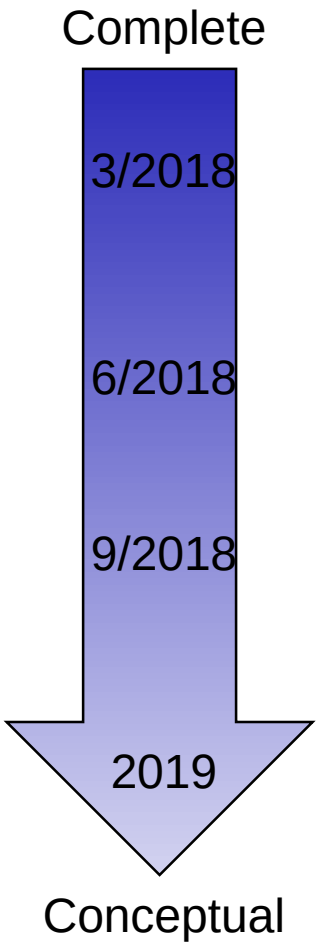
- Performance of storage system not keeping pace with compute
- File I/O can be a major portion of total run time
- As we move to higher resolution the problem only grows
- Difficult to identify bottlenecks without knowing the application
- Difficult to benchmark I/O pattern without porting codes to other systems



Purpose & Requirements

- Purpose
  - A self contained application to capture the I/O patterns of applications, examine them and replicate the pattern on a compute system of interest
- Requirements
  - Capture all POSIX level I/O calls and have capability to be extended in the future (MPI, NetCDF, etc.)
  - Record and replay calls within parallel applications using OpenMP and MPI
  - Present results in a human readable format to facilitate learning and modification of patterns for replay
- OMNIO Is Not
  - A library to facilitate I/O operations (i.e. ADIOS, PIO, etc.)

Current Overview (4 Tools)



- Trace
  - Trace an applications I/O pattern and record in log file
- Statistics
  - Create reports and charts from log files
  - Allow exploration using GUI
- Preprocessor
  - Process log files into instructions for replay and position data to read
- Replay
  - Replay a previously recorded I/O pattern

Trace Implementation

- Implemented in C++11
  - Leverage STL
    - chrono timers
    - map file descriptors
    - etc.
- Compile into four *.so files
  - Serial
  - OpenMP
  - MPI
  - MPI + OpenMP

Define a function pointer type and declare one variable

```
using open_ptr_type  =  int(*)(const char* path, int flags, ...);
static open_ptr_type  open;    //<  Inside struct Posix
```

Look up the “actual” function pointer from the symbol table at startup

```
open_ptr_type   Posix::open  =  (open_ptr_type)dlsym(RTLD_NEXT, "open");
```

Code Example

```
ssize_t read(int fd, void *buf, size_t count){
        Logger&  logger = Logger::instance();
        FileMap& fmap  = FileMap::instance();

        std::string path = fmap.getFilepath(fd);

        ssize_t result;
        if( logger.not_active(path) ){
                result = Posix::read(fd,buf,count);
        }
        else {
                Event ev("read");
                ev.setStartTime();
                result = Posix::read(fd,buf,count);
                ev.setStopTime();
                ev.insert("path",path);
                ev.insert("fd",fd);
                ev.insert("count",count);
                ev.insert("result",result);
                logger.log(ev);
        }
        return result;
}
```

Same interface as intercepted call

Maps file descriptor to file name

Shortcut to “actual” call if not logging file

Time call

Record all arguments

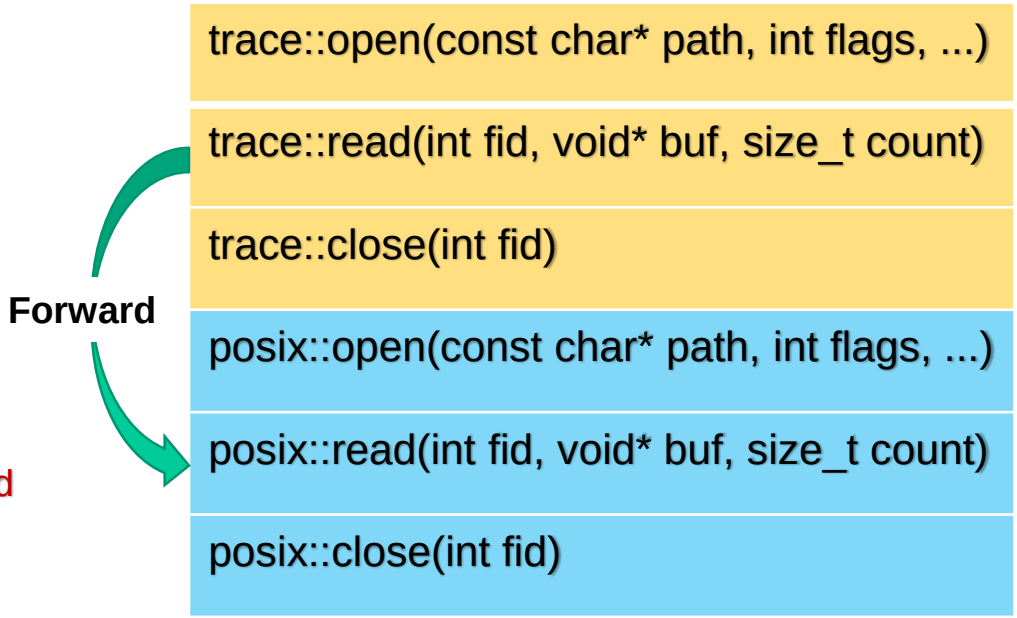
Buffered Output Log

Trace Implementation (cont.)

- Currently Records (24 calls)

open	read	lseek
open64	pread	lseek64
creat	pread64	fsync
creat64	readv	fdatasync
mkstemp	write	close
mkostemp	pwrite	MPI_Init
mkstemps	pwrite64	MPI_Init_thread
mkostemps	writev	MPI_Finalize

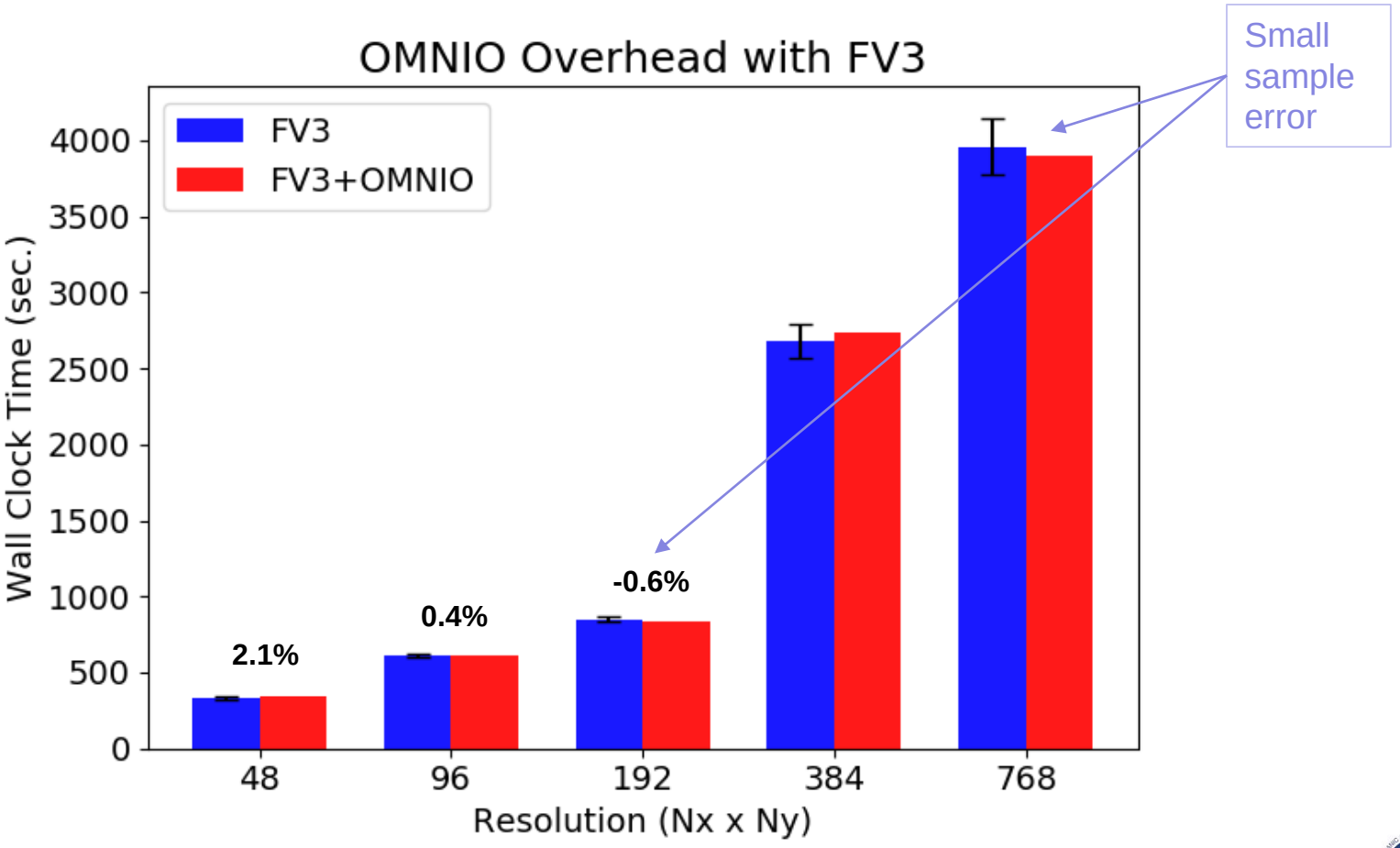
- Pre-Loaded* into Symbol Table



* LD_PRELOAD on most Linux systems
DYLD_INSERT_LIBRARIES on MacOS systems

Minimal Overhead

- Overhead less than run-to-run variability



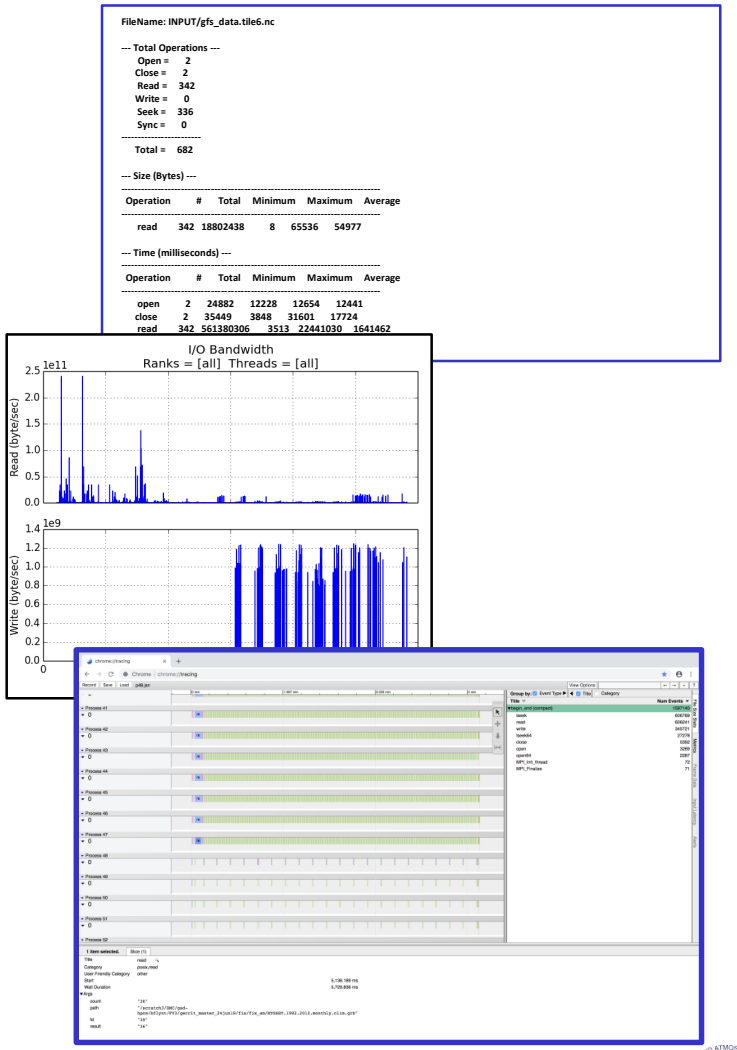
Log Files

- Generates one log file per thread per rank
  - Minimal information to keep file size down
  - Exclude records using wildcard patterns (/path/to/not/record/*)

```
5423817573909 5423875777154 MPI_Init result=0
5423877029892 5423877095612 open fd=20,flags=16777729,mode=438,path=dummy.0.0.fmt
5423877156219 5423877168729 write count=4008,fd=20,path=dummy.0.0.fmt,result=4008
5423877217106 5423877276436 close fd=20,path=dummy.0.0.fmt,result=0
5423877976538 5423877981412 open fd=20,flags=16777216,path=dummy.0.0.fmt
5423878007071 5423878016098 read count=8192,fd=20,path=dummy.0.0.fmt,result=4008
5423878036707 5423878041087 close fd=20,path=dummy.0.0.fmt,result=0
5423878058396 5423882881788 MPI_Finalize result=0
```

Statistics Tool

- Converts log files into:
  - Reports
    - Python for portability
    - Text output
  - Charts
    - Matplotlib library
    - Visual represent report data
  - Graphical User Interface
    - Chrome web browser tracing



Statistics Tool (Reports)

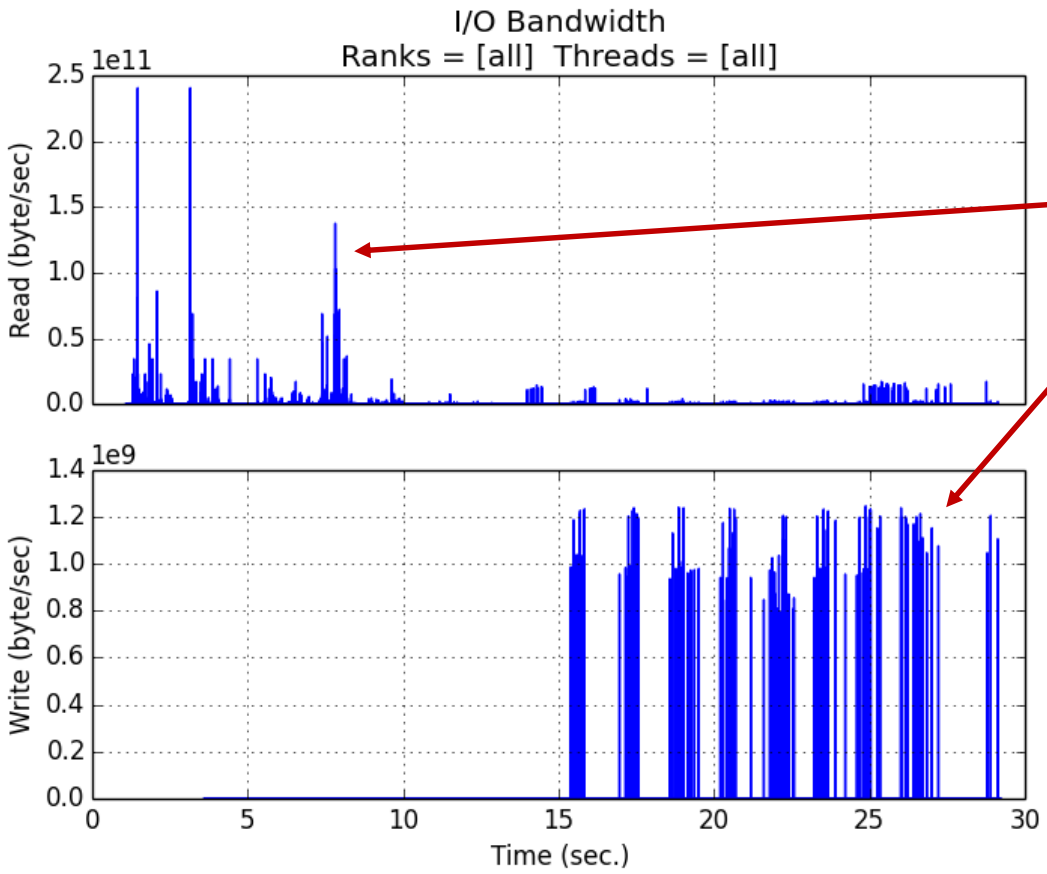
- Statistics

```
FileName: INPUT/gfs_data.tile6.nc

--- Total Operations ---
      Open =      2
     Close =      2
      Read =    342
     Write =      0
      Seek =    336
      Sync =      0
-------------------------
     Total =    682

--- Size (Bytes) ---
-------------------------------------------------------------------------------
 Operation        #     Total    Minimum    Maximum    Average
-------------------------------------------------------------------------------
      read      342  18802438          8      65536      54977

--- Time (microseconds) ---
-------------------------------------------------------------------------------
 Operation        #     Total    Minimum    Maximum    Average
-------------------------------------------------------------------------------
      open        2     24882      12228      12654      12441
     close        2     35449       3848      31601      17724
      read      342 561380306       3513   22441030    1641462
      seek      336    206476        373       3949        614
```

- Statistics Include
  - Granularity
    - File
    - Rank
    - Thread
  - Operations
    - Count
    - Size
    - Bandwidth
    - Time
  - Statistics
    - Minimum
    - Maximum
    - Average

Statistics Tool (Charts)

- Visually represent operations

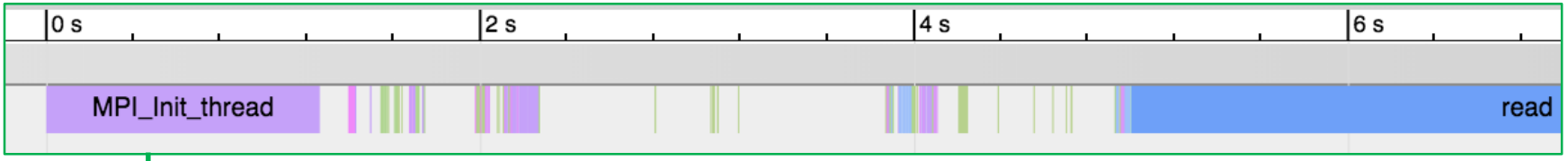


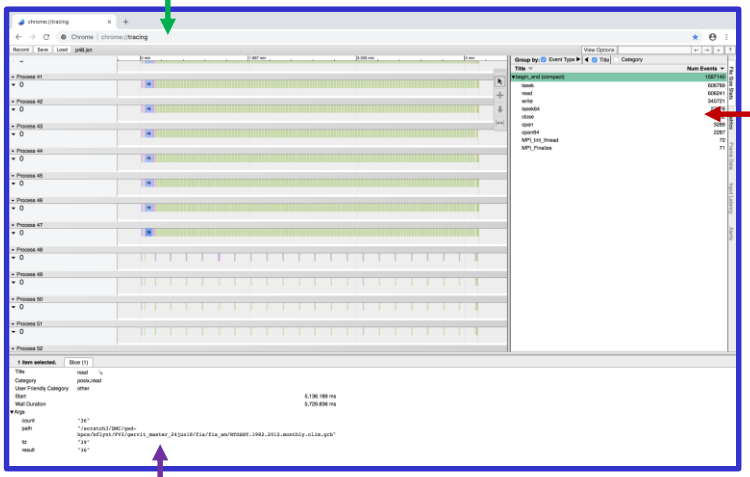
Instantaneous bandwidth at given time

Example: FV3.v0 C96 Test Case
- 24 Nodes – 12 PPN
- Aggregate Bandwidth
  - All Ranks + All Threads

Statistics Tool (GUI)

- Chrome Web Browser





View Options | ← | → | » | ?

Group by: Event Type | Title | Category

Title	Num Events
lseek	606789
read	606241
write	345721
lseek64	27278
close	5392
open	3289
open64	2287
MPI_Init_thread	72
MPI_Finalize	71

File Size Stats | Metrics

Title	read
Category	posix,read
Start	5,000.718 ms
Wall Duration	3,648.749 ms
▸Args	
count	"42"
path	"/scratch3/BMC/gsd-hpcs/bflynt/FV3/gerrit_master_24jun18/fix/fix_am/RTGSST.1982.2012.monthly.clim.grb"
fd	"32"
result	"42"

Preprocessor

- Implementation
  - Python translator
  - Command line arguments

Converts trace format to JSON file of commands

```
5423817573909 5423875777154 MPI_Init result=0
5423877029892 5423877095612 open fd=20,flags=16777729,mode=438,path=dummy.0.0.fmt
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5423878058396 5423882881788 MPI_Finalize result=0
```

```
{
“global”: {
                “time_replay” : “dt”,
                “write_overwrite” : ”False”
},
“0” : {
        “0” : {
                “events” : [
                {“start” : 1023,
                “end” : 2145,
                “command” : “read”,
                “count” : 8192,
                “location” : “/path/to/file.nc”},
                {“start” : 2203,
                “end” : 2318,
                “command” : “read”,
                “count” : 8192,
                “location” : “/path/to/file.nc”}]
        }
} }
```

Preprocessor (cont.)

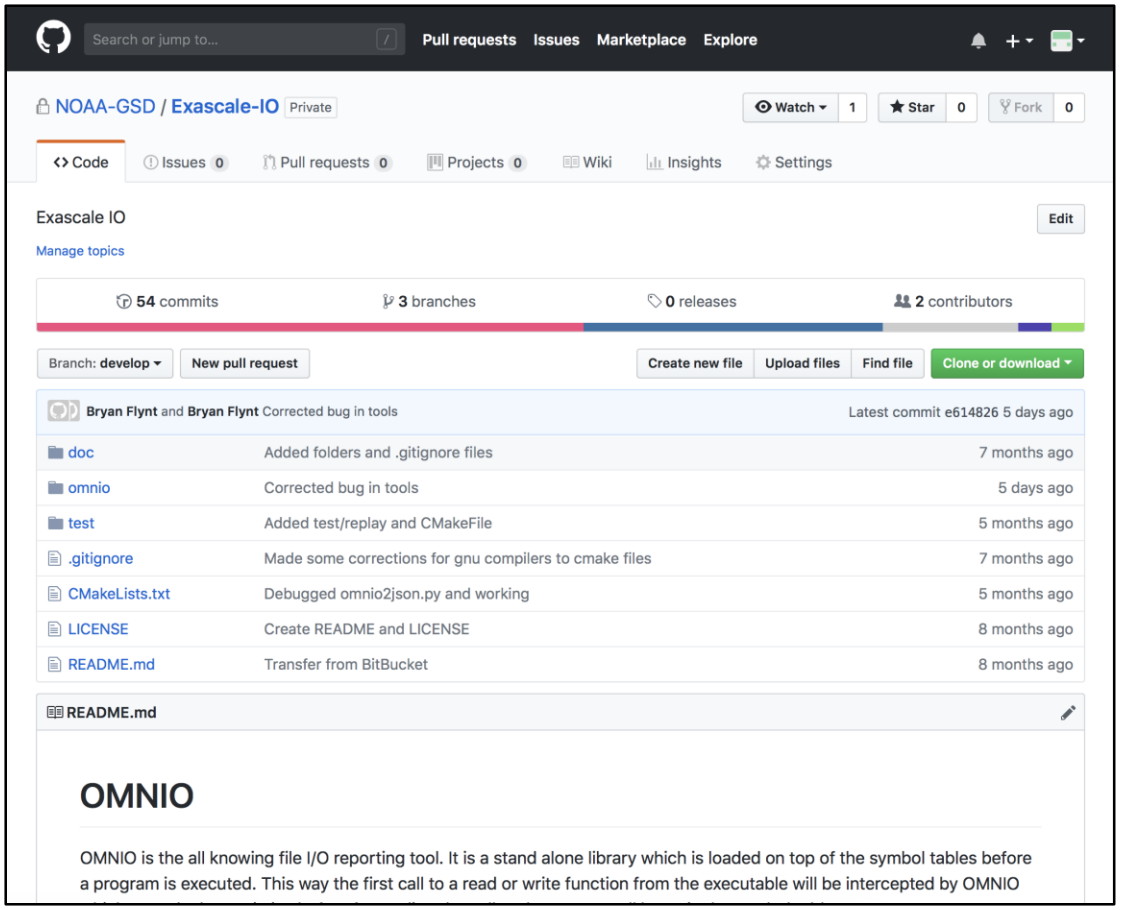
- Considerations
  - Reading
    - Use existing file
      - Same location
      - Different location
    - Create dummy data file
  - Writing
    - Same location (overwrite?)
    - Different location
  - Coordinate locations
    - Write then read again
  - Filtering by
    - File size
    - Locations
  - Timing
    - ASAP
    - Delta time (Δt)
    - Same start time
  - Scaling
    - Increase/decrease operation size for benchmarks

Replay

- Implementation
  - ~~Python implementation~~ (prototype)
  - Wrapped POSIX calls to insure the exact call is used
    - open vs. open64
    - lseek vs. lseek64
  - Options
    - mpi4py - Requires installation beyond basic Python
    - C++ - More complex implementation code

Development

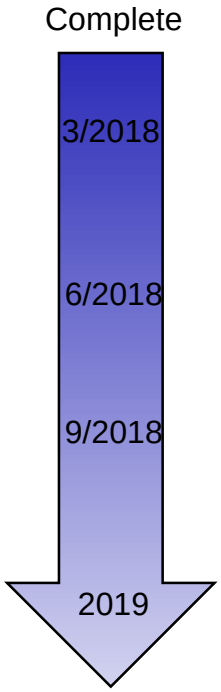
- GitHub Repository
  - Currently private
  - Collaborators welcome
- Managing through
  - Feature branches
  - Pull requests

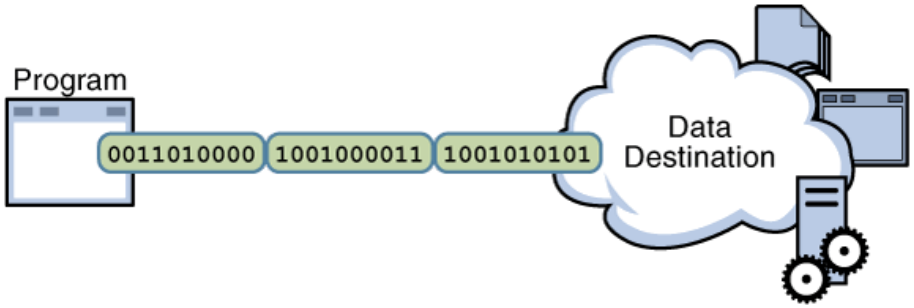


Conclusions

- Motivation
  - Understand current applications
  - Benchmark future system architectures
- OMNIO Tool
  - Trace
  - Statistics
  - Preprocess
  - Replay

- Current Status
  - Complete
    - Trace + Statistics
  - Prototyped
    - Preprocessor
  - Future
    - Replay





Questions

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Back-Up

- FV3
  - nemsio output
  - 5 day forecast
  - 6 hour frequency