Parallel HDF5

Advantage of Parallel HDF5

- Recent success story
  - Trillion particle simulation on hopper @ NERSC
  - 120,000 cores
  - 30TB file
  - 23GB/sec average speed with 35GB/sec peaks (out of 40GB/sec max for system)
- Parallel HDF5 rocks! (when used properly ☺)

Outline

- Overview of Parallel HDF5 design
- Parallel Environment Requirements
- PHDF5 Programming Model
- Examples
- Performance Analysis
- Parallel Tools
- Upcoming features of HDF5 (if time permits)

MPI-I/O VS. HDF5

MPI-IO vs. HDF5

- MPI-IO is an Input/Output API
- It treats the data file as a “linear byte stream” and each MPI application needs to provide its own file view and data representations to interpret those bytes

MPI-IO vs. HDF5

- All data stored are *machine dependent* except the “external32” representation
- External32 is defined in Big Endianness
  - Little-endian machines have to do the data conversion in both read or write operations
  - 64-bit sized data types may lose information

MPI-IO vs. HDF5

- HDF5 is data management software
- It stores data and metadata according to the HDF5 data format definition
- HDF5 file is self-describing
  - Each machine can store the data in its own native representation for efficient I/O without loss of data precision
  - Any necessary data representation conversion is done by the HDF5 library automatically

OVERVIEW OF PARALLEL HDF5 DESIGN

PHDF5 Requirements

- PHDF5 should allow multiple processes to perform I/O to an HDF5 file at the same time
  - Single file image to all processes
  - Compare with one file per process design:
    - Expensive post processing
    - Not usable by different number of processes
    - Too many files produced for file system
- PHDF5 should use a standard parallel I/O interface
- Must be portable to different platforms

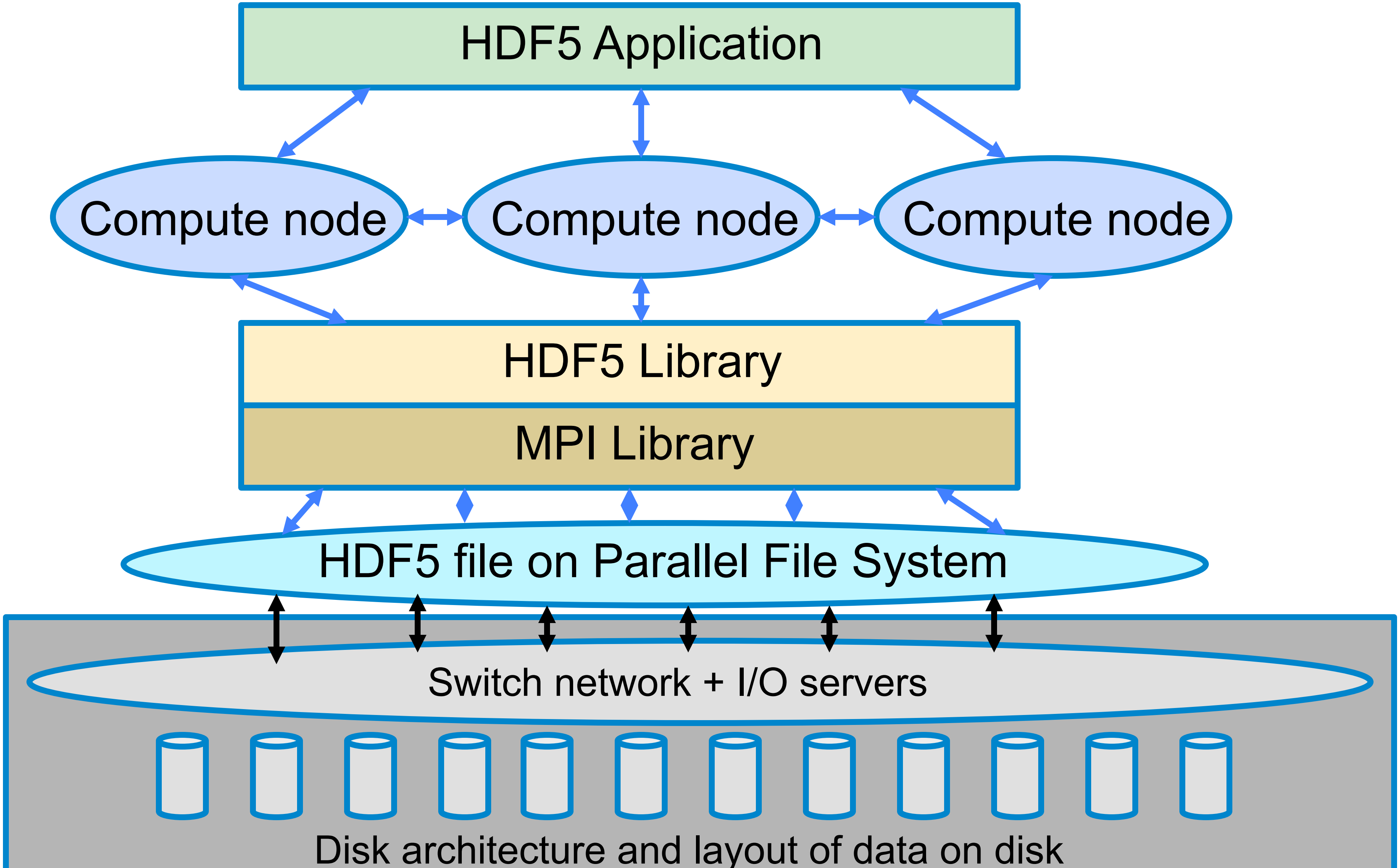
PHDF5 requirements

- Support Message Passing Interface (MPI) programming
- PHDF5 files compatible with serial HDF5 files
  - Shareable between different serial or parallel platforms

Parallel environment requirements

- MPI with POSIX I/O (HDF5 MPI POSIX driver)
  - POSIX compliant file system
  - [No collective I/O operations!]
- MPI with MPI-IO (HDF5 MPI I/O driver)
  - MPICH, OpenMPI w/ROMIO
  - Vendor's MPI-IO
  - Parallel file system
    - IBM GPFS
    - Lustre

PHDF5 implementation layers



PHDF5 CONSISTENCY SEMANTICS

Consistency Semantics

- Consistency semantics: Rules that define the outcome of multiple, possibly concurrent, accesses to an object or data structure by one or more processes in a computer system.

PHDF5 Consistency Semantics

- PHDF5 library defines a set of consistency semantics to let users know what to expect when processes access data managed by the library.
  - When the changes a process makes are actually visible to itself (if it tries to read back that data) or to other processes that access the same file with independent or collective I/O operations
- Consistency semantics vary depending on driver used:
  - MPI-POSIX
  - MPI I/O

HDF5 MPI-POSIX Consistency Semantics

- Same as POSIX I/O semantics

Process 0	Process 1
write()	
MPI_Barrier()	MPI_Barrier()
	read()

- POSIX I/O guarantees that Process 1 will read what Process 0 has written: the atomicity of the read and write calls and the synchronization of the MPI barrier ensures that Process 1 will call the read function after Process 0 is finished with the write function.

HDF5 MPI-I/O consistency semantics

- Same as MPI-I/O semantics

Process 0	Process 1
MPI_File_write_at()	
MPI_Barrier()	MPI_Barrier()
	MPI_File_read_at()

- Default MPI-I/O semantics doesn’t guarantee atomicity or sequence of calls!
- Problems may occur (although we haven’t seen any) when writing/reading HDF5 metadata or raw data

HDF5 MPI-I/O consistency semantics

- MPI I/O provides atomicity and sync-barrier-sync features to address the issue
- PHDF5 follows MPI I/O
  - H5Fset_mpio_atomicity function to turn on MPI atomicity
  - H5Fsync function to transfer written data to storage device (in implementation now)
- Alternatively: We are currently working on reimplementation of metadata caching for PHDF5 (using a metadata server)

HDF5 MPI-I/O consistency semantics

- For more information see "Enabling a strict consistency semantics model in parallel HDF5" linked from H5Fset_mpi_atomicity RM page[1]

[1] http://www.hdfgroup.org/HDF5/doc/RM/Advanced/PHDF5FileConsistencySemantics/PHDF5FileConsistencySemantics.pdf

HDF5 PARALLEL PROGRAMMING MODEL

How to compile PHDF5 applications

- h5pcc – HDF5 C compiler command
  - Similar to mpicc
- h5pfc – HDF5 F90 compiler command
  - Similar to mpif90
- To compile:
  - % h5pcc h5prog.c
  - % h5pfc h5prog.f90

Programming restrictions

- PHDF5 opens a parallel file with an MPI communicator
  - Returns a file handle
  - Future access to the file via the file handle
  - All processes must participate in collective PHDF5 APIs
  - Different files can be opened via different communicators

Collective HDF5 calls

- All HDF5 APIs that modify structural metadata are collective!
  - File operations
    - `H5Fcreate, H5Fopen, H5Fclose, etc`
  - Object creation
    - `H5Dcreate, H5Dclose, etc`
  - Object structure modification (e.g., dataset extent modification)
    - `H5Dextend, etc`
- http://www.hdfgroup.org/HDF5/doc/RM/CollectiveCalls.html

Other HDF5 calls

- Array data transfer can be collective or independent
  - Dataset operations: `H5Dwrite, H5Dread`
- Collectiveness is indicated by function parameters, not by function names as in MPI API

What does PHDF5 support ?

- After a file is opened by the processes of a communicator
  - All parts of file are accessible by all processes
  - All objects in the file are accessible by all processes
  - Multiple processes may write to the same data array
  - Each process may write to individual data array

PHDF5 API languages

- C and F90, 2003 language interfaces
- Platforms supported:
  - Most platforms with MPI-IO supported. e.g.,
    - IBM AIX
    - Linux clusters
    - Cray XT

Programming model

- HDF5 uses access template object (property list) to control the file access mechanism
- General model to access HDF5 file in parallel:
  - Set up MPI-IO access template (file access property list)
  - Open File
  - Access Data
  - Close File

Moving your sequential application to the HDF5 parallel world

MY FIRST PARALLEL HDF5 PROGRAM

Example of PHDF5 C program

Parallel HDF5 program has extra calls

```
MPI_Init(&argc, &argv);

1.  fapl_id = H5Pcreate(H5P_FILE_ACCESS);
2.            H5Pset_fapl_mpio(fapl_id, comm, info);
3.  file_id = H5Fcreate(FNAME,…, fapl_id);
4.  space_id = H5Screate_simple(…);
5.  dset_id = H5Dcreate(file_id, DNAME, H5T_NATIVE_INT,
    space_id,…);
6.  xf_id = H5Pcreate(H5P_DATASET_XFER);
7.          H5Pset_dxpl_mpio(xf_id, H5FD_MPIO_COLLECTIVE);
8.  status = H5Dwrite(dset_id, H5T_NATIVE_INT, …, xf_id…);

MPI_Finalize();
```

Writing patterns

EXAMPLE

Parallel HDF5 tutorial examples

- For simple examples how to write different data patterns see

http://www.hdfgroup.org/HDF5/Tutor/parallel.html

Programming model

- Each process defines memory and file hyperslabs using `H5Sselect_hyperslab`
- Each process executes a write/read call using hyperslabs defined, which can be either collective or independent
- The hyperslab parameters define the portion of the dataset to write to
  - Contiguous hyperslab
  - Regularly spaced data (column or row)
  - Pattern
  - Blocks

Four processes writing by rows

```
HDF5 "SDS_row.h5" {
GROUP "/" {
   DATASET "IntArray" {
      DATATYPE  H5T_STD_I32BE
      DATASPACE  SIMPLE { ( 8, 5 ) / ( 8, 5 ) }
      DATA {
         10, 10, 10, 10, 10,
         10, 10, 10, 10, 10,
         11, 11, 11, 11, 11,
         11, 11, 11, 11, 11,
         12, 12, 12, 12, 12,
         12, 12, 12, 12, 12,
         13, 13, 13, 13, 13,
         13, 13, 13, 13, 13
```

Two processes writing by columns

```
HDF5 "SDS_col.h5" {
GROUP "/" {
   DATASET "IntArray" {
      DATATYPE  H5T_STD_I32BE
      DATASPACE  SIMPLE { ( 8, 6 ) / ( 8, 6 ) }
      DATA {
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200,
         1, 2, 10, 20, 100, 200
```

Four processes writing by pattern

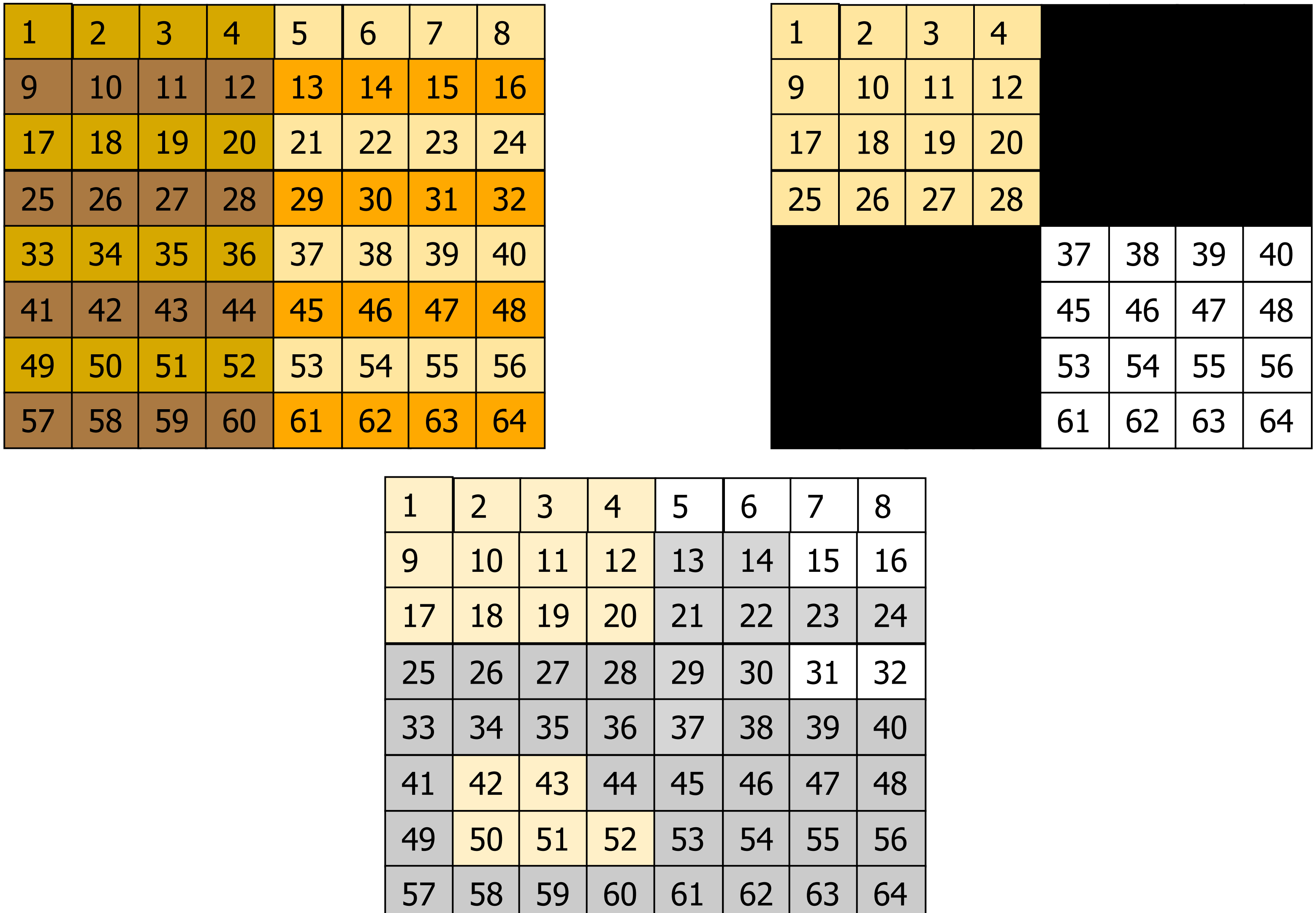
```
HDF5 "SDS_pat.h5" {
GROUP "/" {
   DATASET "IntArray" {
      DATATYPE  H5T_STD_I32BE
      DATASPACE  SIMPLE { ( 8, 4 ) / ( 8, 4 ) }
      DATA {
         1, 3, 1, 3,
         2, 4, 2, 4,
         1, 3, 1, 3,
         2, 4, 2, 4,
         1, 3, 1, 3,
         2, 4, 2, 4,
         1, 3, 1, 3,
         2, 4, 2, 4
```

Four processes writing by blocks

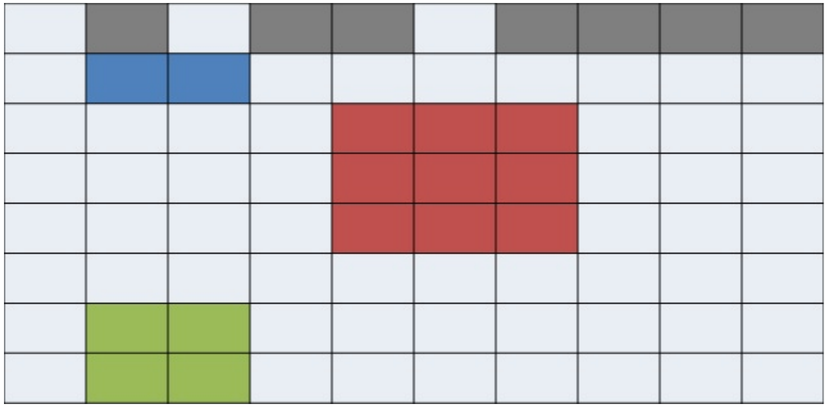
```
HDF5 "SDS_blk.h5" {
GROUP "/" {
   DATASET "IntArray" {
      DATATYPE  H5T_STD_I32BE
      DATASPACE  SIMPLE { ( 8, 4 ) / ( 8, 4 ) }
      DATA {
         1, 1, 2, 2,
         1, 1, 2, 2,
         1, 1, 2, 2,
         1, 1, 2, 2,
         3, 3, 4, 4,
         3, 3, 4, 4,
         3, 3, 4, 4,
         3, 3, 4, 4
```

Complex data patterns

HDF5 doesn't have restrictions on data patterns and data balance



Examples of irregular selection



- Internally, the HDF5 library creates an MPI datatype for each lower dimension in the selection and then combines those types into one giant structured MPI datatype

PERFORMANCE ANALYSIS

Performance analysis

- Some common causes of poor performance
- Possible solutions

My PHDF5 application I/O is slow

- Raw I/O data sizes
- Independent vs. Collective I/O

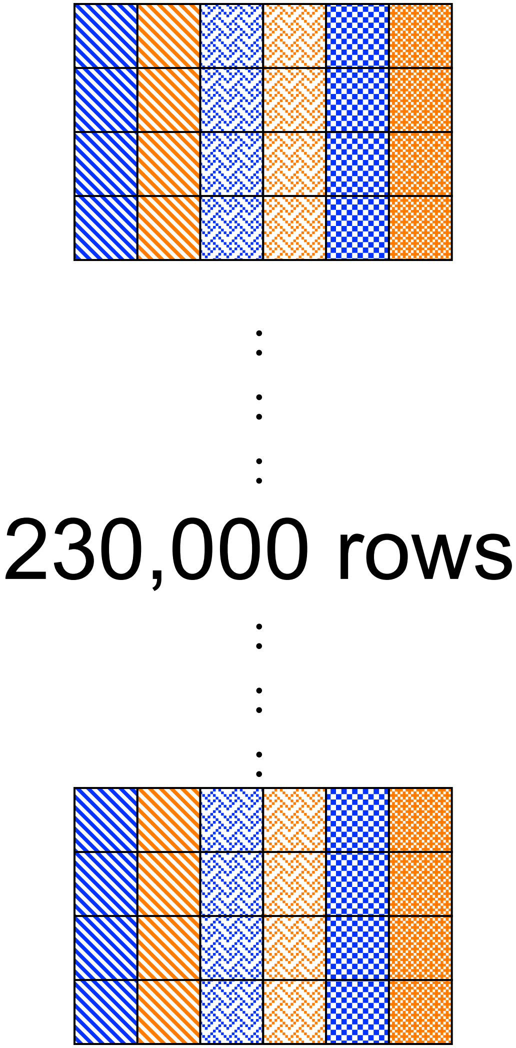
"Tuning HDF5 for Lustre File Systems" by Howison, Koziol, Knaak, Mainzer, and Shalf

- ❖ Chunking and hyperslab selection
- ❖ HDF5 metadata cache
- ❖ Specific I/O system hints

INDEPENDENT VS. COLLECTIVE RAW DATA I/O

Independent vs. collective access

- User reported independent data transfer mode was much slower than the collective data transfer mode
- Data array was tall and thin: 230,000 rows by 6 columns



Collective vs. independent calls

- MPI definition of collective calls:
  - All processes of the communicator must participate in calls in the right order. E.g.,
    - Process1 Process2
    - call A(); call B(); call A(); call B(); **right**
    - call A(); call B(); call B(); call A(); **wrong**
- Independent means not collective ☺
- Collective is not necessarily synchronous, nor must require communication

Debug Slow Parallel I/O Speed(1)

- Writing to one dataset
  - Using 4 processes == 4 columns
  - datatype is 8-byte doubles
  - 4 processes, 1000 rows == 4x1000x8 = 32,000 bytes
- % mpirun -np 4 ./a.out 1000
  - Execution time: 1.783798 s.
- % mpirun -np 4 ./a.out 2000
  - Execution time: 3.838858 s.
- Difference of 2 seconds for 1000 more rows = 32,000 bytes.
- Speed of 16KB/sec!!! *Way too slow.*

Debug slow parallel I/O speed(2)

- Build a version of PHDF5 with
  - ./configure --enable-debug --enable-parallel …
  - This allows the tracing of MPIO I/O calls in the HDF5 library.
- E.g., to trace
  - MPI_File_read_xx and MPI_File_write_xx calls
  - % setenv H5FD_mpio_Debug “rw”

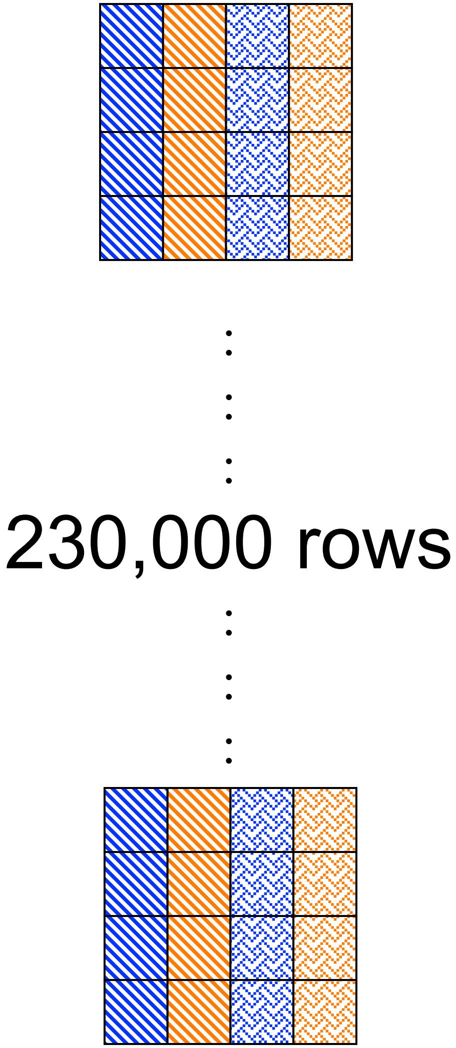
Debug slow parallel I/O speed(3)

% setenv H5FD_mpio_Debug 'rw'
% mpirun -np 4 ./a.out 1000   # Indep.; contiguous.
in H5FD_mpio_write mpi_off=0 size_i=96
in H5FD_mpio_write mpi_off=0 size_i=96
in H5FD_mpio_write mpi_off=0 size_i=96
in H5FD_mpio_write mpi_off=0 size_i=96
in H5FD_mpio_write mpi_off=2056 size_i=8
in H5FD_mpio_write mpi_off=2048 size_i=8
in H5FD_mpio_write mpi_off=2072 size_i=8
in H5FD_mpio_write mpi_off=2064 size_i=8
in H5FD_mpio_write mpi_off=2088 size_i=8
in H5FD_mpio_write mpi_off=2080 size_i=8
…

- Total of 4000 of these little 8 bytes writes == 32,000 bytes.

Independent calls are many and small

- Each process writes one element of one row, skips to next row, write one element, so on.
- Each process issues 230,000 writes of 8 bytes each.

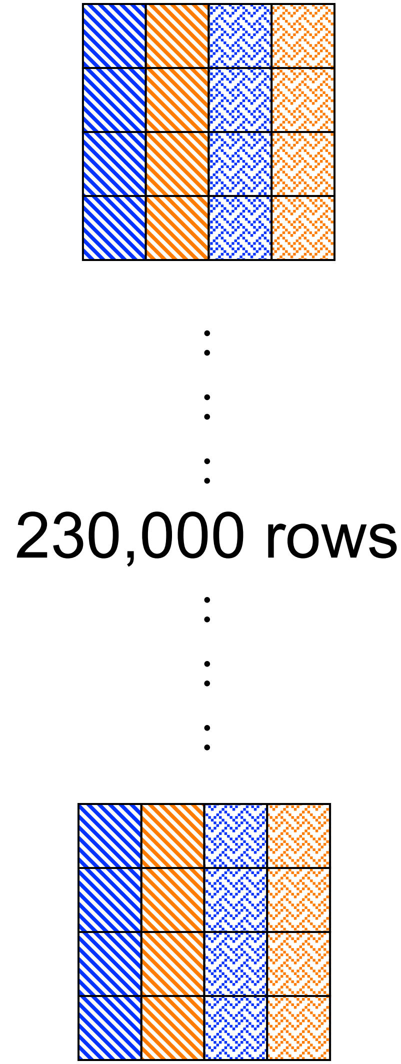


Debug slow parallel I/O speed (4)

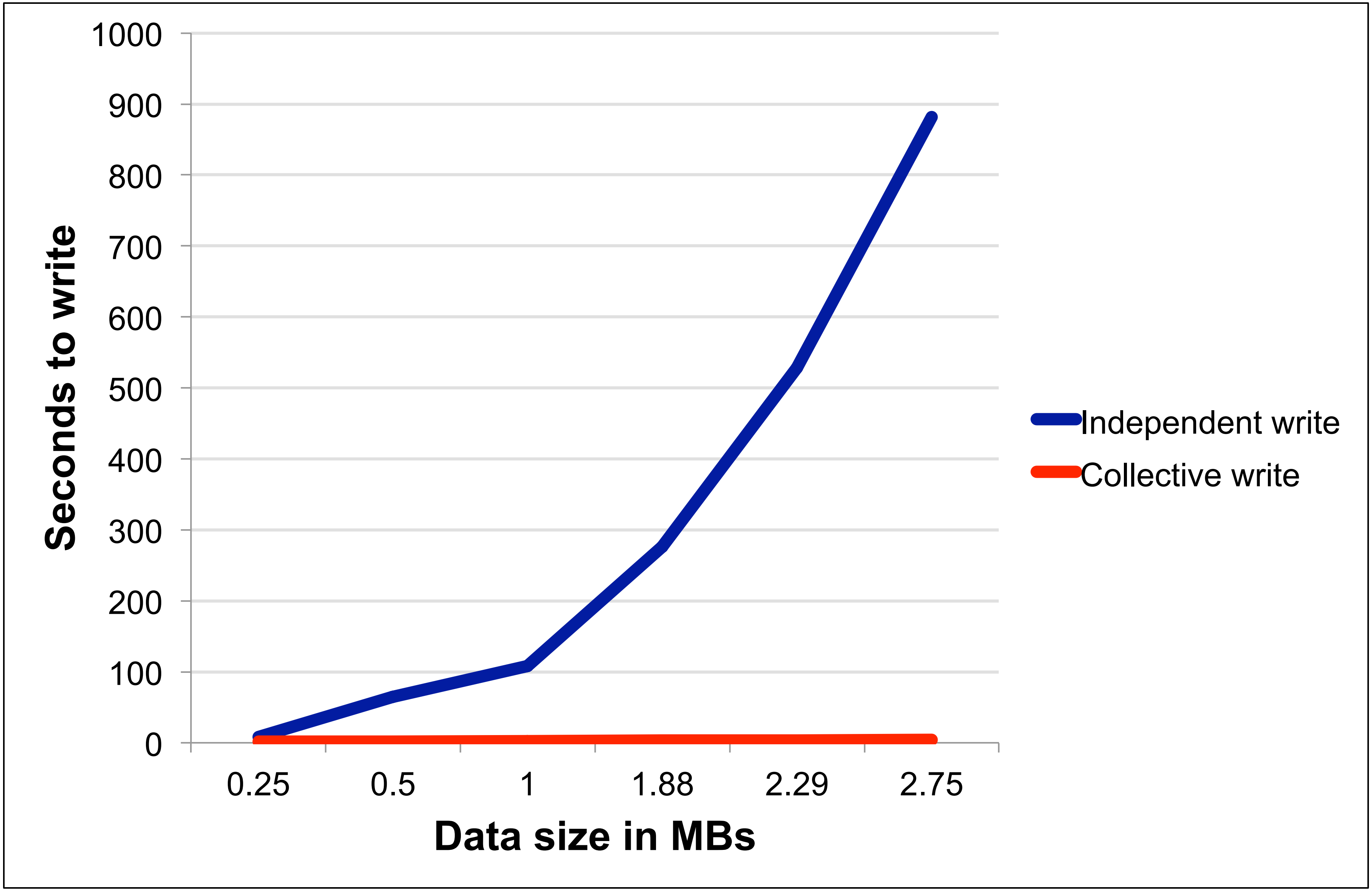
```
% setenv H5FD_mpio_Debug 'rw'
% mpirun -np 4 ./a.out 1000     # Indep., Chunked by column.
in H5FD_mpio_write  mpi_off=0       size_i=96
in H5FD_mpio_write  mpi_off=0       size_i=96
in H5FD_mpio_write  mpi_off=0       size_i=96
in H5FD_mpio_write  mpi_off=0       size_i=96
in H5FD_mpio_write  mpi_off=3688    size_i=8000
in H5FD_mpio_write  mpi_off=11688   size_i=8000
in H5FD_mpio_write  mpi_off=27688   size_i=8000
in H5FD_mpio_write  mpi_off=19688   size_i=8000
in H5FD_mpio_write  mpi_off=96      size_i=40
in H5FD_mpio_write  mpi_off=136     size_i=544
in H5FD_mpio_write  mpi_off=680     size_i=120
in H5FD_mpio_write  mpi_off=800     size_i=272
…
Execution time: 0.011599 s.
```

Use collective mode or chunked storage

- Collective I/O will combine many small independent calls into few but bigger calls
- Chunks of columns speeds up too



Collective vs. independent write



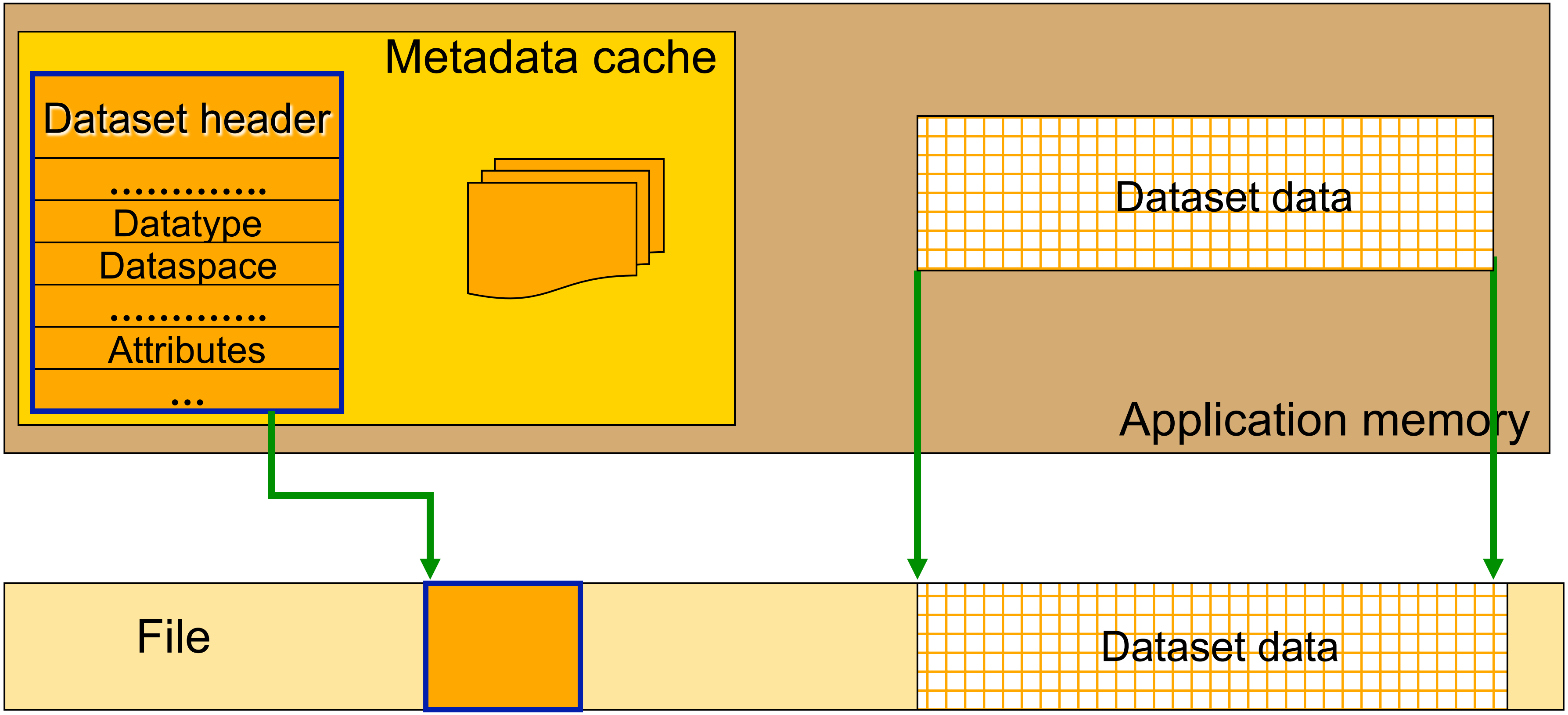
Collective I/O in HDF5

- Set up using a Data Transfer Property List (DXPL)
- All processes must participate in the I/O call (H5Dread/write) with a selection (which could be a NULL selection)
- Some cases where collective I/O is not used even when the use asks for it:
  - Data conversion
  - Compressed Storage
  - Chunking Storage:
    - When the chunk is not selected by a certain number of processes

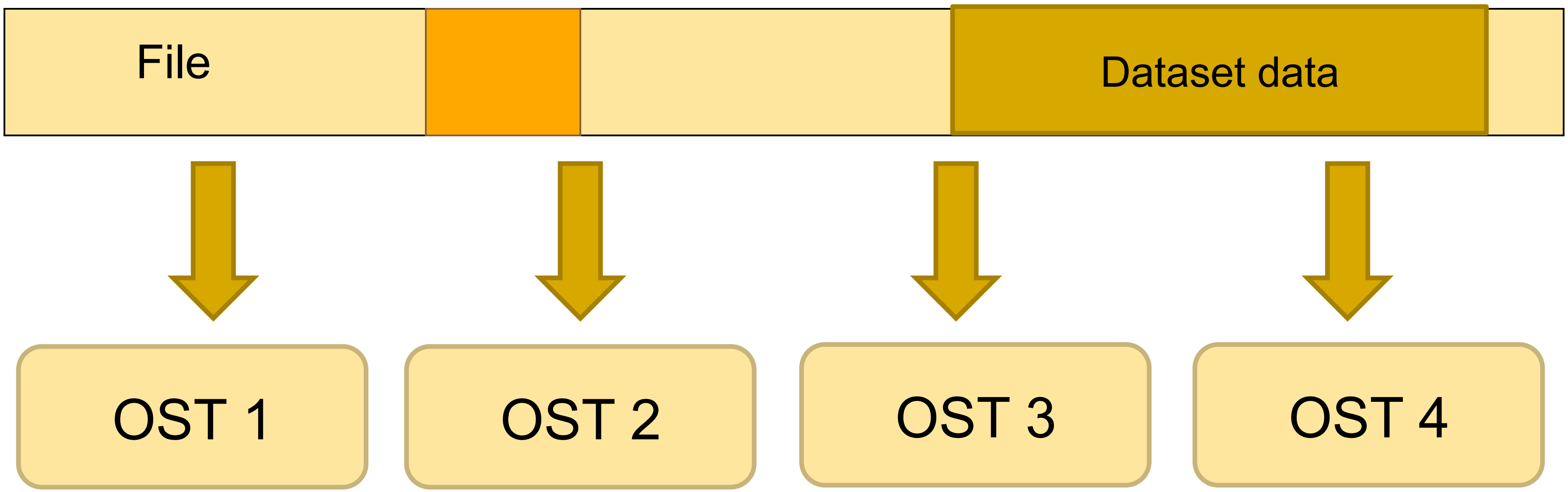
EFFECT OF HDF5 STORAGE

Contiguous storage

- Metadata header separate from dataset data
- Data stored in one contiguous block in HDF5 file



On a parallel file system

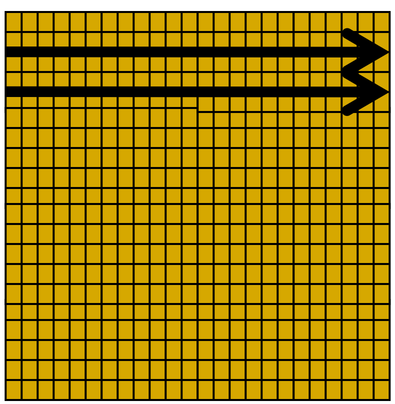


The file is striped over multiple OSTs depending on the stripe size and stripe count that the file was created with.

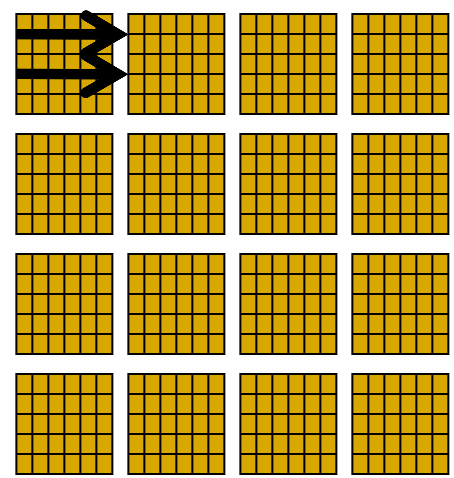
Chunked storage

- Data is stored in chunks of predefined size
  - Two-dimensional instance may be referred to as data tiling
- HDF5 library writes/reads the whole chunk

Contiguous

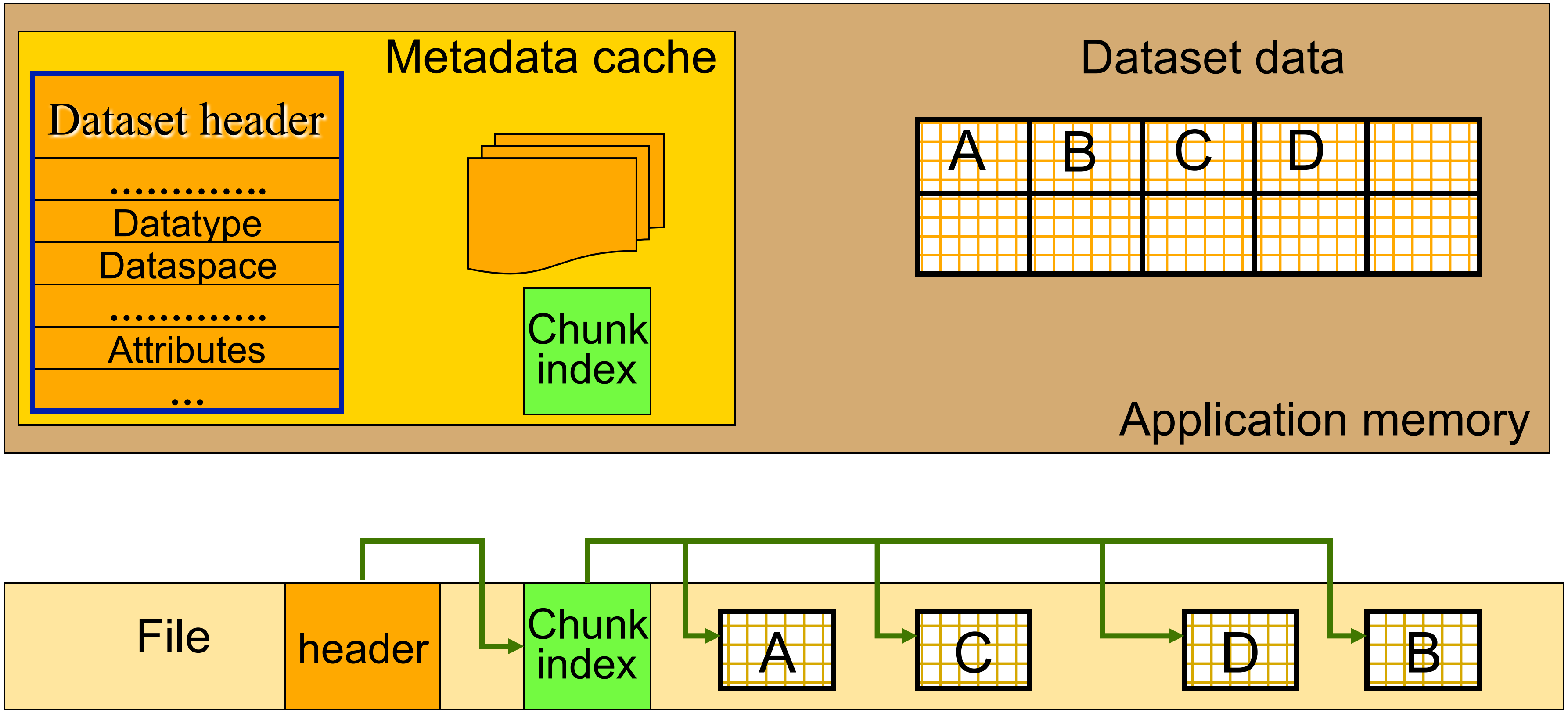


Chunked

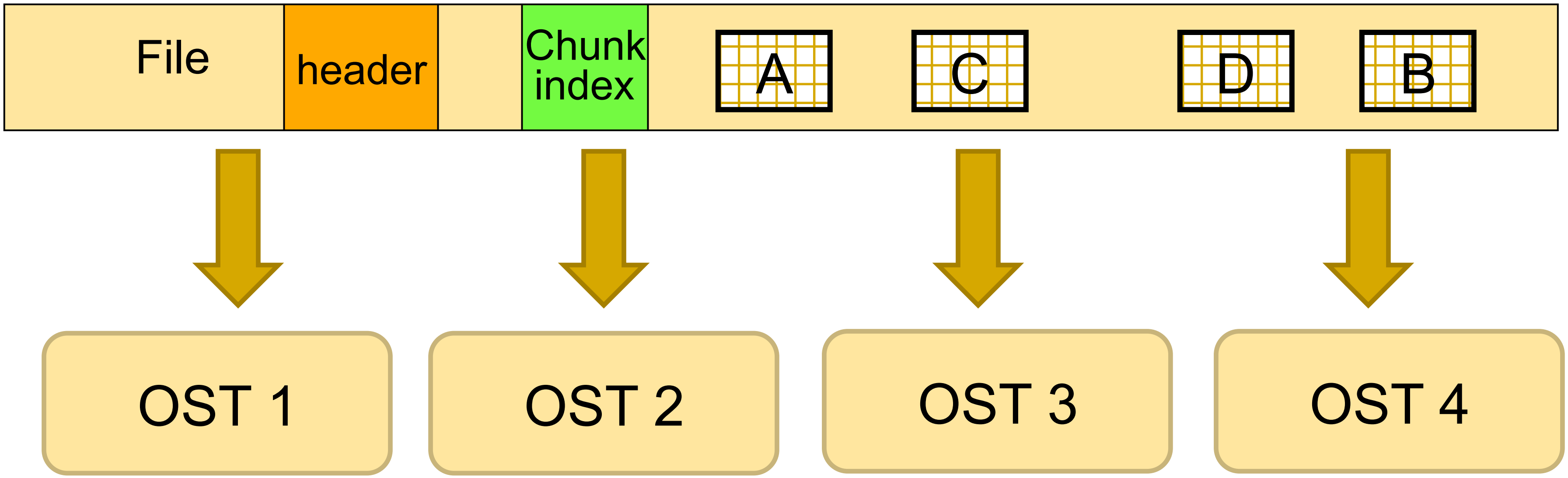


Chunked storage (cont.)

- Dataset data is divided into equally sized blocks (chunks).
- Each chunk is stored separately as a contiguous block in HDF5 file.



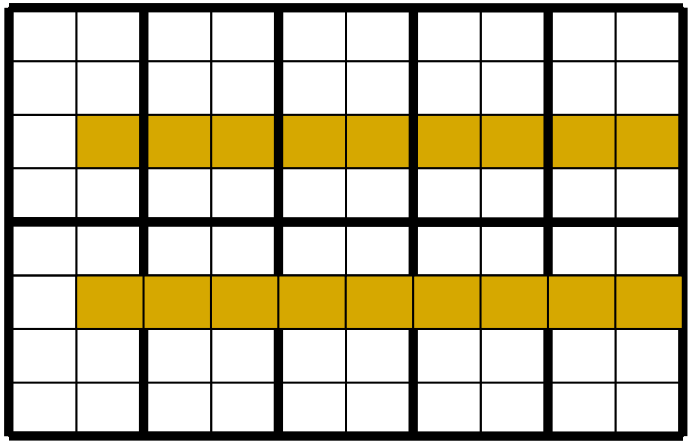
On a parallel file system

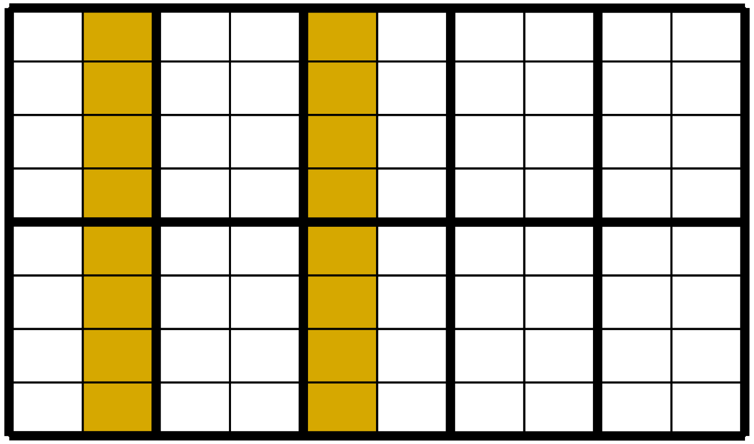


The file is striped over multiple OSTs depending on the stripe size and stripe count that the file was created with

Which is better for performance?

- It depends!!
- Consider these selections:





- If contiguous: 2 seeks
- If chunked: 10 seeks

- If contiguous: 16 seeks
- If chunked: 4 seeks

Add to that striping over a Parallel File System, which makes this problem very hard to solve!

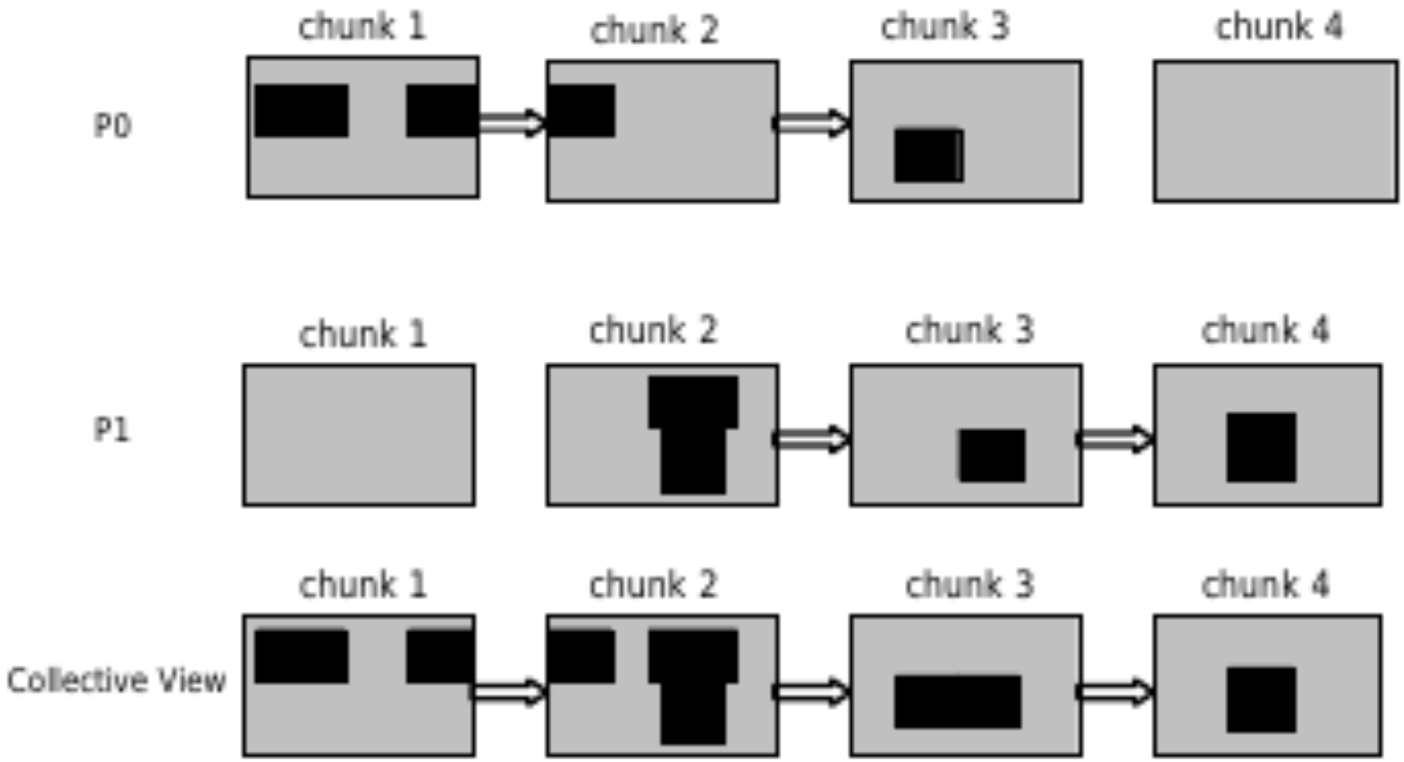
Chunking and hyperslab selection

- When writing or reading, try to use hyperslab selections that coincide with chunk boundaries.
- If not possible, HDF5 provides some options

Parallel I/O on chunked datasets

- Multiple options for performing I/O when collective:
  - Operate on all chunks in one collective I/O operation: “Linked chunk I/O”
  - Operate on each chunk collectively: “Multi-chunk I/O”
  - Break collective I/O and perform I/O on each chunk independently (also in “Multi-chunk I/O” algorithm)

Linked chunk I/O

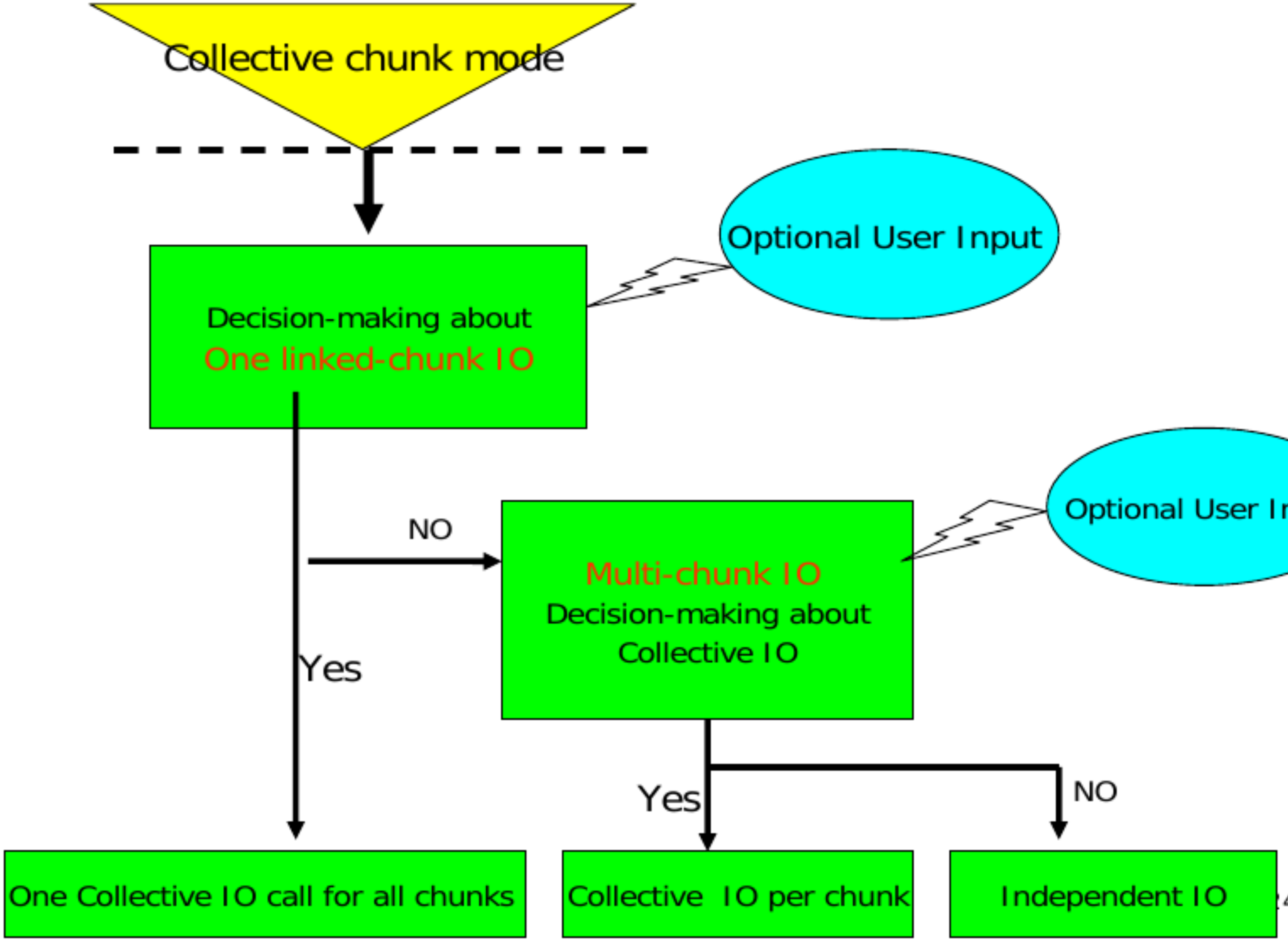


- One MPI Collective I/O Call

Multi-chunk I/O

- Collective I/O per chunk
- Determine for each chunk if enough processes have a selection inside to do collective I/O
- If not enough, use independent I/O

Decision making



EFFECT OF HDF5 METADATA CACHE

PHDF5 and Metadata

- Metadata operations:
  - Creating/removing a dataset, group, attribute, etc…
  - Extending a dataset's dimensions
  - Modifying group hierarchy
  - etc …
- All operations that modify metadata are collective, i.e., all processes have to call that operation:
  - If you have 10,000 processes running your application, and one process needs to create a dataset, ***ALL*** processes must call H5Dcreate to create 1 dataset.

Space allocation

- Allocating space at the file's EOA is very simple in serial HDF5 applications:
  - the EOA value begins at offset 0 in the file
  - when space is required, the EOA value is incremented by the size of the block requested.
- Space allocation using the EOA value in parallel HDF5 applications can result in a race condition if processes do not synchronize with each other:
  - multiple processes believe that they are the sole owner of a range of bytes within the HDF5 file.
- Solution: Make it Collective

Example

- Consider this case, where 2 processes want to create a dataset each.

P1	P2
H5Dcreate(D1)	H5Dcreate(D2)

Each call has to allocate space in file to store the dataset header.

Bytes 4 to 10 in the file are free	Bytes 4 to 10 in the file are free

Conflict!

Example

P1	P2
H5Dcreate(D1)	**H5Dcreate(D1)**

Allocate space in file to store the dataset header.

Bytes 4 to 10 in the file are free.

Create the dataset.

P1	P2
H5Dcreate(D2)	**H5Dcreate(D2)**

Allocate space in file to store the dataset header.

Bytes 11 to 17 in the file are free.

Create the dataset.

Metadata cache

- To handle synchronization issues, all HDF5 operations that could potentially modify the metadata in an HDF5 file are required to be collective
  - A list of those routines is available in the HDF5 reference manual (http://www.hdfgroup.org/HDF5/doc/RM/CollectiveCalls.html)
- If those operations are not collective, how can each process manage its Metadata Cache?
  - Do not have one, i.e. always access metadata directly from disk
  - Disastrous for performance as metadata is usually very small

Managing the metadata cache

- All operations that **modify** metadata in the HDF5 file are collective:
  - All processes will have the same dirty metadata entries in their cache (i.e., metadata that is inconsistent with what is on disk).
  - Processes are not required to have the same clean metadata entries (i.e., metadata that is in sync with what is on disk).
- Internally, the metadata cache running on process 0 is responsible for managing changes to the metadata in the HDF5 file.
  - All the other caches must retain dirty metadata until the process 0 cache tells them that the metadata is clean (i.e., on disk).

Example

- Metadata Cache is clean for all processes:

P0	P1	P2	P3
E1	E1	E4	E12
E2	E7	E6	E32
E3	E8	E1	E1
E4	E2	E5	E4

Example

- All processes call H5Gcreate that modifies metadata entry E3 in the file:

P0	P1	P2	P3
E3	E3	E3	E3
E1	E1	E4	E12
E2	E7	E6	E32
E4	E8	E1	E1

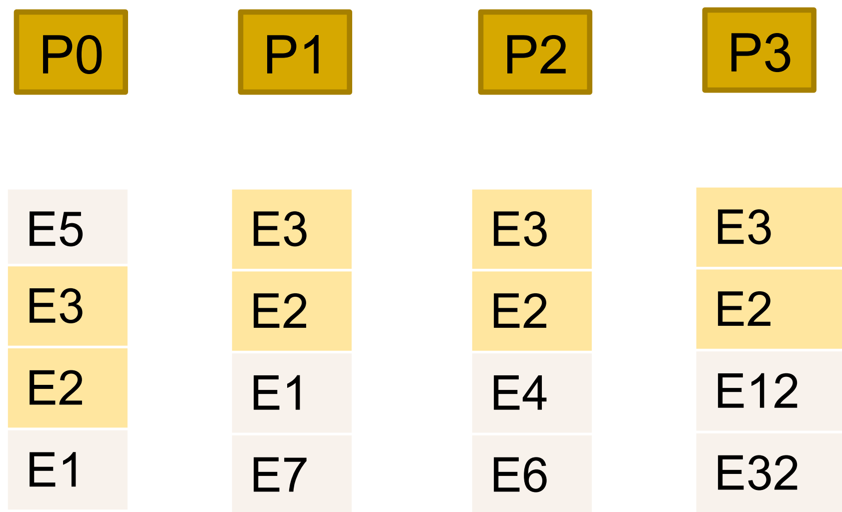
Example

- All processes call H5Dcreate that modifies metadata entry E2 in the file:

P0	P1	P2	P3
E3	E3	E3	E3
E2	E2	E2	E2
E1	E1	E4	E12
E4	E7	E6	E32

Example

- Process 0 calls H5Dopen on a dataset accessing entry E5



Flushing the cache

- Initiated when:
  - The size of dirty entries in cache exceeds a certain threshold
  - The user calls a flush
- The actual flush of metadata entries to disk is currently implemented in two ways:
  - Single Process (Process 0) write
  - Distributed write

Single Process (Process 0) write

- All processes enter a synchronization point.
- Process 0 writes all the dirty entries to disk while other processes wait and do nothing
- Process 0 marks all the dirty entries as clean
- Process 0 broadcasts the cleaned entries to all processes that marks them as clean too

Distributed write

- All processes enter a synchronization point.
- Process 0 broadcasts the metadata that needs to be flushed to all processes
- Using a distributed algorithm each determines what part of the metadata cache entries it needs to write, and writes them to disk independently
- All processes mark the flushed metadata as clean

PARALLEL TOOLS

Parallel tools

- h5perf
  - Performance measuring tool showing I/O performance for different I/O APIs

h5perf

- An I/O performance measurement tool
- Tests 3 File I/O APIs:
  - POSIX I/O (open/write/read/close…)
  - MPI-I/O (MPI_File_{open,write,read,close})
  - PHDF5
    - H5Pset_fapl_mpio (using MPI-I/O)
    - H5Pset_fapl_mpiposix (using POSIX I/O)
- An indication of I/O speed upper limits

Useful parallel HDF5 links

- Parallel HDF information site

  http://www.hdfgroup.org/HDF5/PHDF5/
- Parallel HDF5 tutorial available at

  http://www.hdfgroup.org/HDF5/Tutor/
- HDF Help email address

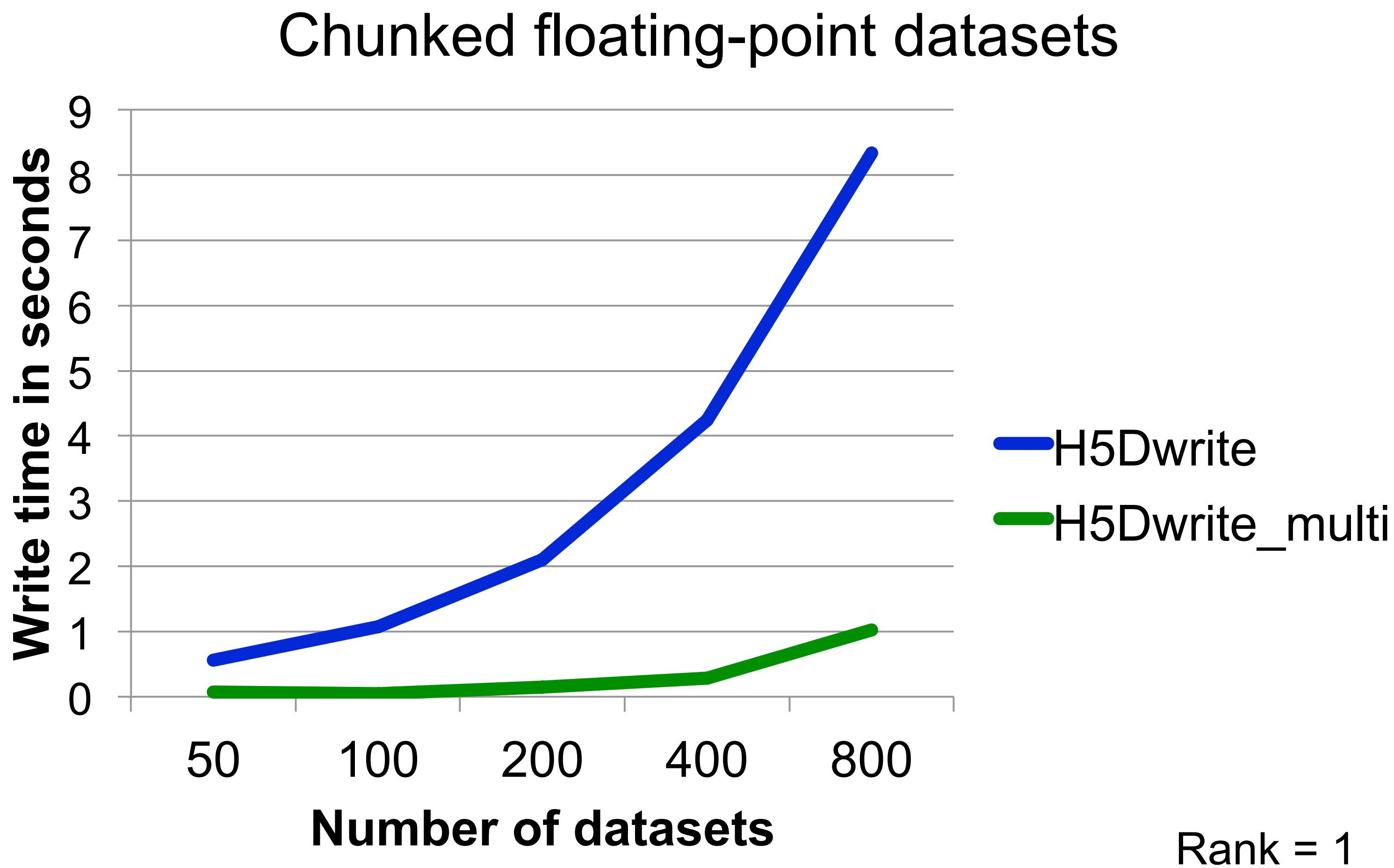
  help@hdfgroup.org

UPCOMING FEATURES IN HDF5

PHDF5 Improvements in Progress

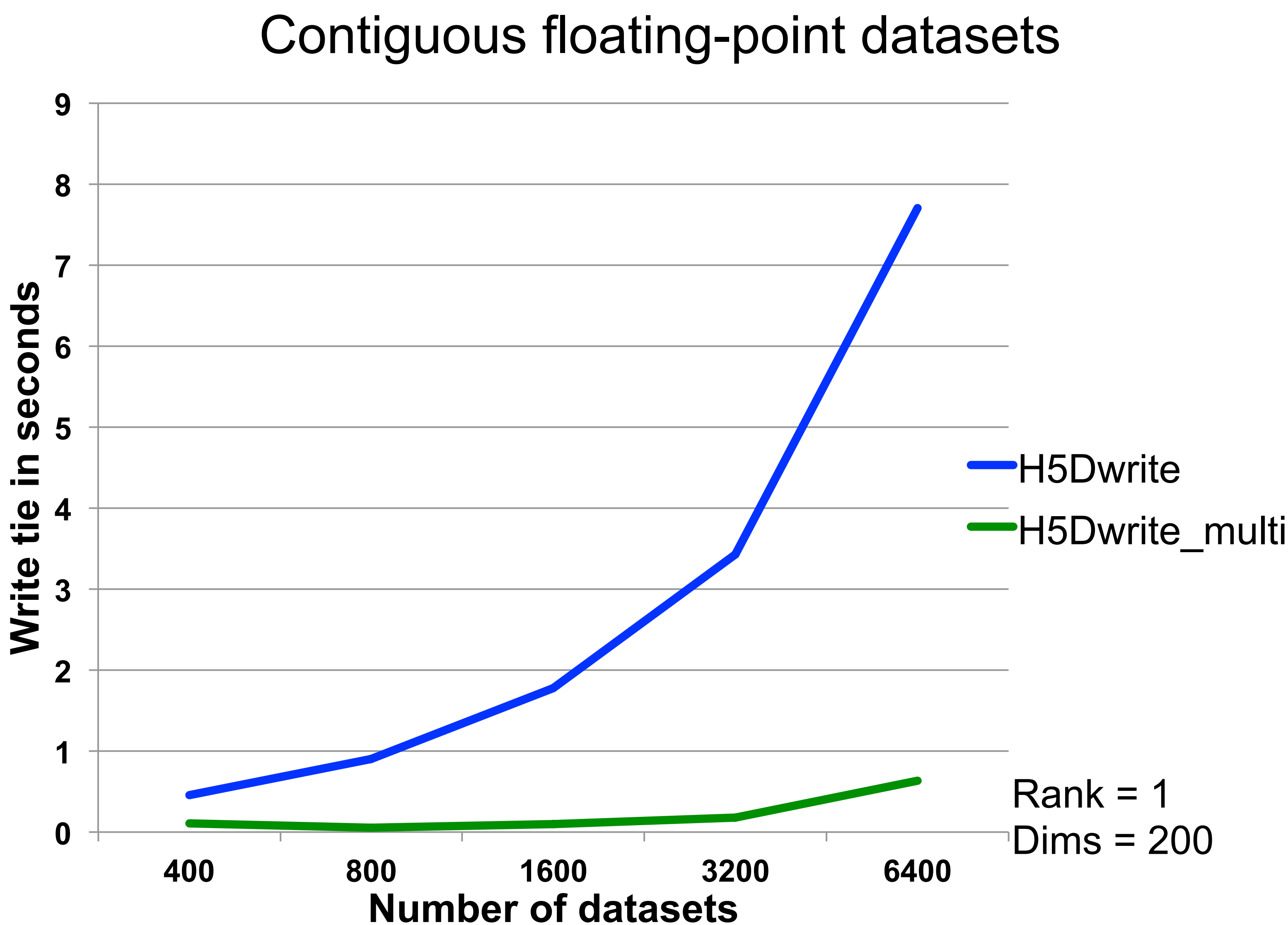
- Multi-dataset read/write operations
  - Allows single collective operation on multiple datasets
  - H5Dmulti_read/write(<array of datasets, selections, etc>)
  - Order of magnitude speedup (see next slides)

H5Dwrite vs. H5Dwrite_multi



Rank = 1
Dims = 200
Chunk size = 20

H5Dwrite vs. H5Dwrite_multi



PHDF5 Improvements in Progress

- Avoid truncation
  - File format currently requires call to truncate file, when closing
  - Expensive in parallel (MPI_File_set_size)
  - Change to file format will eliminate truncate call

PHDF5 Improvements in Progress

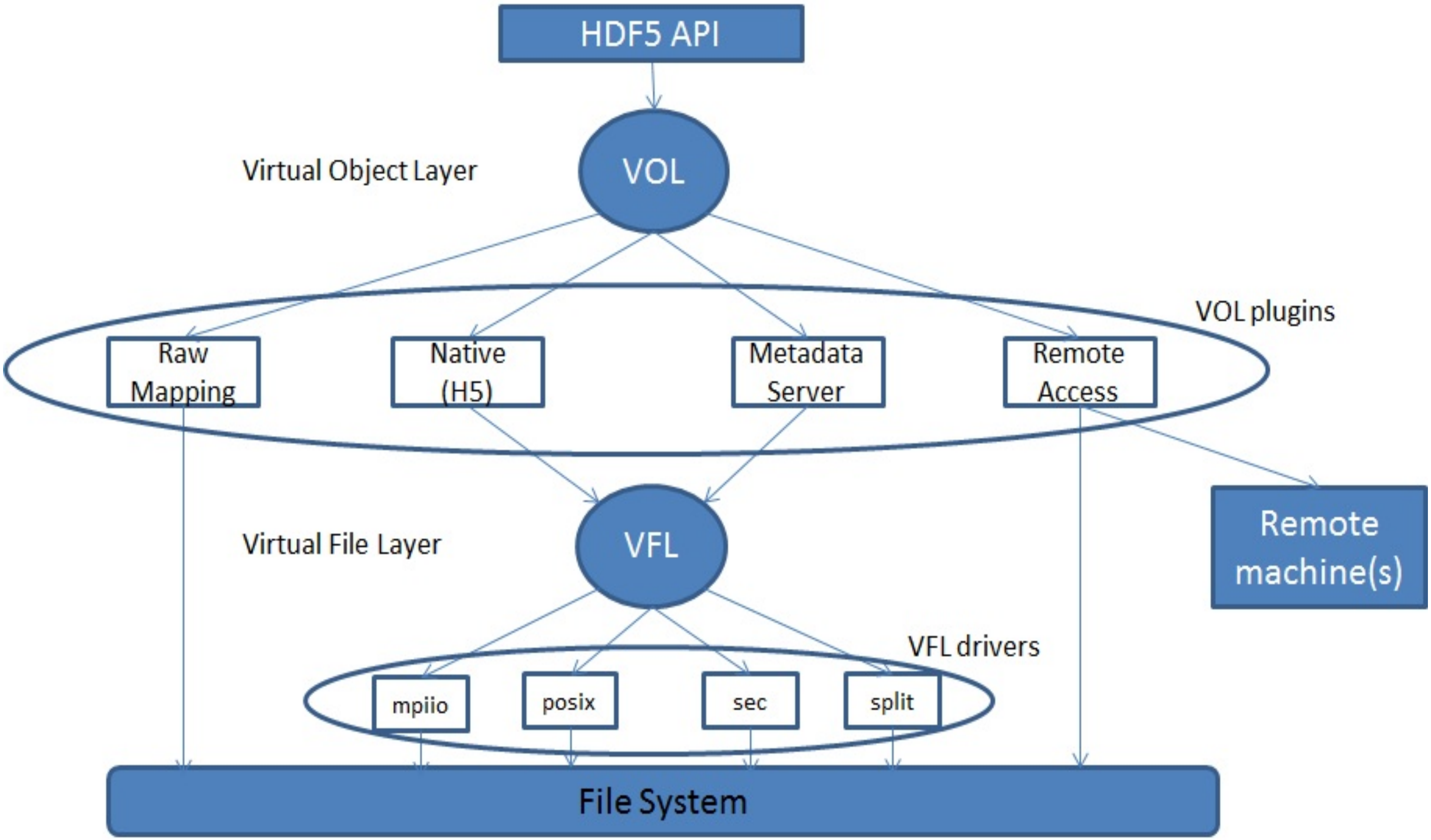
- Collective Object Open
  - Currently, object open is independent
  - All processes perform I/O to read metadata from file, resulting in I/O storm at file system
  - Change will allow a single process to read, then broadcast metadata to other processes
- Virtual Object Layer (VOL)
- I/O Autotuning

VIRTUAL OBJECT LAYER (VOL)

Virtual Object Layer (VOL)

- Goal
  - Provide an application with the HDF5 data model and API, but allow different underlying storage mechanisms
- New layer below HDF5 API
  - Intercepts all API calls that can touch the data on disk and routes them to a VOL plugin
- Potential VOL plugins:
  - Native HDF5 driver (writes to HDF5 file)
  - Raw driver (maps groups to file system directories and datasets to files in directories)
  - Remote driver (the file exists on a remote machine)

Virtual Object Layer



Why not use the VFL?

- VFL is implemented below the HDF5 abstract model
  - Deals with blocks of bytes in the storage container
  - Does not recognize HDF5 objects nor abstract operations on those objects
- VOL is layered right below the API layer to capture the HDF5 model

Sample API Function Implementation

```
hid_t H5Dcreate2 (hid_t loc_id, const char *name,
hid_t type_id, hid_t space_id, hid_t lcpl_id, hid_t
dcpl_id, hid_t dapl_id) {
/* Check arguments */
     …
/* call corresponding VOL callback for H5Dcreate */
 dset_id = H5_VOL_create (TYPE_DATASET, …);
/*
 Return result to user (yes the dataset is created,
 or no here is the error)
*/
 return dset_id;
}
```

Work in progress: VOL

CONSIDERATIONS

VOL Plugin Selection

- Use a pre-defined VOL plugin:

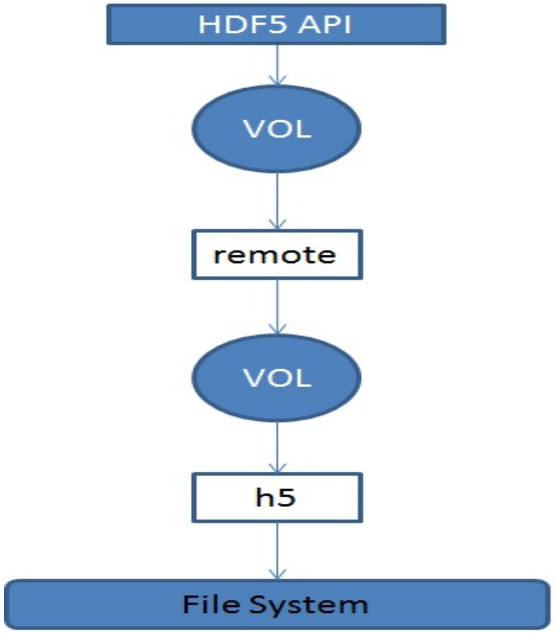
```
hid_t fapl = H5Pcreate(H5P_FILE_ACCESS);
H5Pset_fapl_mds_vol(fapl, …);
hid_t file = H5Fcreate("foo.h5", …, …, fapl);
H5Pclose(fapl);
```

- Register user defined VOL plugin:

```
H5VOLregister (H5VOL_class_t *cls)
H5VOLunregister (hid_t driver_id)
H5Pget_plugin_info (hid_t plist_id)
```

Interchanging and Stacking Plugins

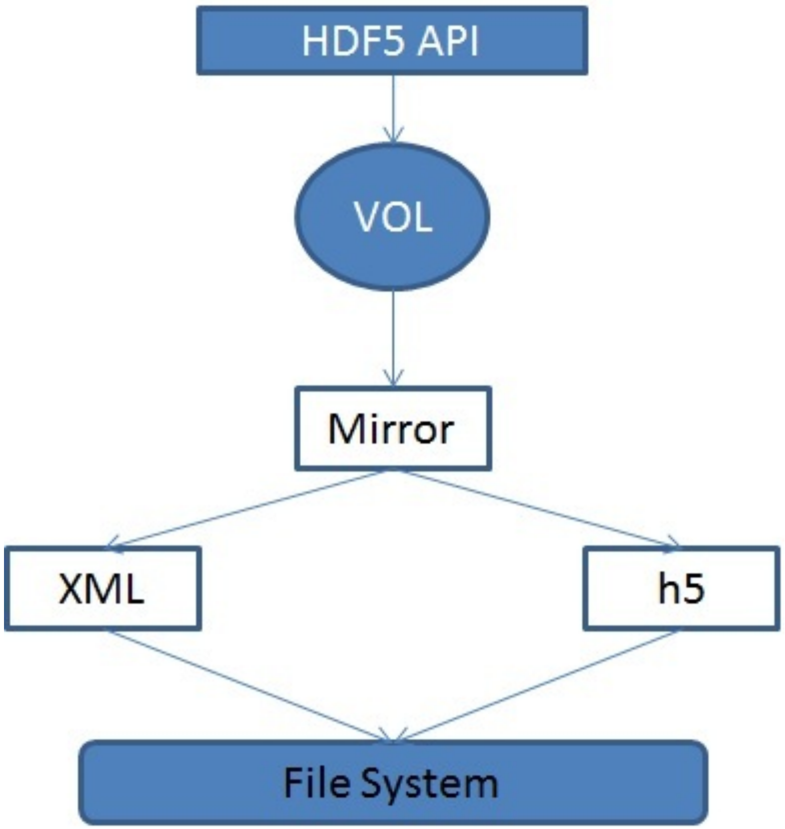
- Interchanging VOL plugins
  - Should be a valid thing to do
  - User's responsibility to ensure plugins coexist
- Stacking plugins



- Stacking should make sense.
- For example, the first VOL plugin in a stack could be a statistics plugin, that does nothing but gather information on what API calls are made and their corresponding parameters.

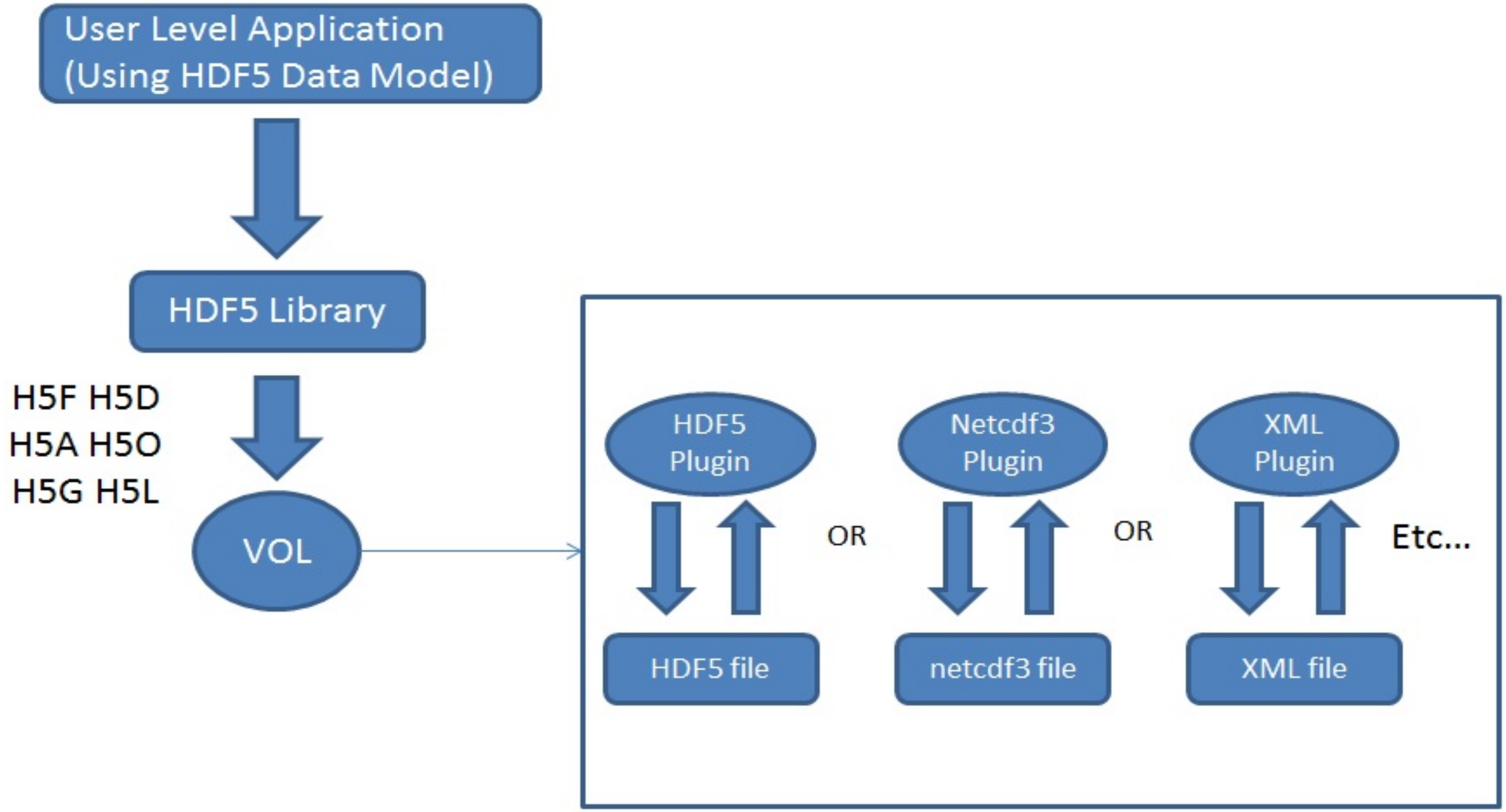
Mirroring

- Extension to stacking
- HDF5 API calls are forwarded through a mirror plugin to two or more VOL plugins

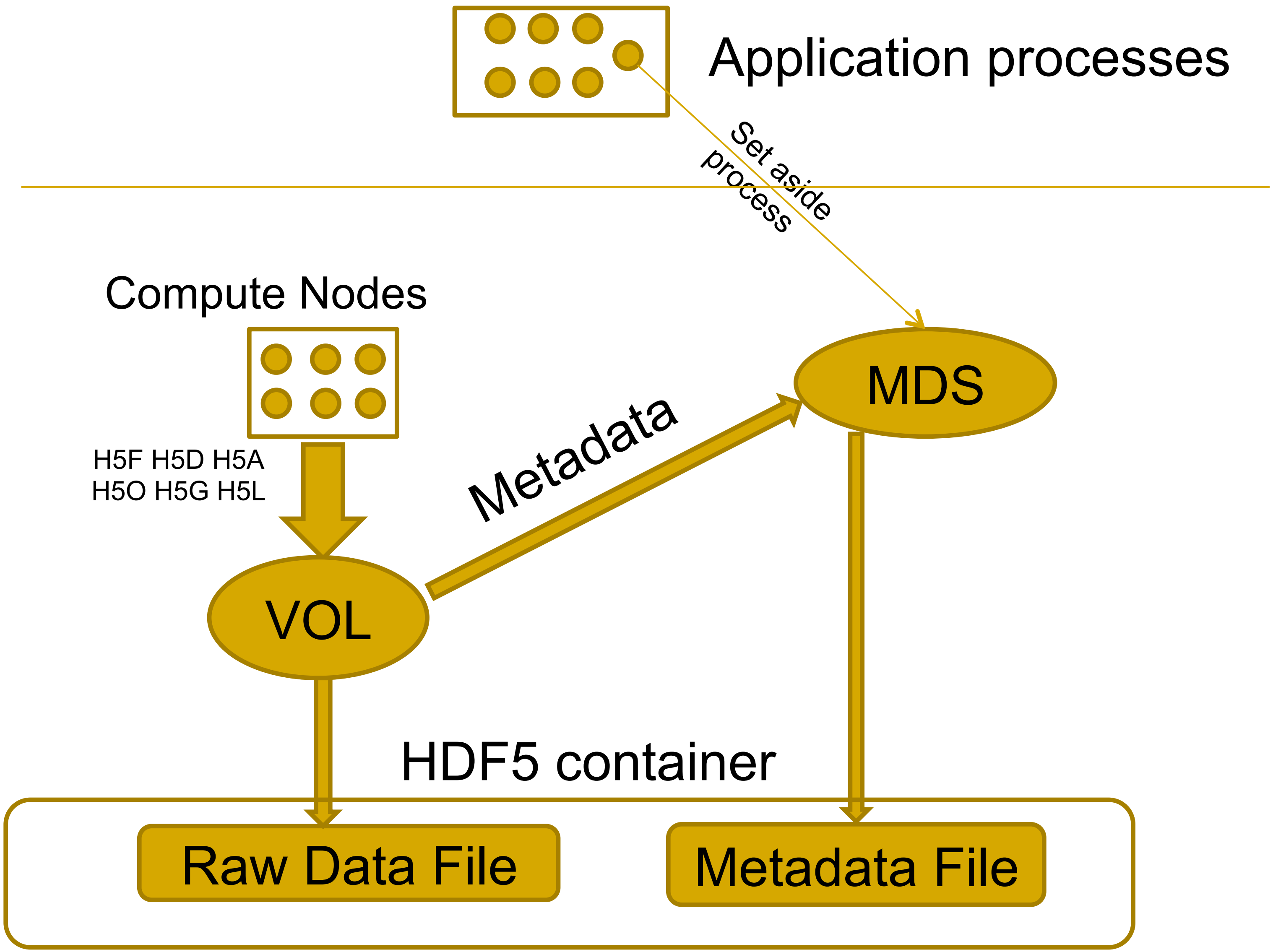


Sample Plugins (I)

- Different File Format plugins



Sample Plugins: Metadata Server



Raw Plugin

- The flexibility of the virtual object layer provides developers with the option to abandon the single file, binary format like the native HDF5 implementation.
- A “raw” file format could map HDF5 objects (groups, datasets, etc …) to file system objects (directories, files, etc …).
- The entire set of raw file system objects created would represent one HDF5 container.
- Useful to the PLFS package (http://institute.lanl.gov/plfs/)

Remote Plugin

- A remote VOL plugin would allow access to files located remotely.
- The plugin could have an HDF5 server module located where the HDF5 file resides and listens to incoming requests from a remote process.
- Use case: Remote visualization
  - Large, remote datasets are very expensive to migrate to the local visualization system.
  - It would be faster to just enable *in situ* visualization to remotely access the data using the HDF5 API.

Implementation

- VOL Class
  - Data structure containing general variables and a collection of function pointers for HDF5 API calls
- Function Callbacks
  - API routines that potentially touch data on disk
  - H5F, H5D, H5A, H5O, H5G, H5L, and H5T

Implementation

- We will end up with a large set of function callbacks:
  - Lump all the functions together into one data structure OR
  - Have a general class that contains all common functions, and then children of that class that contain functions specific to certain HDF5 objects OR
  - For each object have a set of callbacks that are specific to that object (This is design choice that has been taken).

Filters

- Need to keep HDF5 filters in mind
- Where is the filter applied, before or after the VOL plugin?
  - Logical guess now would be before, to avoid having all plugins deal with filters

Current status of VOL

- ?

Research Focus -

AUTOTUNING

Autotuning Background

- Software Autotuning:
  - Employ empirical techniques to evaluate a set of alternative mappings of computation kernels to an architecture and select the mapping that obtains the best performance.
- Autotuning Categories:
  - Self-tuning library generators such as ATLAS, PhiPAC and OSKI for linear algebra, etc.
  - Compiler-based autotuners that automatically generate and search a set of alternative implementations of a computation
  - Application-level autotuners that automate empirical search across a set of parameter values proposed by the application programmer

HDF5 Autotuning

- Why?
  - Because the dominant I/O support request at NERSC is poor I/O performance, many/most of which can be solved by enabling Lustre striping, or tuning another I/O parameter
  - *Scientists shouldn't have to figure this stuff out!*
- Two Areas of Focus:
  - Evaluate techniques for autotuning HPC application I/O
    - File system, MPI, HDF5
  - Record and Replay HDF5 I/O operations

Autotuning HPC I/O

- Goal: Avoid tuning each application to each machine and file system
  - Create I/O autotuner library that can inject “optimal” parameters for I/O operations on a given system
- Using Darshan* tool to create wrappers for HDF5 calls
  - Application can be dynamically linked with I/O autotuning library
  - No changes to application or HDF5 library
- Using several HPC applications currently:
  - VPIC, GCRM, Vorpal

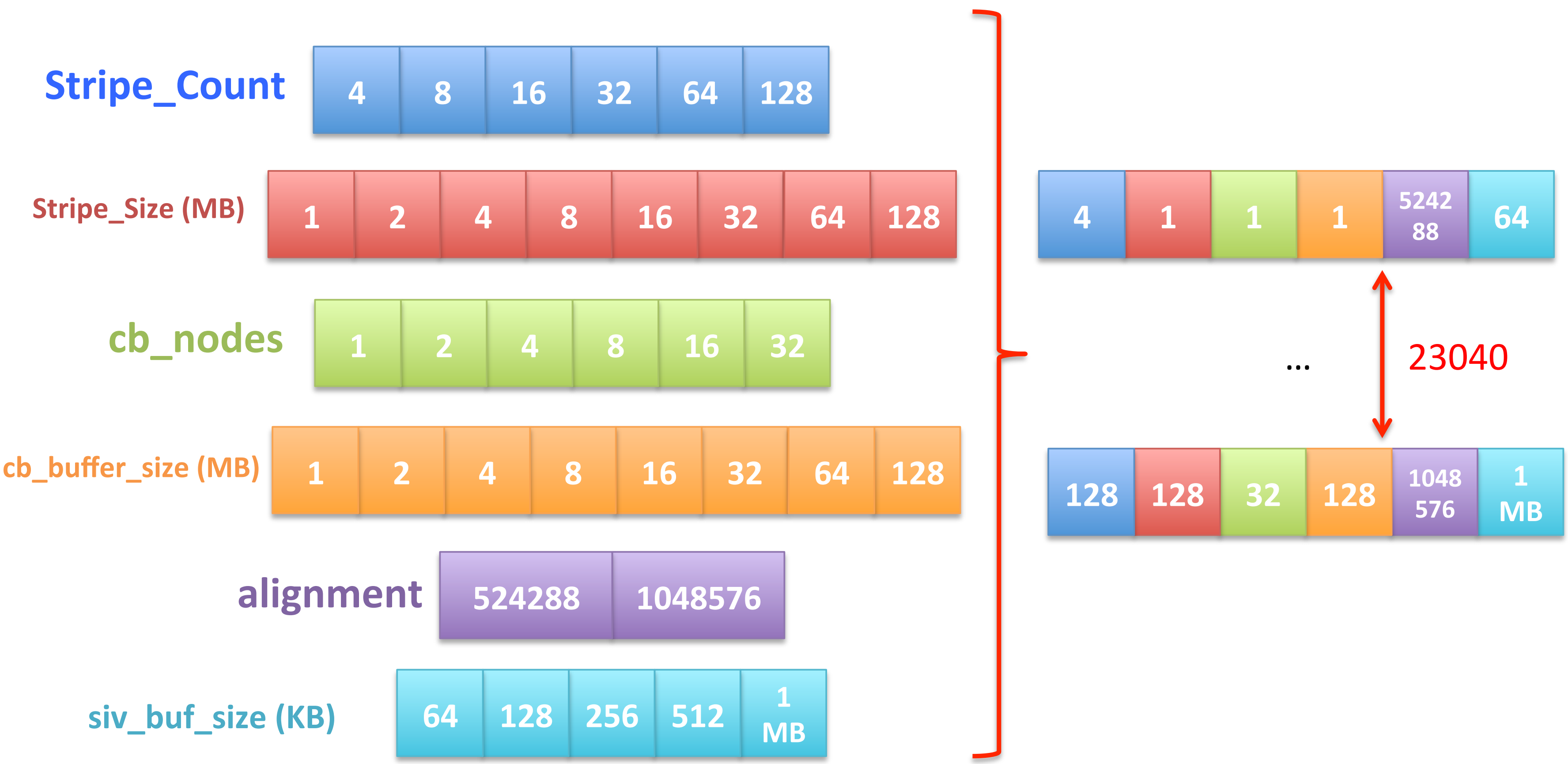
* - http://www.mcs.anl.gov/research/projects/darshan/

Autotuning HPC I/O

- Initial parameters of interest
  - File System (Lustre): stripe count, stripe unit
  - MPI-I/O: Collective buffer size, coll. buffer nodes
  - HDF5: Alignment, sieve buffer size

Autotuning HPC I/O

The whole space visualized



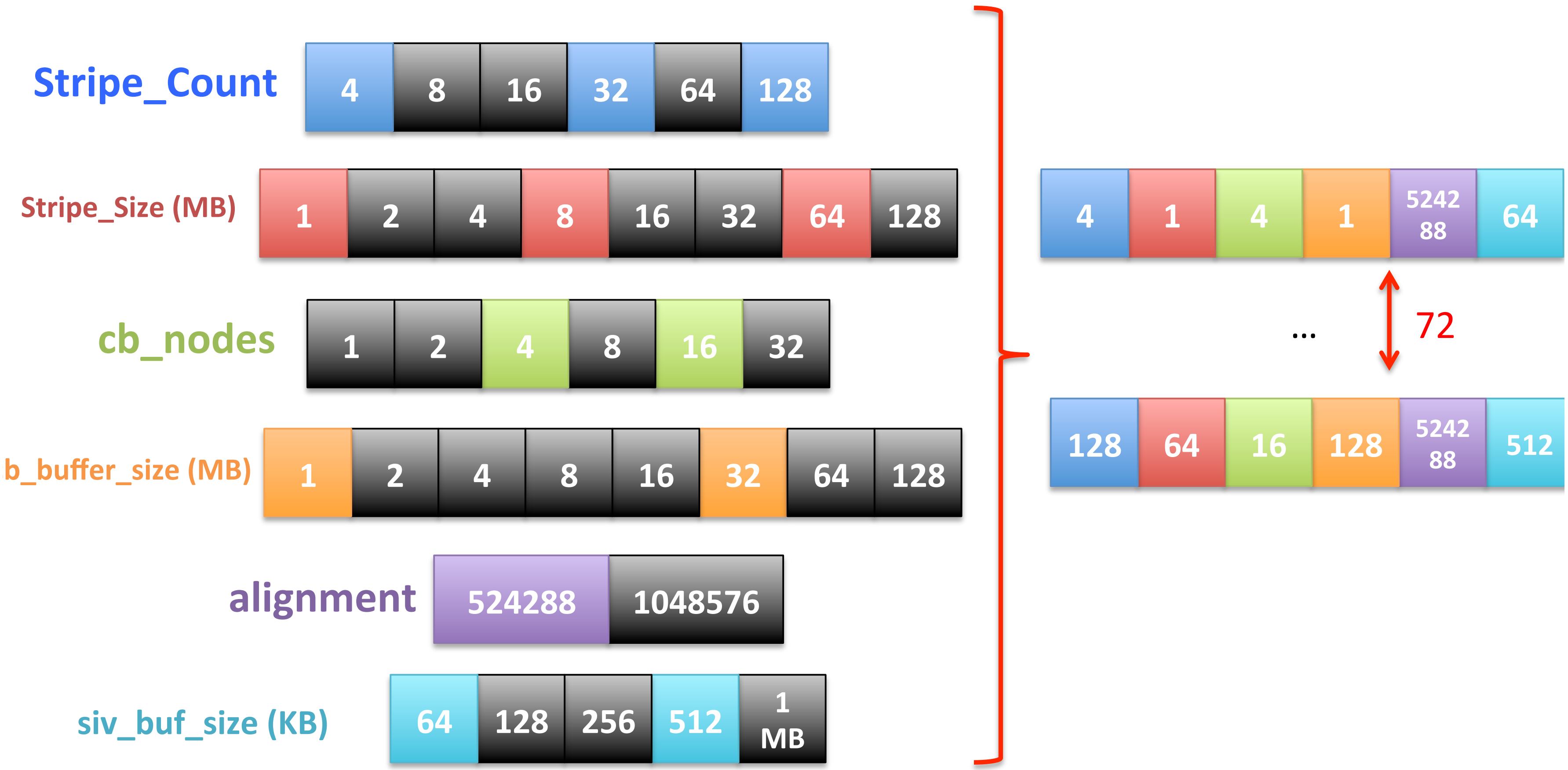
Autotuning HPC I/O

- Autotuning Exploration/Generation Process:
  - Iterate over running application many times:
    - Intercept application's I/O calls
    - Inject autotuning parameters
    - Measure resulting performance
- Analyze performance information from many application runs to create configuration file, with best parameters found for application/ machine/file system

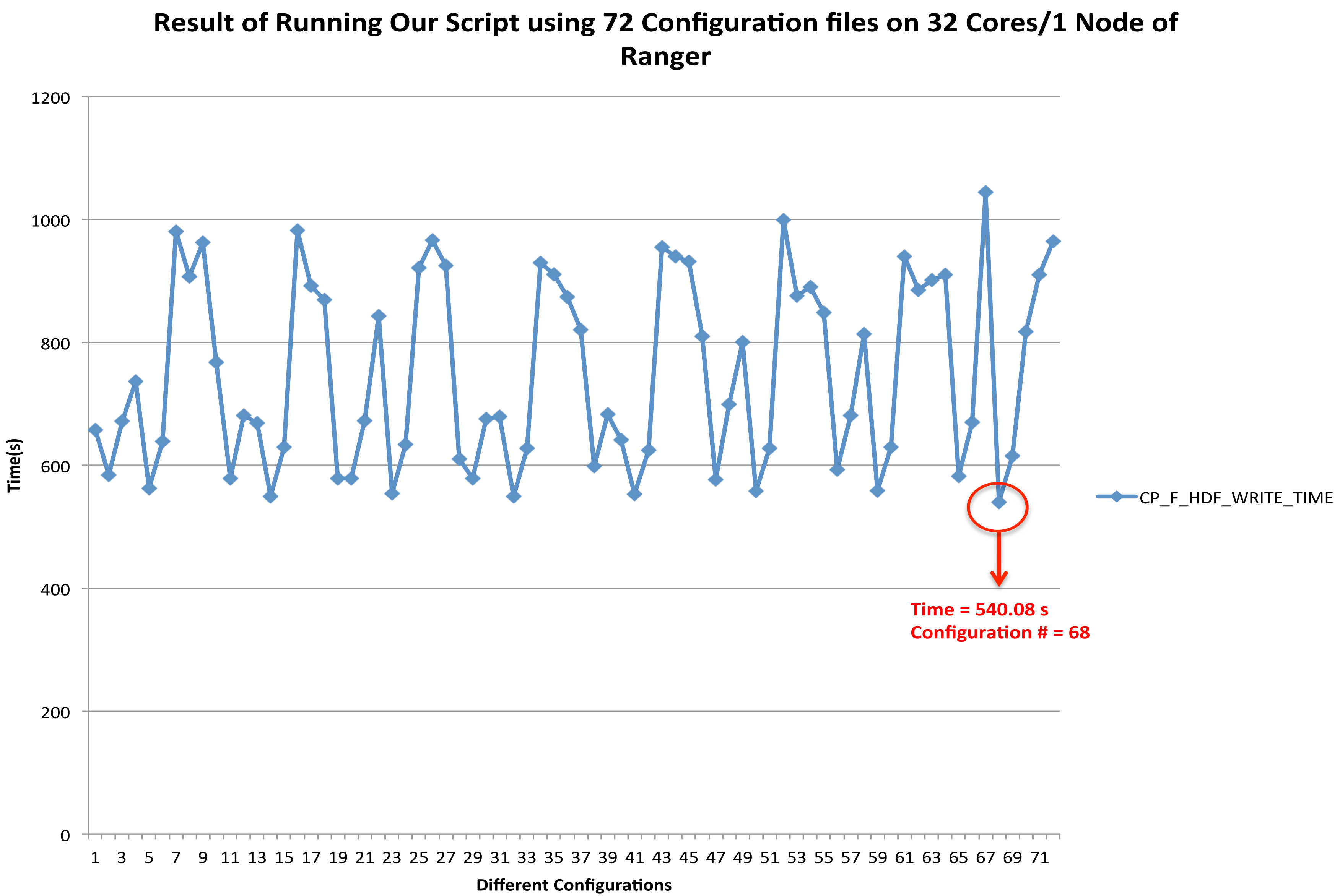
Autotuning HPC I/O

- Using the I/O Autotuning Library:
  - Dynamically link with I/O autotuner library
  - I/O autotuner library automatically reads parameters from config file created during exploration process
  - I/O autotuner automatically injects autotuning parameters as application operates

Smaller set of space visualized



Autotuning HPC I/O



Configuration #68

```
<Parameters>
        <High_Level_IO_Library>
                <sieve_buf_size> 524280 </sieve_buf_size>
                <alignment> 262144,524288 </alignment>
                <!-- H5Pset_alignment function gets 2 args: (Threshold, Alignment) -
        </High_Level_IO_Library>

        <Middleware_Layer>
                <cb_buffer_size> 134217728 </cb_buffer_size>
                <cb_nodes> 16 </cb_nodes>
        </Middleware_Layer>

        <Parallel_File_System>
                <striping_factor> 32 </striping_factor>
                <striping_unit> 8388608 </striping_unit>
        </Parallel_File_System>
</Parameters>
```

Autotuning in HDF5

- “Auto-Tuning of Parallel IO Parameters for HDF5 Applications”, Babak Behzad, et al, poster @ SC12
- Forthcoming: "Taming Parallel I/O Complexity with Auto-Tuning”, Babak Behzad, et al, paper accepted to SC13

Autotuning HPC I/O

- Remaining research:
  - Determine “speed of light” for I/O on system and use that to define “good enough” performance
  - Entire space is too large to fully explore, we are now evaluating genetic algorithm techniques to help find “good enough” parameters
  - How to factor out “unlucky” exploration runs
  - Methods for avoiding overriding application parameters with autotuned parameters

Thank You!

Questions?