HDF5 vs. Other Binary File Formats

Introduction to the HDF5's most powerful features

HDF5 vs. Others in a Nutshell

- Portable self-described files
- No limitation on the file size
- Fast and flexible I/O including parallel
- Internal compression

HDF5 vs. Others

- Data Model
  - General data model that enables complex data relationships and dependencies
  - Unlimited variety of datatypes
- File
  - Portable self-described binary file with random access
  - Flexible storage mechanism
    - Internal compression with unlimited number of compression methods
    - Ability to access sub-sets of compressed data
    - Ability to share data between files

HDF5 vs. Others

- Library
  - Flexible, efficient I/O
    - Partial I/O
    - Parallel I/O
    - Customized I/O
  - Data transformation during I/O
    - Type conversions
    - Custom transformations
  - Portable
    - Available for numerous platforms and compilers

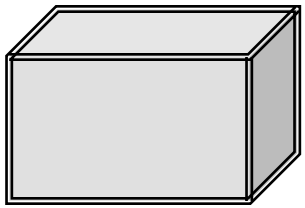
Outline

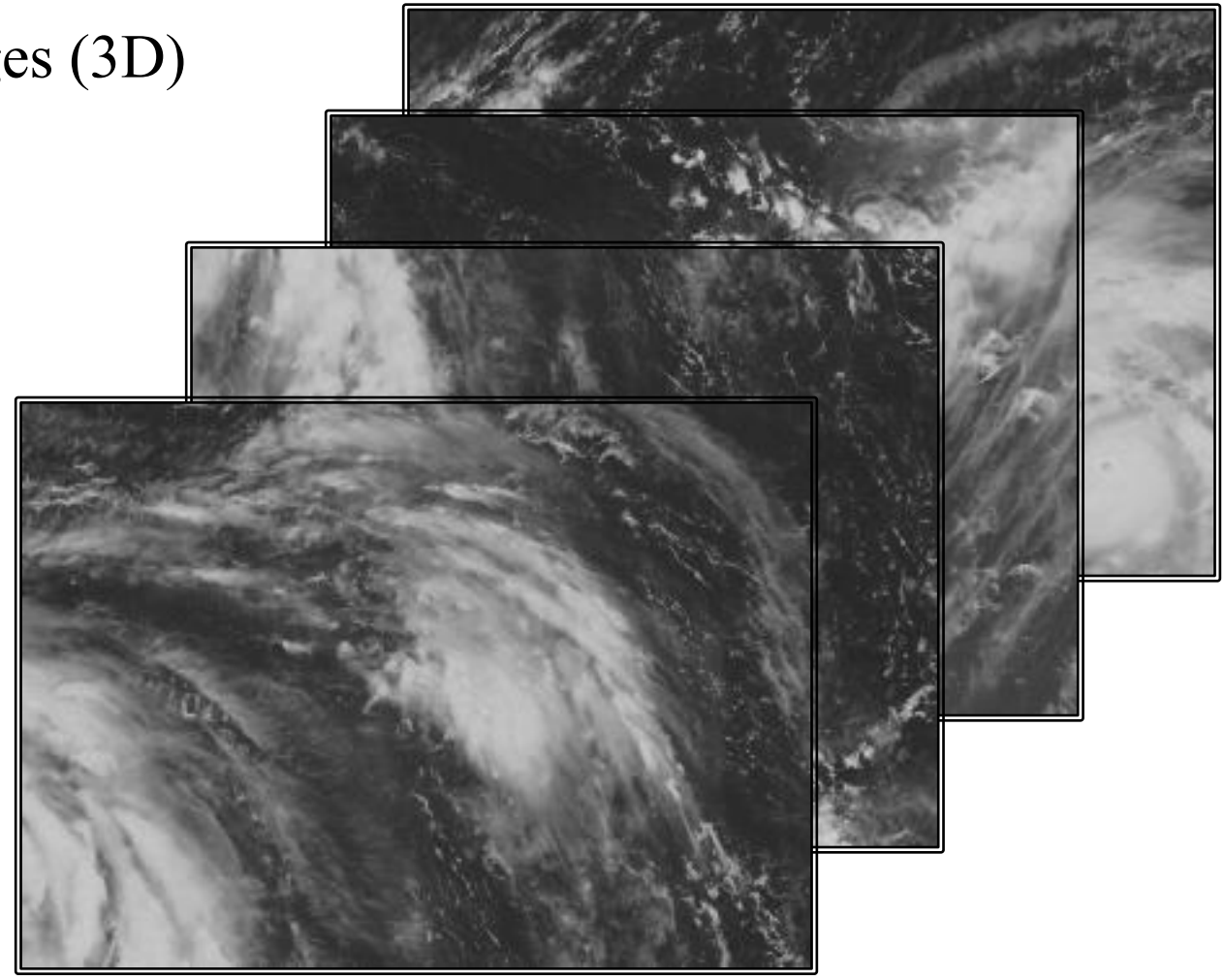
- Partial I/O in HDF5
- HDF5 datatypes
- Storage mechanisms
  - External
  - Chunking and compression

PARTIAL I/O OR WORKING WITH SUBSETS

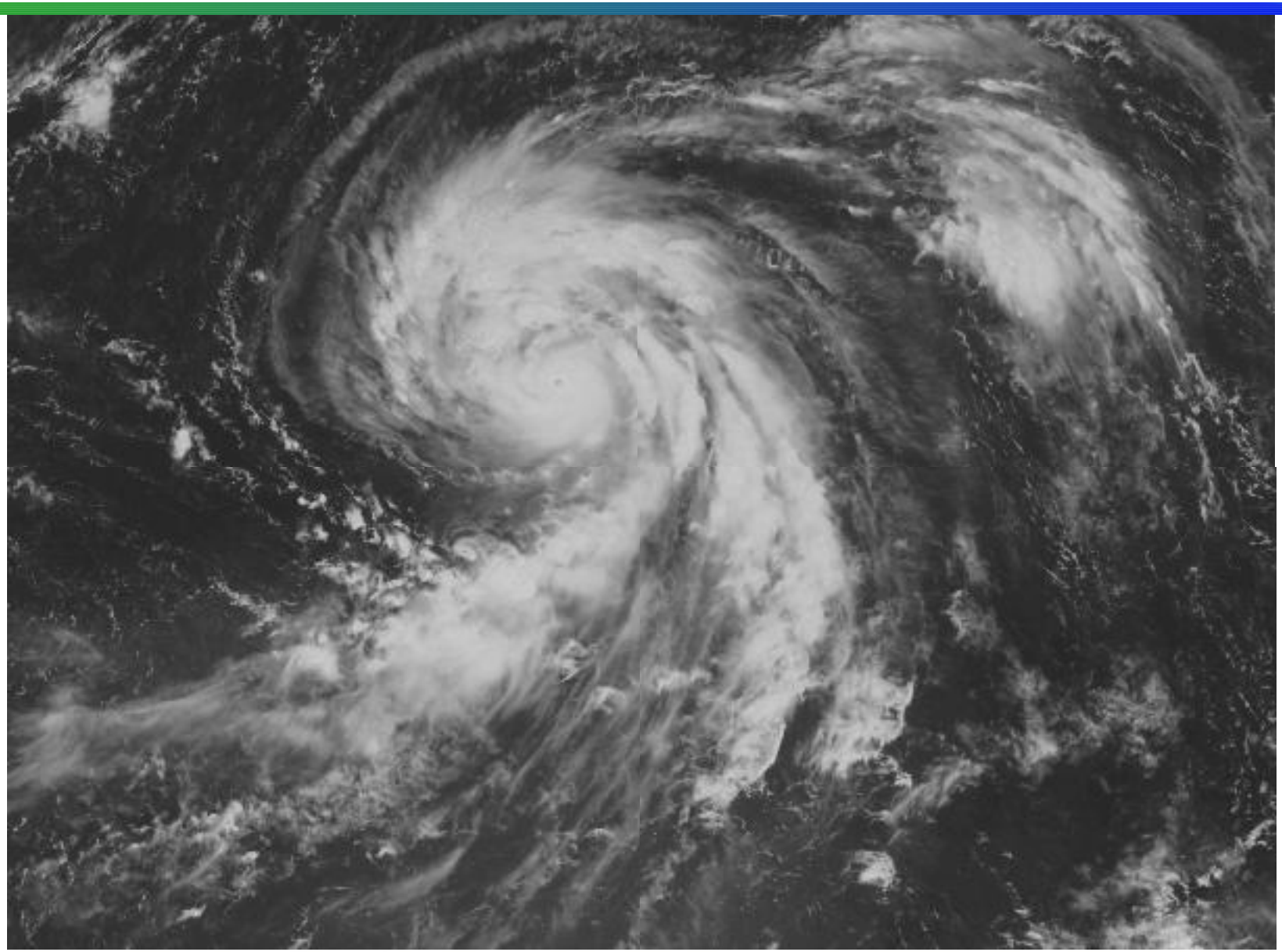
Collect data one way ….

Array of images (3D)

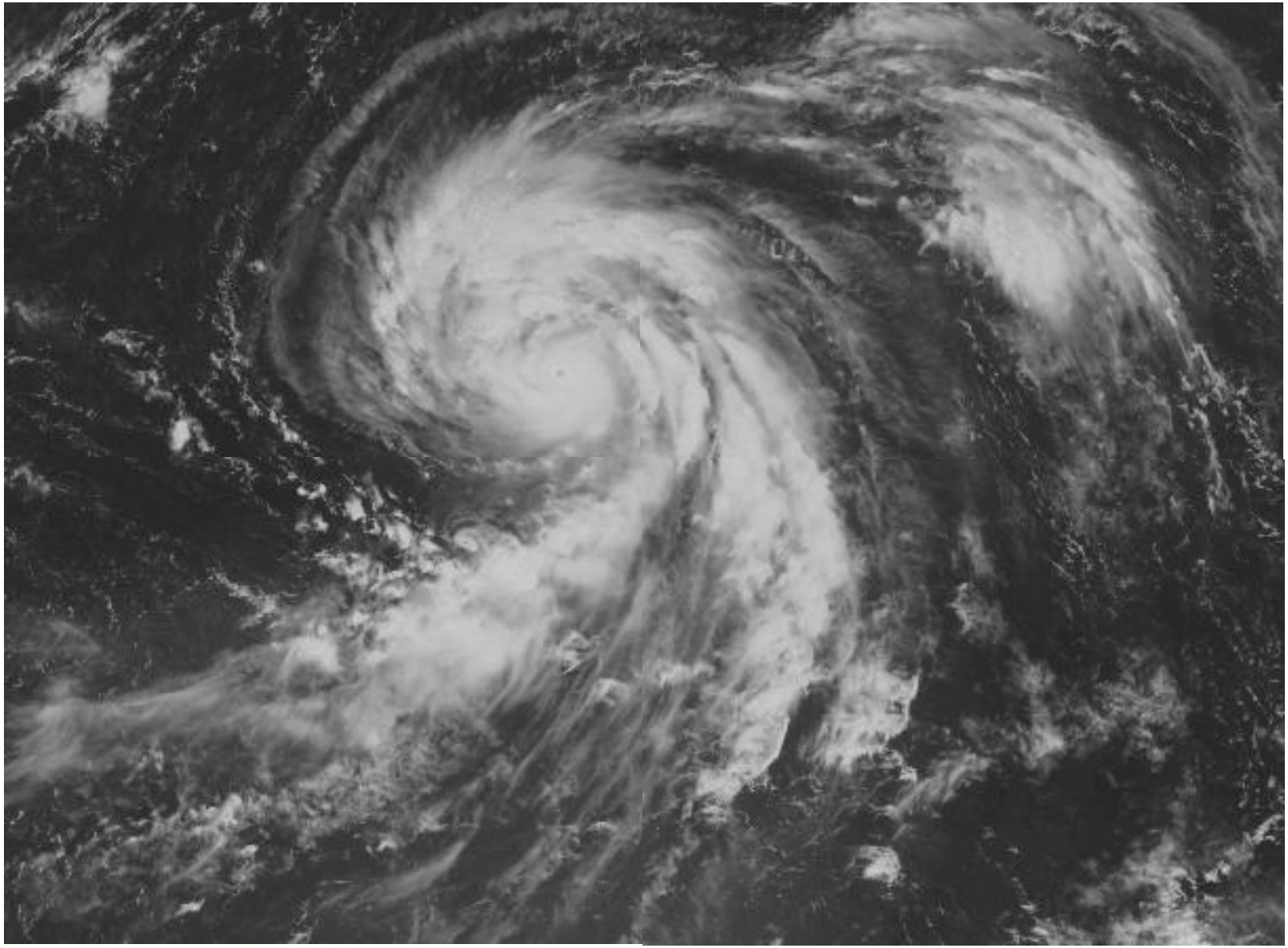




Display data another way …



Data is too big to read….



HDF5 Library Features

- HDF5 Library provides capabilities to
  - Describe subsets of data and perform write/ read operations on subsets
    - Hyperslab selections and partial I/O
  - Store descriptions of the data subsets in a file
    - Region references
  - Use efficient storage mechanism to achieve good performance while writing/reading subsets of data

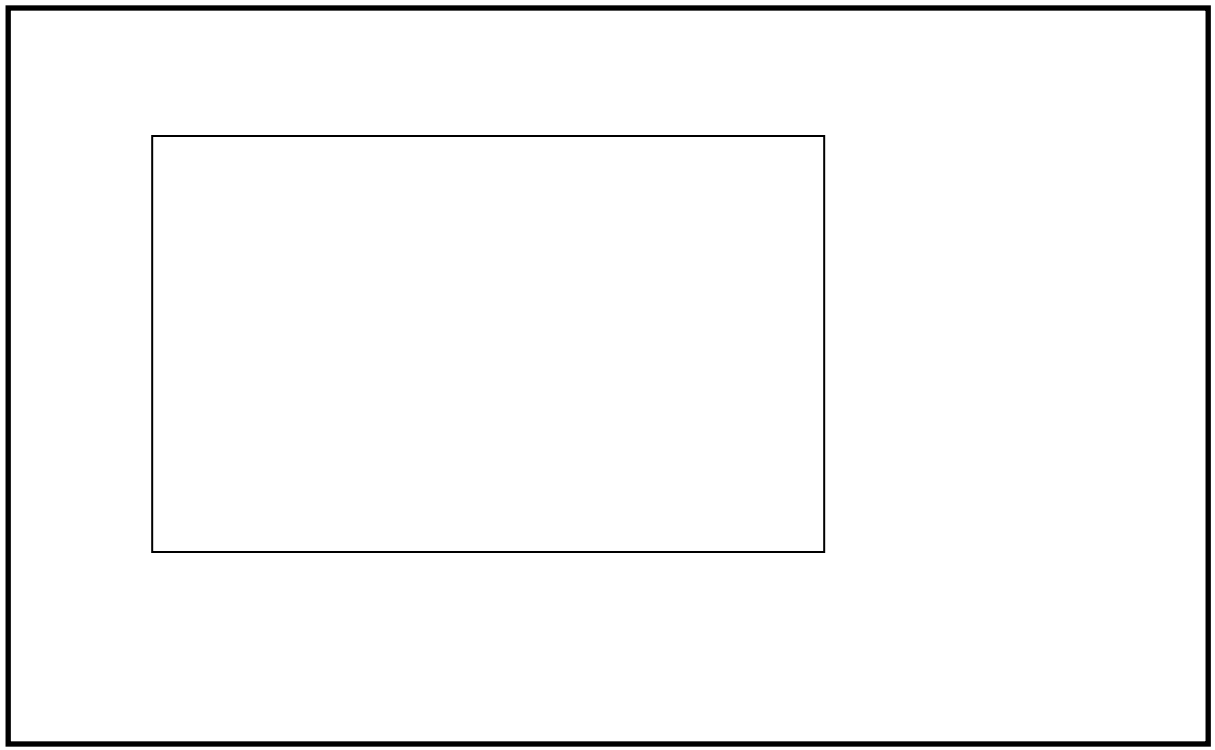
How to Describe a Subset in HDF5?

- Before writing and reading a subset of data one has to describe it to the HDF5 Library
- HDF5 APIs and documentation refer to a subset as a “selection” or a “hyperslab selection”.
- If specified, HDF5 Library will perform I/O on a selection *only* and not on all elements of a dataset.

Types of Selections in HDF5

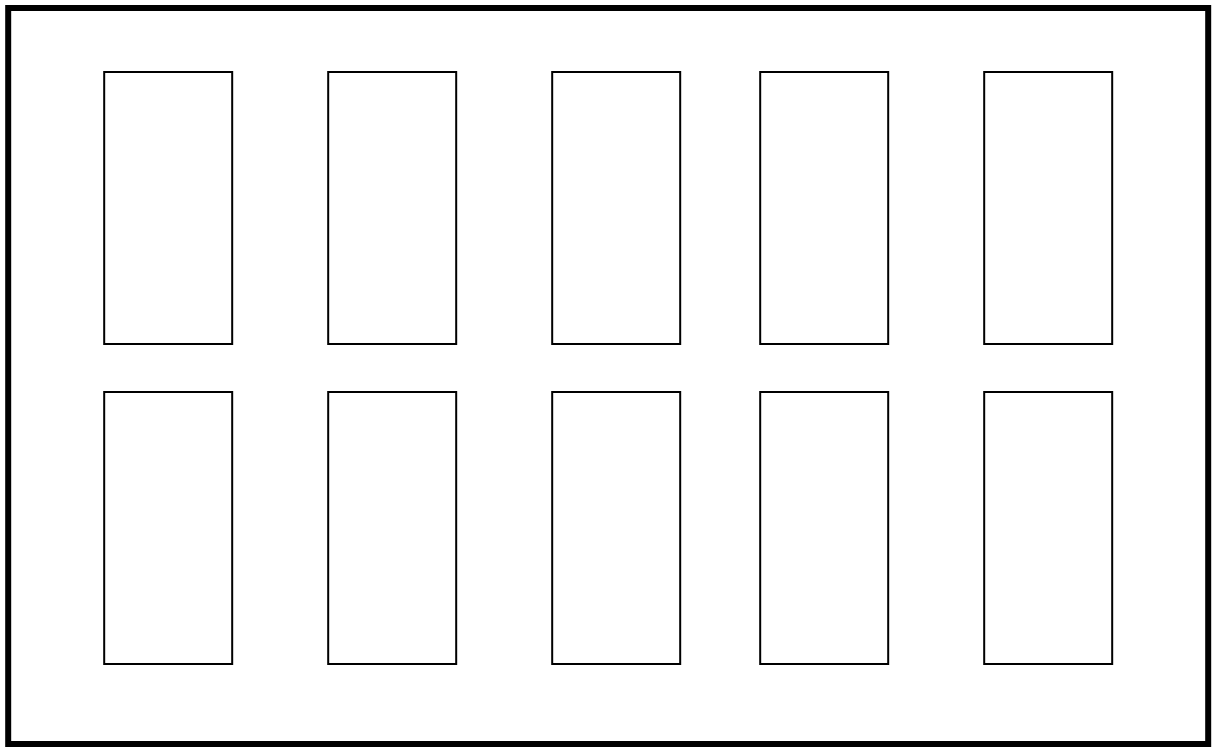
- Two types of selections
  - Hyperslab selection
    - Simple hyperslab (sub-array)
    - Regular hyperslab (patterns of sub-arrays)
    - Result of set operations on hyperslabs (union, difference, …)
  - Point selection
- Hyperslab selection is especially important for doing parallel I/O in HDF5 (See Parallel HDF5 Tutorial)

Simple Hyperslab



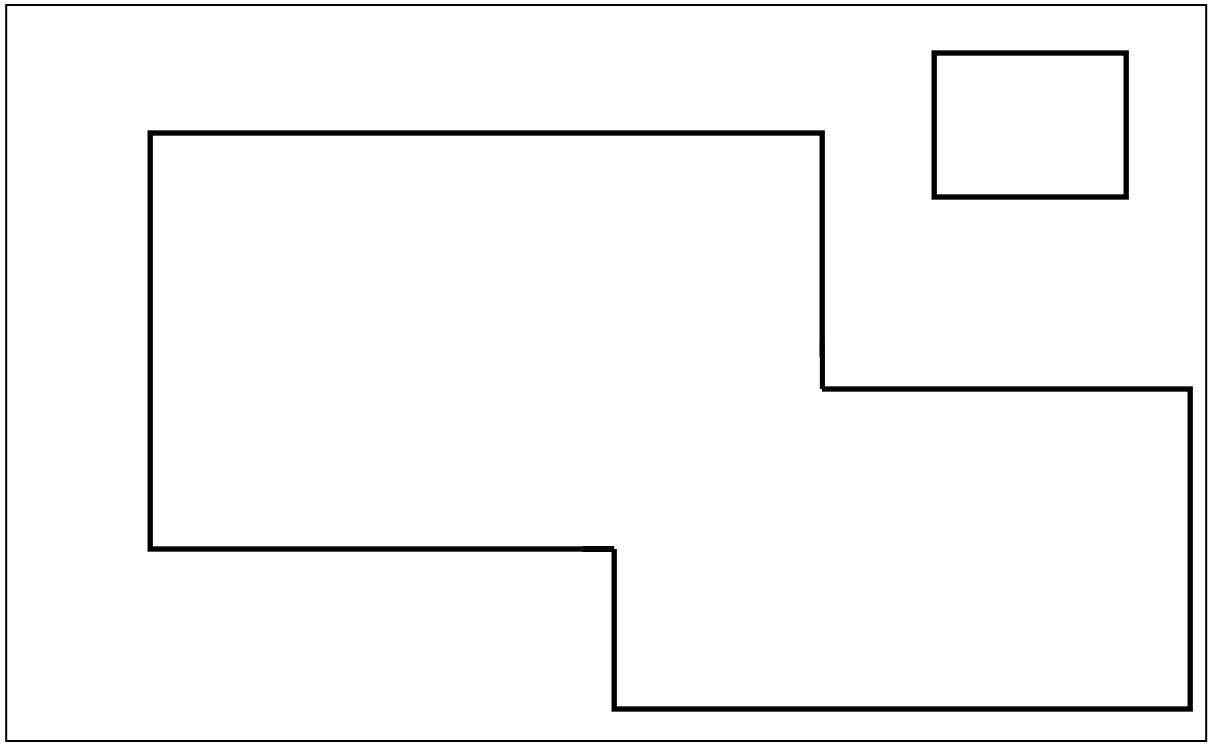
Contiguous subset or sub-array

Regular Hyperslab



Collection of regularly spaced equal size blocks

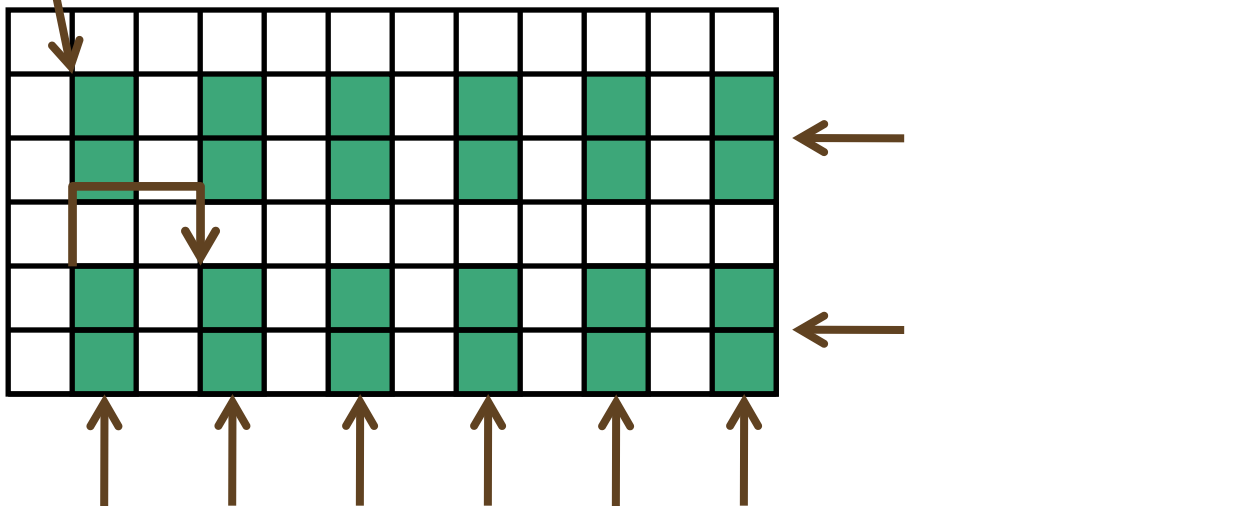
Hyperslab Selection



Result of union operation on three simple hyperslabs

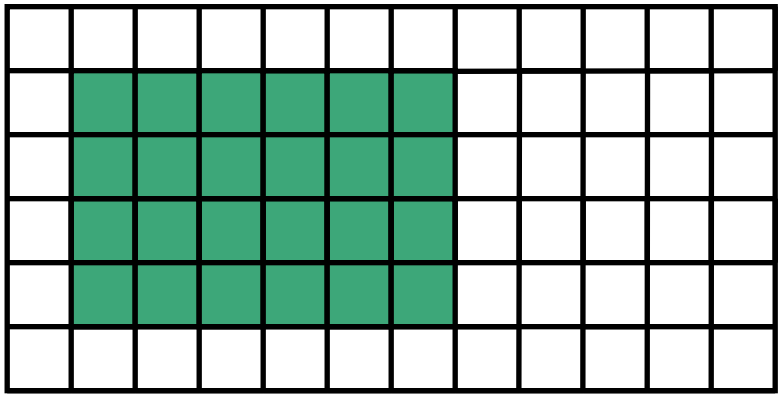
Hyperslab Description

- Offset - starting location of a hyperslab (1,1)
- Stride - number of elements that separate each block (3,2)
- Count - number of blocks (2,6)
- Block - block size (2,1)
- *Everything is "measured" in number of elements*



Simple Hyperslab Description

- Two ways to describe a simple hyperslab
- As *several* blocks
  - **Stride – (1,1)**
  - **Count – (4,6)**
  - Block – (1,1)
- As *one* block
  - Stride – (1,1)
  - Count – (1,1)
  - **Block – (4,6)**

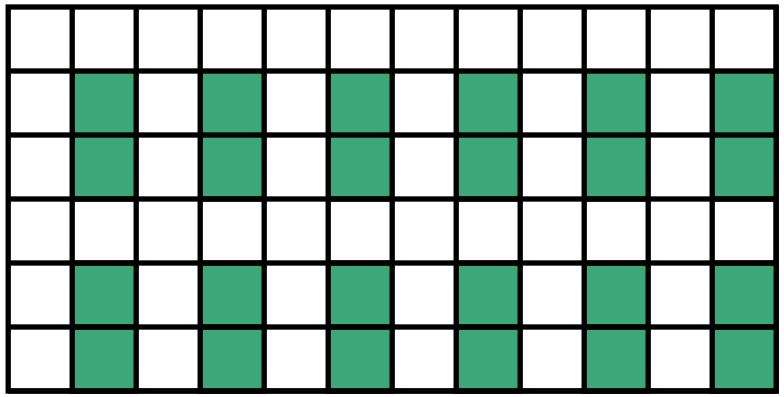


No performance penalty for one way or another

Hyperslab Selection Troubleshooting

- Selected elements have to be within the current space extent
- offset + (count-1) *stride + block =< dim
- Checking in the horizontal direction we have

  1 + (6-1) * 2 + 1 = 12



dim = (6, 12)
offset = (1, 1)
stride = (3, 2)
count = (2, 6)
block = (2, 1)

Example : Reading Two Rows

Data in a file
4x6 matrix

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

Buffer in memory
1-dim array of length 14

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Example: Reading Two Rows

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

```
start  = {1,0}
count  = {2,6}
block  = {1,1}
stride = {1,1}
```

```
filespace = H5Dget_space (dataset);
H5Sselect_hyperslab (filespace, H5S_SELECT_SET,
                     start, NULL, count, NULL)
```

Example: Reading Two Rows

```
start[1] = {1}
count[1] = {12}
dim[1]   = {14}
```

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

```
memspace = H5Screate_simple(1, dim, NULL);
H5Sselect_hyperslab (memspace, H5S_SELECT_SET,
                     start, NULL, count, NULL)
```

Example: Reading Two Rows

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

```
H5Dread (…, …, memspace, filespace, …, …);
```

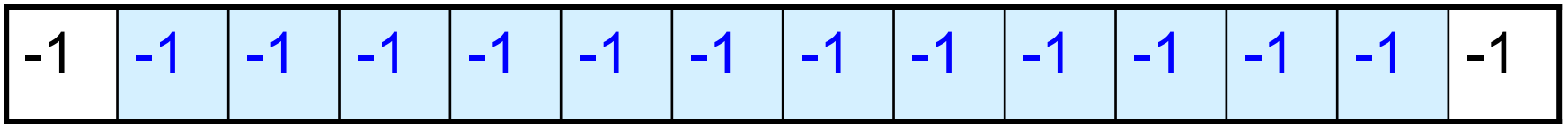
-1	7	8	9	10	11	12	13	14	15	16	17	18	-1

Things to Remember

- *Number* of elements selected in a file and in a memory buffer *must be the same*
  - `H5Sget_select_npoints` returns number of selected elements in a hyperslab selection
- HDF5 partial I/O is tuned to move data between selections that have the same dimensionality
- *Allocate a buffer of an appropriate size* when reading data; use `H5Tget_native_type` and `H5Tget_size` to get the correct size of the data element in memory.

Example: Reading Two Rows

```
start[1] = {1}
count[1] = {12}
dim[1]   = {14}
```




```
memspace = H5Screate_simple(1, dim, NULL);
H5Sselect_hyperslab (memspace, H5S_SELECT_SET,
                     start, NULL, count, NULL)
```

Example:h5ex_d_hyper.c

```
HDF5 "h5ex_d_hyper.h5" {
GROUP "/" {
   DATASET "DS1" {
      DATATYPE  H5T_STD_I32LE
      DATASPACE  SIMPLE { ( 6, 8 ) / ( 6, 8 ) }
      DATA {
      (0,0): 0, 1, 0, 0, 1, 0, 0, 1,
      (1,0): 1, 1, 0, 1, 1, 0, 1, 1,
      (2,0): 0, 0, 0, 0, 0, 0, 0, 0,
      (3,0): 0, 1, 0, 0, 1, 0, 0, 1,
      (4,0): 1, 1, 0, 1, 1, 0, 1, 1,
      (5,0): 0, 0, 0, 0, 0, 0, 0, 0
      }
   }
}
}
```

HDF5 DATATYPES

An HDF5 Datatype is…

- A description of dataset element type
- Grouped into “classes”:
  - Atomic – integers, floating-point values
  - Enumerated
  - Compound – like C structs
  - Array
  - Opaque
  - References
    - Object – similar to soft link
    - Region – similar to soft link to dataset + selection
  - Variable-length
    - Strings – fixed and variable-length
    - Sequences – similar to Standard C++ vector class

HDF5 Datatypes

- HDF5 has a rich set of pre-defined datatypes and supports the creation of an unlimited variety of complex user-defined datatypes.
- Self-describing:
  - Datatype definitions are stored in the HDF5 file *with* the data.
  - Datatype definitions include information such as *byte order (endianness), size, and floating point representation* to fully describe how the data is stored and to insure portability across platforms.

HDF5 Datatypes (cont)

- Self-describing:
  - Datatype definitions are stored in the HDF5 file *with* the data.
  - Datatype definitions include information such as *byte order (endianness), size, and floating point representation* to fully describe how the data is stored and to insure portability across platforms.

Datatype Conversion

- Datatypes that are compatible, but not identical are converted automatically when I/O is performed
- Compatible datatypes:
  - All atomic datatypes are compatible
  - Identically structured array, variable-length and compound datatypes whose base type or fields are compatible
  - Enumerated datatype values on a “by name” basis
- Make datatypes identical for best performance

Datatypes Used in JPSS files

- In h5dump output search for “DATATYPE” keyword; those correspond to (…)

```
DATATYPE  H5T_STRING      C string
DATATYPE  H5T_STD_U8BE    unsigned char
DATATYPE  H5T_STD_U16BE   short (big-endian)
DATATYPE  H5T_STD_I32BE   int (big-endian)
DATATYPE  H5T_IEEE_F32BE  float (big-endian)
DATATYPE  H5T_STD_U64BE   unsigned long long
DATATYPE  H5T_REFERENCE { H5T_STD_REF_OBJECT }
DATATYPE  H5T_REFERENCE { H5T_STD_REF_DSETREG }
```

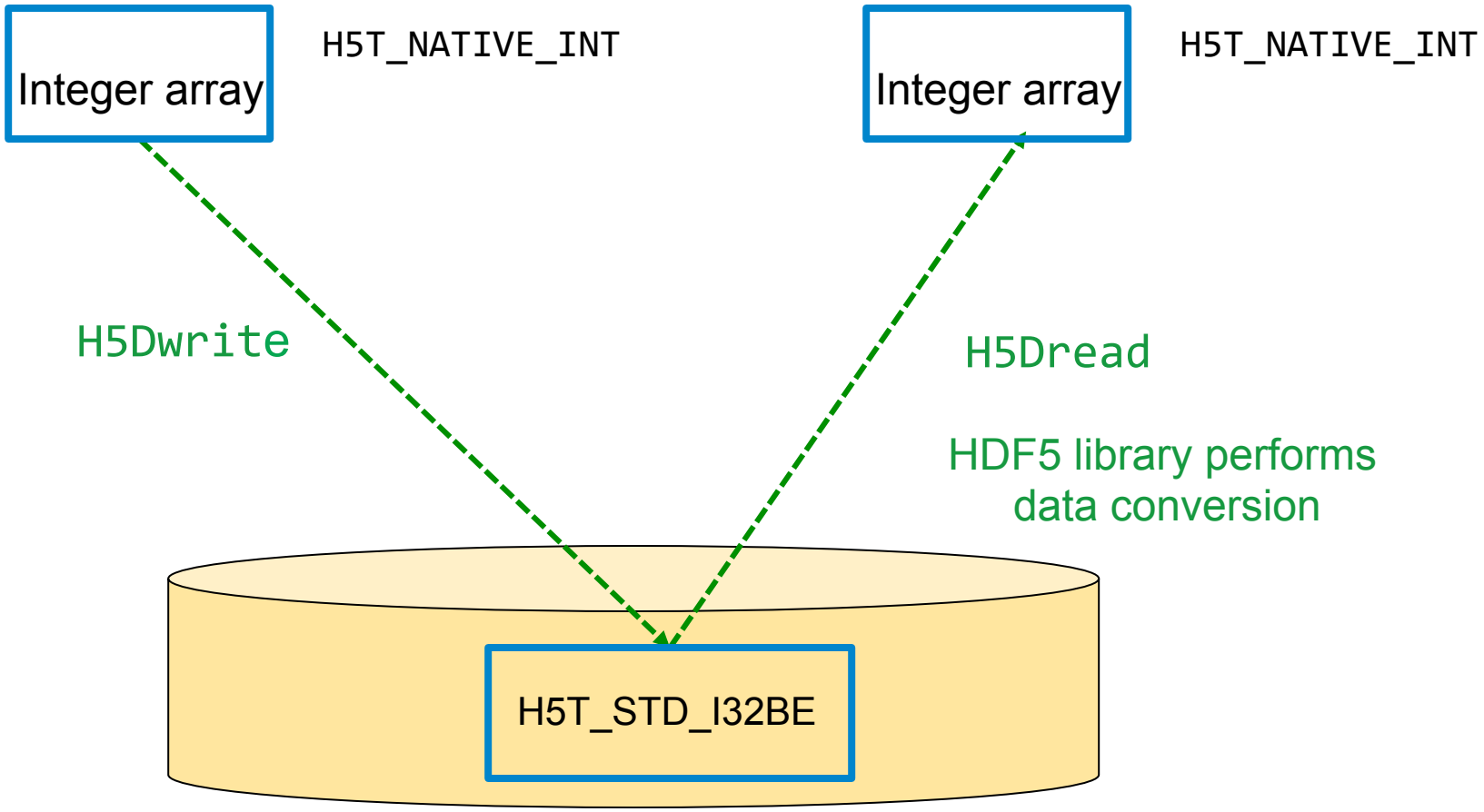
Native types from each language are mapped to HDF5 pre-defined datatypes

https://www.hdfgroup.org/HDF5/doc/RM/PredefDTypes.html

Datatype Conversion Example

Array of integers on AIX platform
Native integer is big-endian, 4 bytes

Array of integers on x86_64 platform
Native integer is little-endian, 4 bytes



Datatype Conversion

Datatype of data in the file

```
dataset = H5Dcreate(file, DATASETNAME, H5T_STD_I32LE,
                    space, H5P_DEFAULT, H5P_DEFAULT);
```

Datatype of data in memory buffer

```
H5Dwrite(dataset, H5T_NATIVE_INT, H5S_ALL, H5S_ALL,
                  H5P_DEFAULT, buf);
```

By specifying 4-bytes little-endian in the file, one will avoid data conversion when reading on little-endian machines

STORING STRINGS

Storing Strings in HDF5

- Array of characters (Array datatype or extra dimension in dataset)
  - Quick access to each character
  - Extra work to access and interpret each string
- Fixed length

```
string_id = H5Tcopy(H5T_C_S1);
H5Tset_size(string_id, size);
```

  - Wasted space in shorter strings
  - Can be compressed if used in datasets
- Variable length

```
string_id = H5Tcopy(H5T_C_S1);
H5Tset_size(string_id, H5T_VARIABLE);
```

  - Overhead as for all VL datatypes
  - Compression will not be applied to actual data in datasets

Storing Strings in HDF5

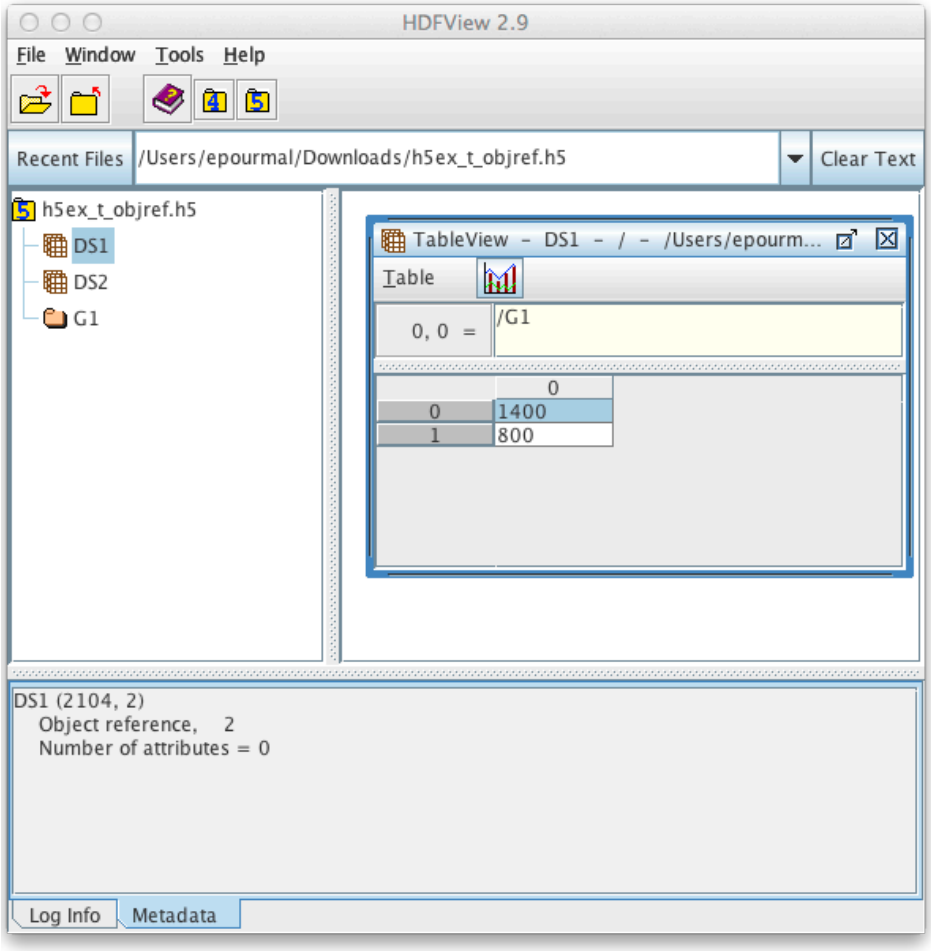
- Store the data in two datasets:
  - 1D char dataset stores concatenated strings.
  - 2D dataset stores (start, end) indices of each string in the first dataset.
    - Essentially a "hand-constructed" version of how we store variable length data.
    - Since the data are stored in datasets, they can be chunked, compressed, etc.
    - Slower than other access methods.
- When using attribute, use VL string H5_SCALAR dataspace instead H5S_SIMPLE to save some programming effort

USING DATATYPE TO REFERENCE DATA

Reference Datatypes

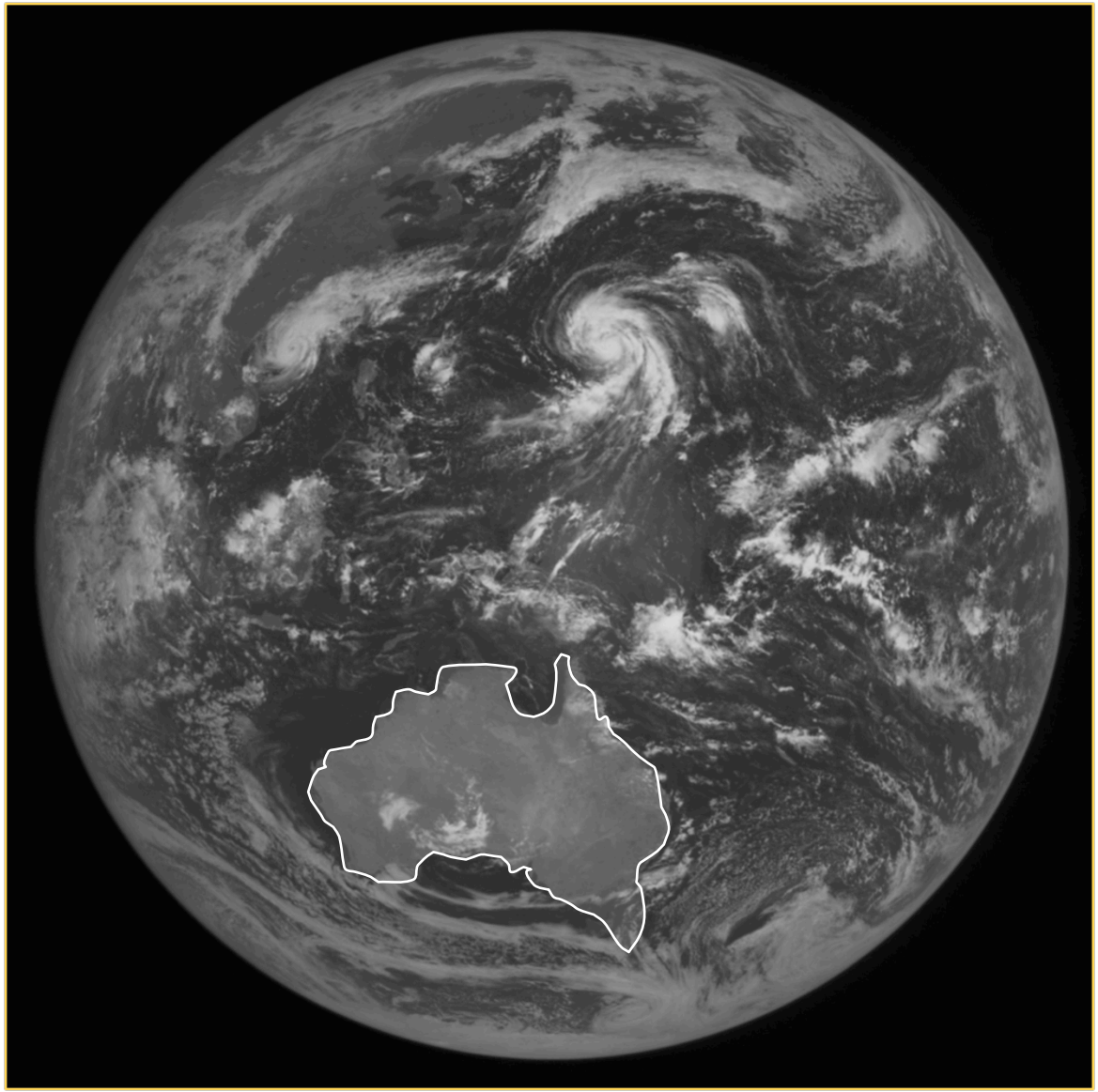
- Object Reference
  - Pointer to an object in a file
  - Predefined datatype H5T_STD_REF_OBJ
- Dataset Region Reference
  - Pointer to a dataset + dataspace selection
  - Predefined datatype H5T_STD_REF_DSETREG

Reference to Dataset

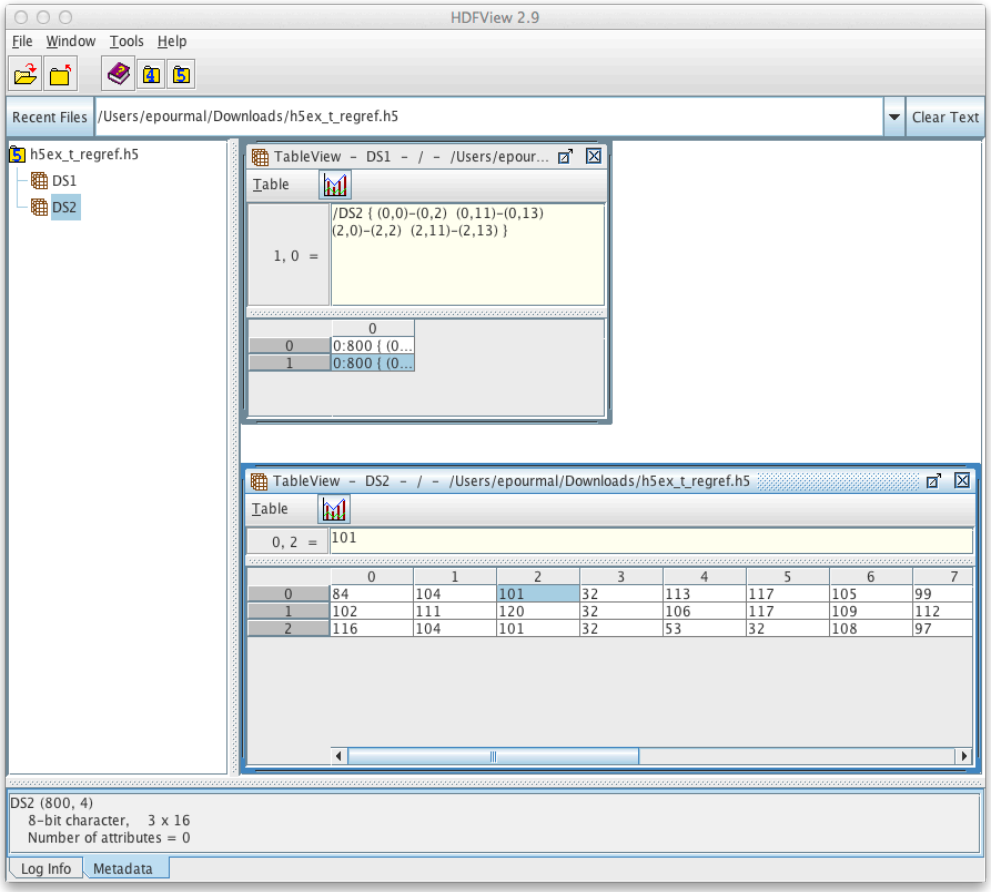



```
h5dump h5ex_t_objref.h5
HDF5 "h5ex_t_objref.h5" {
GROUP "/" {
   DATASET "DS1" {
      DATATYPE  H5T_REFERENCE { H5T_STD_REF_OBJECT }
      DATASPACE  SIMPLE { ( 2 ) / ( 2 ) }
      DATA {
      (0): GROUP 1400 /G1 , DATASET 800 /DS2
      }
   }
   DATASET "DS2" {
      DATATYPE  H5T_STD_I32LE
      DATASPACE  NULL
      DATA {
      }
   }
   GROUP "G1" {
   }
}
}
```

Saving Selected Region in a File



Reference to Regions




```
HDF5 "h5ex_t_regref.h5" {
GROUP "/" {
  DATASET "DS1" {
    DATATYPE  H5T_REFERENCE { H5T_STD_REF_DSETREG }
    DATASPACE  SIMPLE { ( 2 ) / ( 2 ) }
    DATA {
      DATASET /DS2 {(0,1), (2,11), (1,0), (2,4)},
      DATASET /DS2 {(0,0)-(0,2), (0,11)-(0,13), (2,0)-(2,2), (2,11)-(2,13)}
    }
  }
  DATASET "DS2" {
    DATATYPE  H5T_STD_I8LE
    DATASPACE  SIMPLE { ( 3, 16 ) / ( 3, 16 ) }
    DATA {
    (0,0): 84, 104, 101, 32, 113, 117, 105, 99, 107, 32, 98, 114, 111, 119,
    (0,14): 110, 0,
    (1,0): 102, 111, 120, 32, 106, 117, 109, 112, 115, 32, 111, 118, 101,
    (1,13): 114, 32, 0,
    (2,0): 116, 104, 101, 32, 53, 32, 108, 97, 122, 121, 32, 100, 111, 103,
    (2,14): 115, 0
    }
  }
}
}
```

Example: h5ex_t_objref.c

```
HDF5 "h5ex_t_objref.h5" {
GROUP "/" {
   DATASET "DS1" {
      DATATYPE  H5T_REFERENCE
{ H5T_STD_REF_OBJECT }
      DATASPACE  SIMPLE { ( 2 ) / ( 2 ) }
      DATA {
      (0): GROUP 1400 /G1 , DATASET 800 /DS2
      }
   }
   DATASET "DS2" {
      DATATYPE  H5T_STD_I32LE
      DATASPACE  NULL
      DATA {
      }
   }
   GROUP "G1" {
   }
}
}
```

Example: h5ex_t_objref.c

```
HDF5 "h5ex_t_regref.h5" {
GROUP "/" {
   DATASET "DS1" {
      DATATYPE  H5T_REFERENCE { H5T_STD_REF_DSETREG }
      DATASPACE  SIMPLE { ( 2 ) / ( 2 ) }
      DATA {
         DATASET /DS2 {(0,1), (2,11), (1,0), (2,4)},
         DATASET /DS2 {(0,0)-(0,2), (0,11)-(0,13), (2,0)-(2,2), (2,11)-(2,13)}
      }
   }
   DATASET "DS2" {
      DATATYPE  H5T_STD_I8LE
      DATASPACE  SIMPLE { ( 3, 16 ) / ( 3, 16 ) }
      DATA {
      (0,0): 84, 104, 101, 32, 113, 117, 105, 99, 107, 32, 98, 114, 111, 119, 110, 0,
      (1,0): 102, 111, 120, 32, 106, 117, 109, 112, 115, 32, 111, 118, 101, 114, 32, 0,
      (2,0): 116, 104, 101, 32, 53, 32, 108, 97, 122, 121, 32, 100, 111, 103, 115, 0
      }
   }
}
}
```

Object References in JPSS file

```
h5dump -d /Data_Products/VIIRS-M16-SDR/VIIRS-M16-SDR_Aggr /mnt/hdf/JPSS/CLASS/122293334/
SVM16_npp_d20120424_t0302382_e0304023_b02536_c20120502162515786022_noaa_ops.h5
HDF5 "/mnt/hdf/JPSS/CLASS/122293334/
SVM16_npp_d20120424_t0302382_e0304023_b02536_c20120502162515786022_noaa_ops.h5" {
DATASET "/Data_Products/VIIRS-M16-SDR/VIIRS-M16-SDR_Aggr" {
   DATATYPE  H5T_REFERENCE { H5T_STD_REF_OBJECT }
   DATASPACE  SIMPLE { ( 16 ) / ( H5S_UNLIMITED ) }
   DATA {
   (0): DATASET 7152 /All_Data/VIIRS-M16-SDR_All/Radiance ,
   (1): DATASET 4925568 /All_Data/VIIRS-M16-SDR_All/BrightnessTemperature ,
   (2): DATASET 9843656 /All_Data/VIIRS-M16-SDR_All/ModeScan ,
   (3): DATASET 9846024 /All_Data/VIIRS-M16-SDR_All/ModeGran ,
   (4): DATASET 9848568 /All_Data/VIIRS-M16-SDR_All/PadByte1 ,
   (5): DATASET 9850936 /All_Data/VIIRS-M16-SDR_All/NumberOfScans ,
   (6): DATASET 9853304 /All_Data/VIIRS-M16-SDR_All/NumberOfMissingPkts ,
   (7): DATASET 9855672 /All_Data/VIIRS-M16-SDR_All/NumberOfBadChecksums ,
   (8): DATASET 9858040 /All_Data/VIIRS-M16-SDR_All/NumberOfDiscardedPkts ,
   (9): DATASET 9861088 /All_Data/VIIRS-M16-SDR_All/QF1_VIIRSMBANDSDR ,
   (10): DATASET 12321576 /All_Data/VIIRS-M16-SDR_All/QF2_SCAN_SDR ,
   (11): DATASET 12323944 /All_Data/VIIRS-M16-SDR_All/QF3_SCAN_RDR ,
   (12): DATASET 12326312 /All_Data/VIIRS-M16-SDR_All/QF4_SCAN_SDR ,
   (13): DATASET 12328680 /All_Data/VIIRS-M16-SDR_All/QF5_GRAN_BADDETECTOR ,
   (14): DATASET 12331376 /All_Data/VIIRS-M16-SDR_All/RadianceFactors ,
   (15): DATASET 12333744 /All_Data/VIIRS-M16-SDR_All/BrightnessTemperatureFactors
   }
```

Region References in JPSS file

```
HDF5 "/mnt/hdf/JPSS/CLASS/GMODO-SVM01/GMODO-
SVM01_npp_d20130506_t1827179_e1832583_b07894_c20150408194443913666_XXXX_XXX.h5" {
DATASET "/Data_Products/VIIRS-MOD-GEO/VIIRS-MOD-GEO_Gran_2" {
   DATATYPE  H5T_REFERENCE { H5T_STD_REF_DSETREG }
   DATASPACE  SIMPLE { ( 22 ) / ( H5S_UNLIMITED ) }
   DATA {
      DATASET /All_Data/VIIRS-MOD-GEO_All/StartTime {(96)-(143)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/MidTime {(96)-(143)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/Latitude {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/Longitude {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SolarZenithAngle {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SolarAzimuthAngle {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SatelliteZenithAngle {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SatelliteAzimuthAngle {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/Height {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SatelliteRange {(1536,0)-(2303,3199)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SCPosition {(96,0)-(143,2)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SCVelocity {(96,0)-(143,2)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SCAttitude {(96,0)-(143,2)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SCSolarZenithAngle {(96)-(143)},
      DATASET /All_Data/VIIRS-MOD-GEO_All/SCSolarAzimuthAngle {(96)-(143)},
      …
}
```

STORAGE

HDF5 Dataset

Metadata

Dataspace

Rank

3

Dimensions

Dim_1 = 4

Dim_2 = 5

Dim_3 = 7

Datatype

IEEE 32-bit float

Storage info

Chunked

Compressed

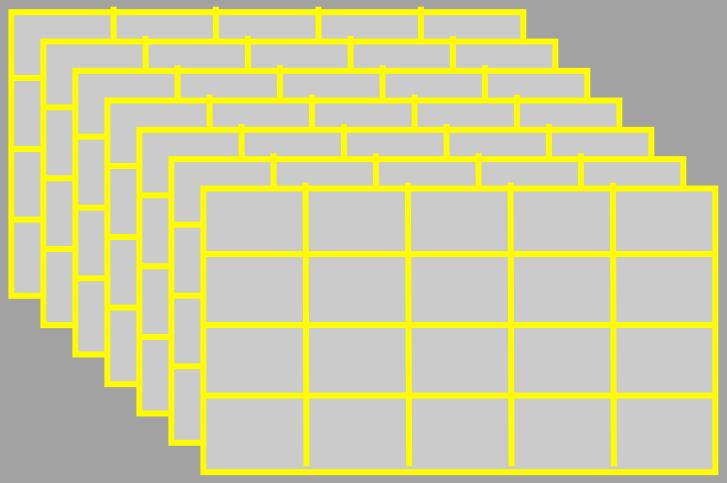
Attributes

Time = 32.4

Pressure = 987

Temp = 56

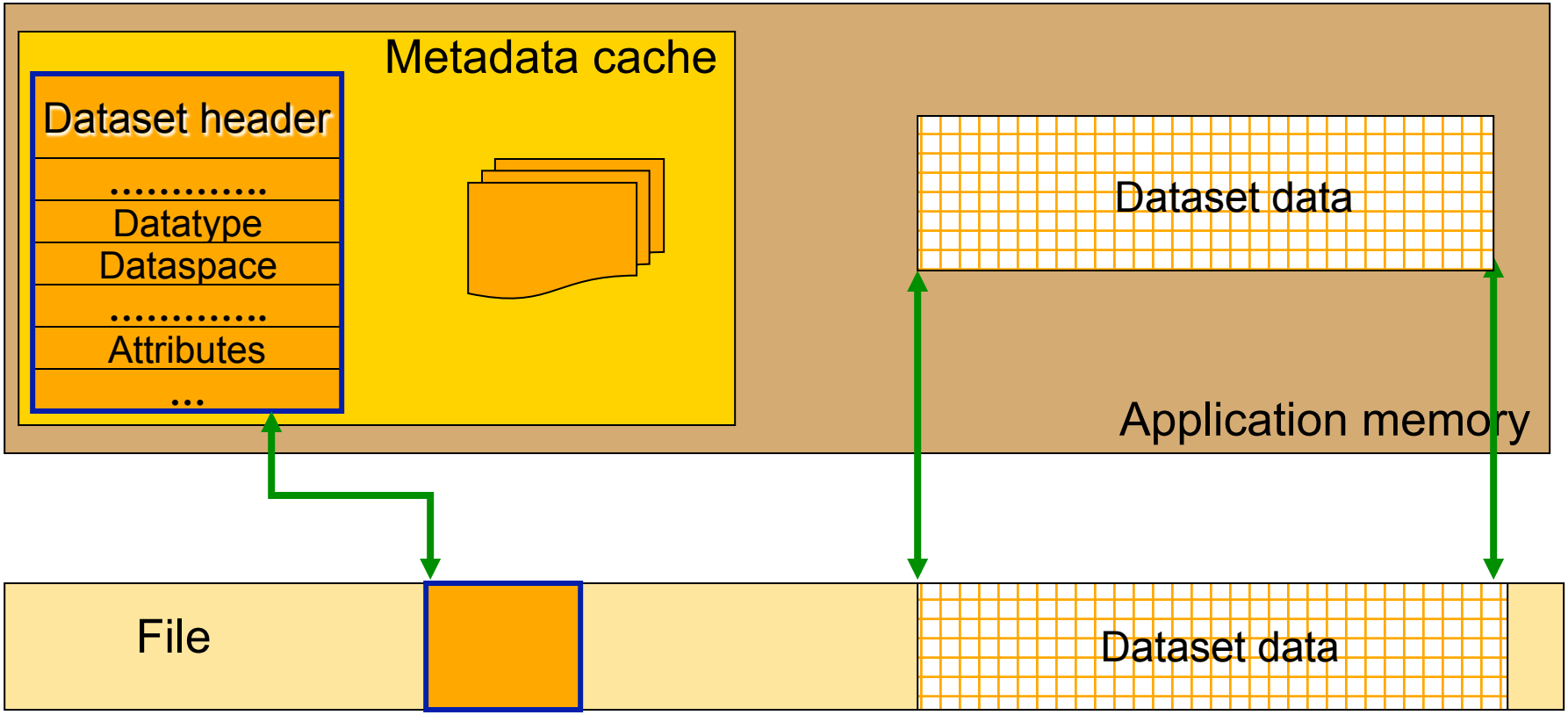
Dataset data



CONTIGUOUS STORAGE

Contiguous storage layout

- Data stored in one contiguous block in HDF5 file



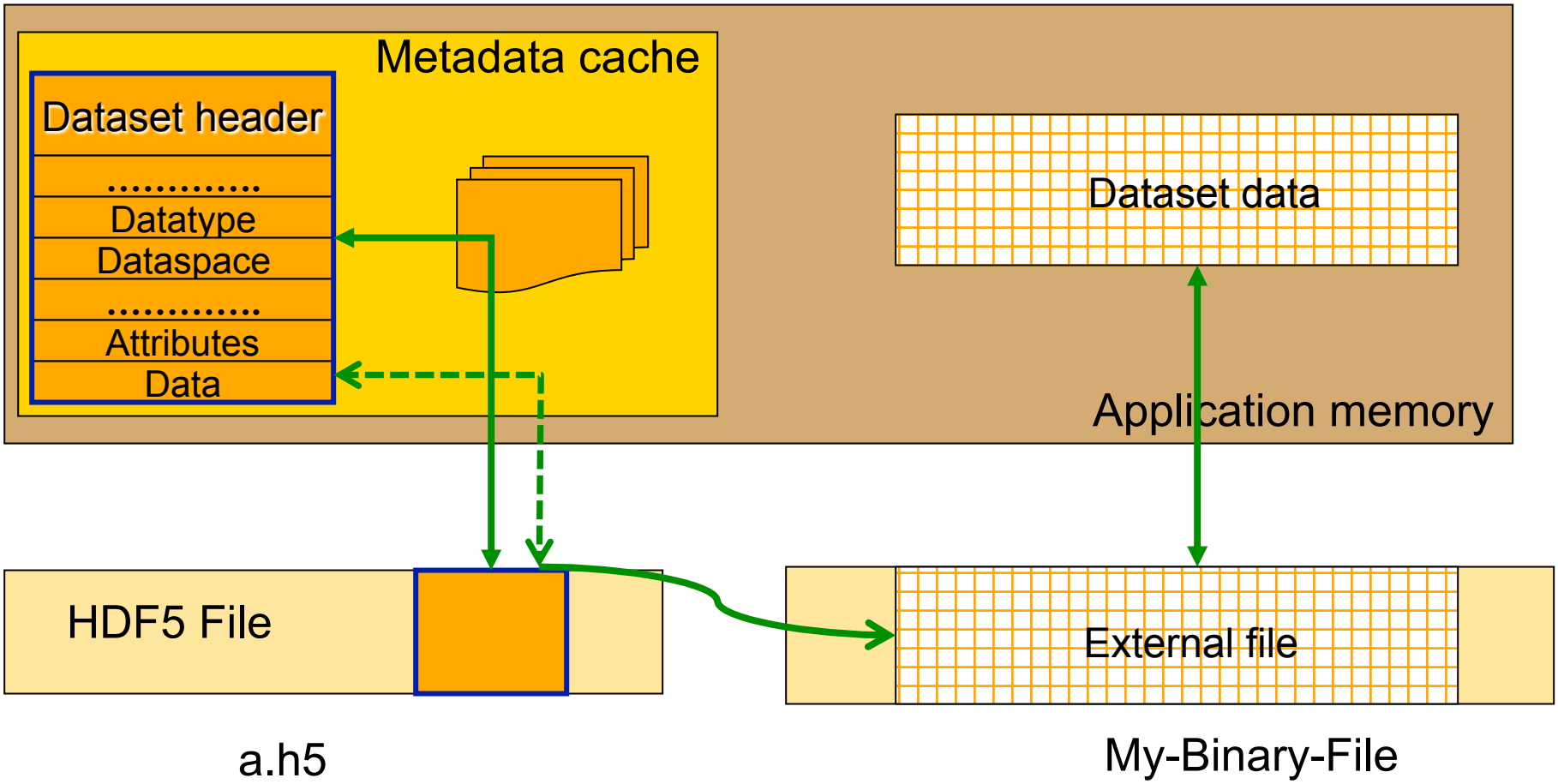
Contiguous Storage

- Pros:
  - Default storage mechanism for HDF5 dataset
  - Allows sub-setting
  - Efficient access to the whole dataset or two contiguous (in the file) subset
  - Can be easily located in the HDF5 file
- Cons:
  - No compression
    - Will be enabled in HDF5 1.10.0 release
  - Data cannot be added

EXTERNAL DATASET

External Dataset

Data stored in one contiguous block in external binary file



External Storage

- Pros:
  - Mechanism to reference data stored in a non-HDF5 binary file
  - Can be easily “imported” to HDF5 with h5repack
  - Allows sub-setting
  - Efficient access to the whole dataset or to contiguous (in the file) subset
- Cons:
  - Two or more files
  - No compression
  - Data cannot be added

External Example and Demo

```
HDF5 "h5ex_d_extern-new.h5" {
GROUP "/" {
  DATASET "DSExternal" {
    DATATYPE  H5T_STD_I32BE
    DATASPACE  SIMPLE { ( 28 ) / ( 28 ) }
    STORAGE_LAYOUT {
      CONTIGUOUS
      EXTERNAL {
        FILENAME h5ex_d_extern.data SIZE 112 OFFSET 0
      }
    }
    FILTERS {
      NONE
    }
    FILLVALUE {
      FILL_TIME H5D_FILL_TIME_IFSET
      VALUE  0
    }
    ALLOCATION_TIME {
      H5D_ALLOC_TIME_LATE
    }
    DATA {
    (0): 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 2, 2, 2, 2, 3,
    (22): 3, 3, 3, 3, 3, 3
    }
....
```

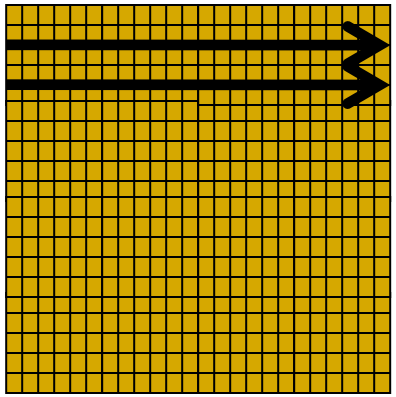
```
[   0   0   0   0   0   0   0]
[   1   1   1   1   1   1   1]
[   2   2   2   2   2   2   2]
[   3   3   3   3   3   3   3]
```

CHUNKING IN HDF5

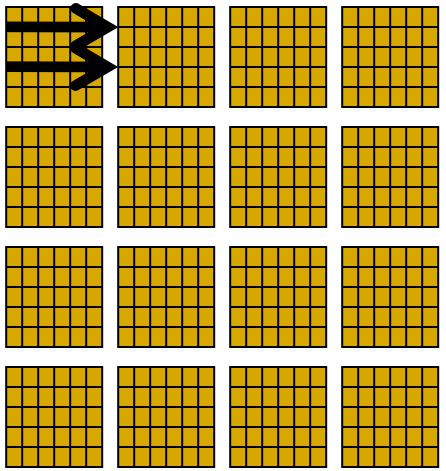
What is HDF5 Chunking?

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

Contiguous

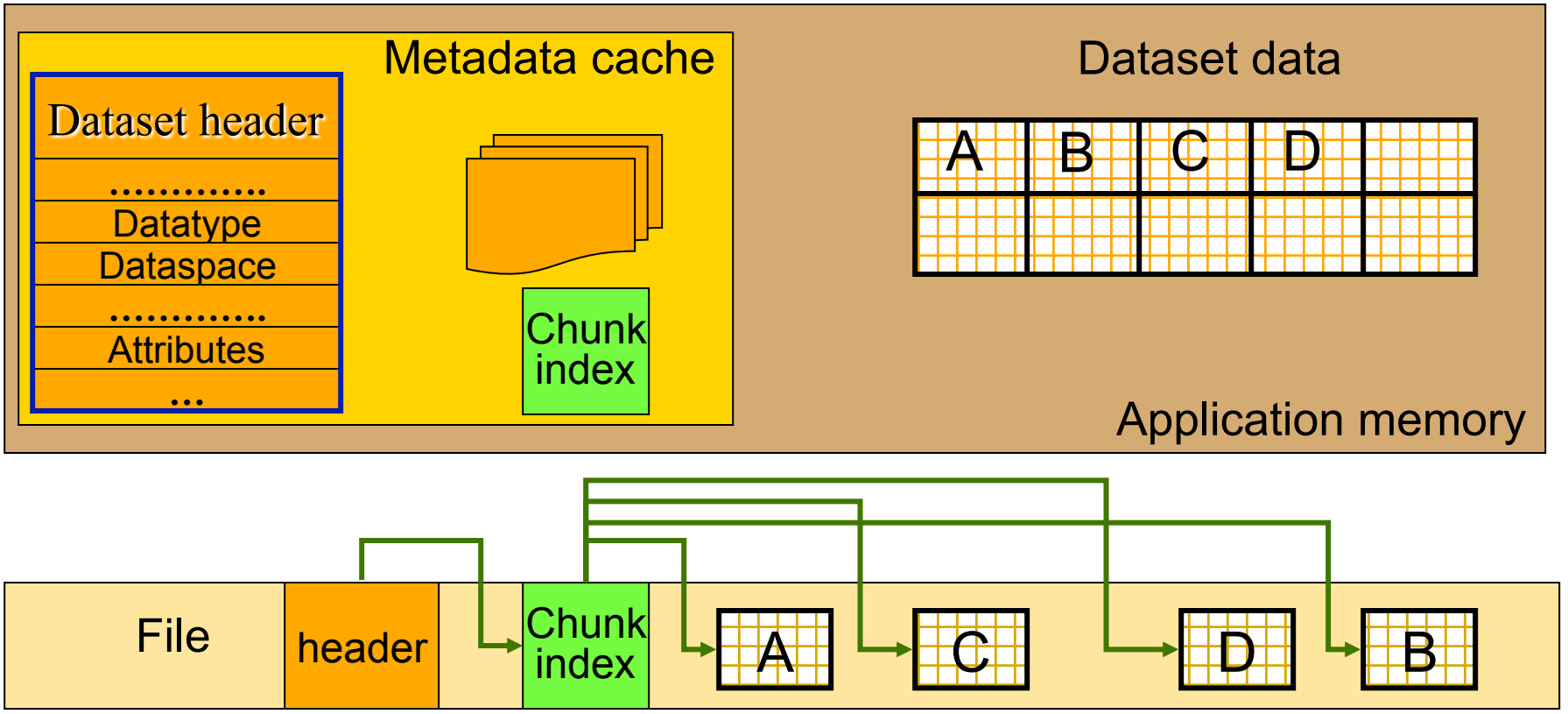


Chunked



What is HDF5 Chunking?

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

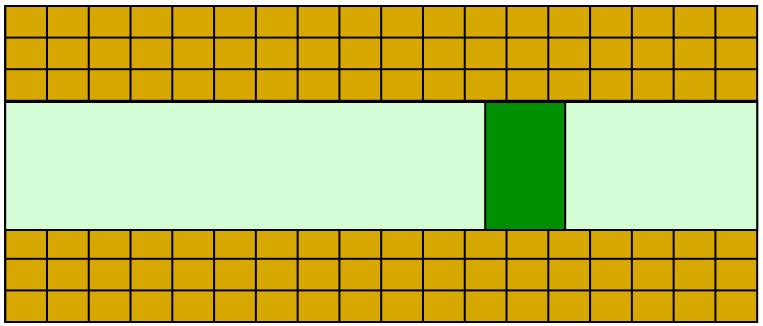


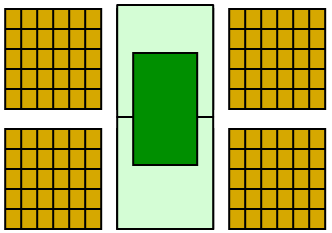
Why HDF5 chunking?

- Chunking is required for several HDF5 features
  - Applying compression and other filters like checksum
  - Expanding/shrinking dataset dimensions and adding/”deleting” data

Why HDF5 Chunking?

- If used appropriately chunking improves partial I/O for big datasets





Only two chunks are involved in I/O

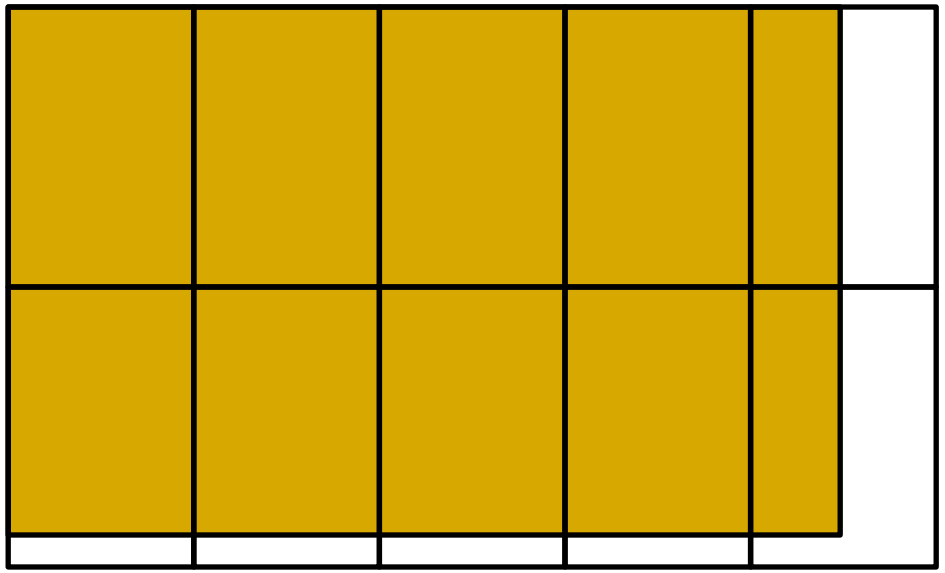
Creating Chunked Dataset

1. Create a dataset creation property list.
2. Set property list to use chunked storage layout.
3. Create dataset with the above property list.

```
dcpl_id   = H5Pcreate(H5P_DATASET_CREATE);
rank = 2;
ch_dims[0] = 100;
ch_dims[1] = 200;
H5Pset_chunk(dcpl_id, rank, ch_dims);
dset_id = H5Dcreate (…, dcpl_id);
H5Pclose(dcpl_id);
```

Creating Chunked Dataset

- Things to remember:
  - Chunk always has the same rank as a dataset
  - Chunk's dimensions do not need to be factors of dataset's dimensions
  - *Caution: May cause **more** I/O than desired (see white portions of the chunks below)*



Chunking Limitations

- Limitations
  - Chunk dimensions cannot be bigger than dataset dimensions
  - *Number of elements a chunk is limited to 4GB*
    - H5Pset_chunk fails otherwise
  - *Total size chunk is limited to 4GB*
    - Total size = (number of elements) * (size of the datatype)
    - H5Dwrite fails later on

Writing or Reading Chunked Dataset

1. Chunking is transparent to the application.
2. Use the same set of operations as for contiguous dataset, for example,

```
H5Dopen(…);
H5Sselect_hyperslab (…);
H5Dread(…);
```

3. Selections do not need to coincide precisely with the chunk boundaries.

Creating Compressed Dataset

1. Create a dataset creation property list
2. Set property list to use chunked storage layout
3. Set property list to use filters
4. Create dataset with the above property list

```
dcpl_id = H5Pcreate(H5P_DATASET_CREATE);
rank = 2;
ch_dims[0] = 100;
ch_dims[1] = 100;
H5Pset_chunk(dcpl_id, rank, ch_dims);
H5Pset_deflate(dcpl_id, 9);
dset_id = H5Dcreate (…, dcpl_id);
H5Pclose(dcpl_id);
```

Example: h5_d_unlimgzip.c

H5_d_unlimgzip.h5

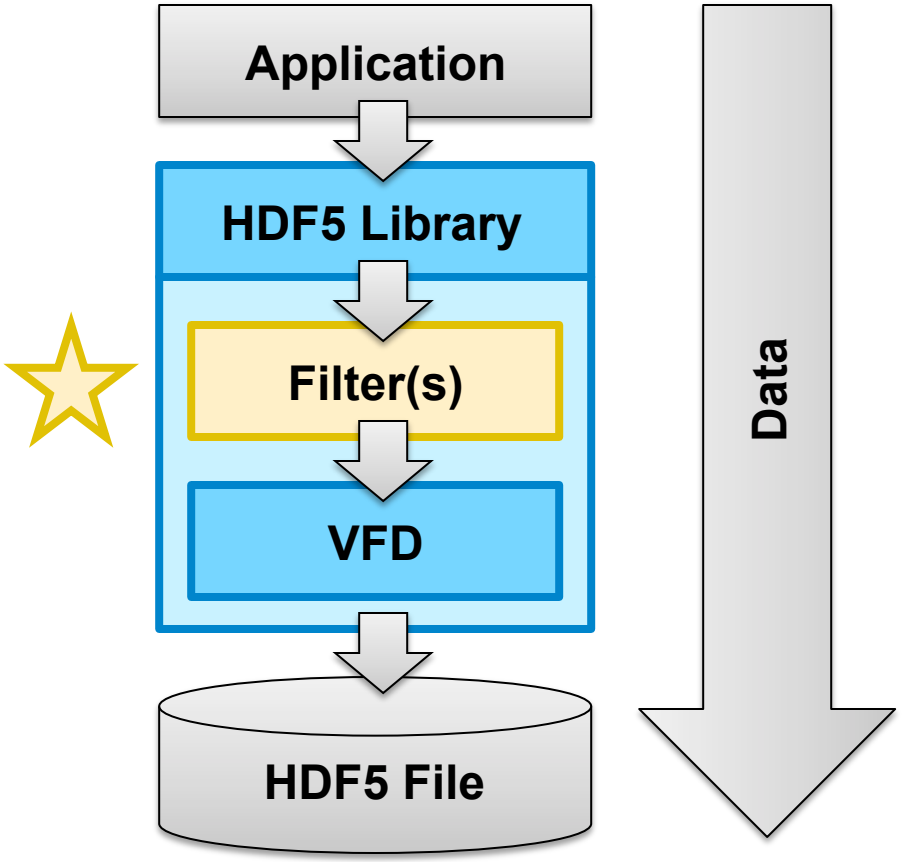
```
[  0  -1  -2  -3  -4  -5  -6   7   8   9 ]
[  0   0   0   0   0   0   0   7   8   9 ]
[  0   1   2   3   4   5   6   7   8   9 ]
[  0   2   4   6   8  10  12   7   8   9 ]
[  0   1   2   3   4   5   6   7   8   9 ]
[  0   1   2   3   4   5   6   7   8   9 ]
```

First write
Second write

HDF5 FILTERS AND COMPRESSION

What is an HDF5 filter?

- Data transformation performed by the HDF5 library during I/O operations



What is an HDF5 filter?

HDF5 filters (or *built-in* filters)

- Supported by The HDF Group (internal)
- Come with the HDF5 library source code

User-defined filters

- Filters written by HDF5 users and/or available with some applications (h5py, PyTables)
- May be or may not be registered with The HDF Group

HDF5 filters

- Filters are arranged in a pipeline so the output of one filter becomes the input of the next filter
- The filter pipeline can be only applied to
  - *Chunked* datasets
    - HDF5 library passes each chunk through the filter pipeline on the way to or from disk
  - Groups
    - Link names are stored in a local heap, which may be compressed with a filter pipeline
- The filter pipeline is permanent for dataset or a group

Applying filters to a dataset

```
dcpl_id   = H5Pcreate(H5P_DATASET_CREATE);
cdims[0] = 100;
cdims[1] = 100;
H5Pset_chunk(dcpl_id, 2, cdims);
H5Pset_shuffle(dcpl);
H5Pset_deflate(dcpl_id, 9);
dset_id = H5Dcreate (…, dcpl_id);
H5Pclose(dcpl_id);
```

Applying filters to a group

```
gcpl_id   = H5Pcreate(H5P_GROUP_CREATE);
H5Pset_deflate(dcpl_id, 9);
group_id = H5Gcreate (…, gcpl_id, …);
H5Pclose(gcpl_id);
```

Internal HDF5 Filters

- Internal filters are implemented by The HDF Group and come with the library
  - FLETCHER32
  - SHUFFLE
  - SCALEOFFSET
  - NBIT

- HDF5 internal filters can be configured out using --disable-filters="filter1, filter2, .."

External HDF5 Filters

- External HDF5 filters rely on the third-party libraries installed on the system
  - GZIP
    - By default HDF5 configure uses ZLIB installed on the system
    - Configure will proceed if ZLIB is not found on the system
  - SZIP (added by NASA request)
    - Optional; have to be configured in using --with-szlib=/path….
    - Configure will proceed if SZIP is not found
    - Comes with a license http://www.hdfgroup.org/doc_resource/SZIP/Commercial_szip.html
    - Decoder is free; for encoder see the license terms

Checking available HDF5 Filters

- Use API (`H5Zfilter_avail`)
- Check libhdf5.settings file

Features:

Parallel HDF5: no

.....

I/O filters (external): deflate(zlib),szip(encoder)

.....

Internal filters are always present now.

Third-party HDF5 filters

- Compression methods supported by HDF5 user community

  http://www.hdfgroup.org/services/contributions

  - LZO, BZIP2, BLOSC (PyTables)
  - LZF (h5py)
  - MAFISC
    - The Website has a patch for external module loader
- Registration process
  - Helps with filter's provenance

Example: h5dump output on BZIP2 data

```
HDF5 "h5ex_d_bzip2.h5" {
GROUP "/" {
   DATASET "DS-bzip2" {
      ...
      }
      FILTERS {
         UNKNOWN_FILTER {
            FILTER_ID 307
            COMMENT bzip2
            PARAMS { 9 }
         }
      }
   .....
      }
      DATA {h5dump error: unable to print data

      }
```

Problem with using custom filters

- "Off the shelf" HDF5 tools do not work with the third-party filters
  - h5dump, MATLAB and IDL, etc.
- Solution
  - Use dynamically loaded filters

https://www.hdfgroup.org/HDF5/doc/Advanced/DynamicallyLoadedFilters/HDF5DynamicallyLoadedFilters.pdf

DYNAMICALLY LOADED FILTERS IN HDF5

Dynamically loaded filters

- The HDF5 third-party filters are available as shared libraries or DLLs on the user's system.
- There are predefined default locations where the HDF5 library searches the shared libraries or DLLs with the HDF5 filter functions.

  /usr/local/hdf5/lib/plugin
- The default location may be overwritten by an environment variable.

  HDF5_PLUGIN_PATH
- Once a filter plugin library is loaded, it stays loaded until the HDF5 library is closed.

Programming Model

- When create set the filter using the filter ID

```
dcpl = H5Pcreate (H5P_DATASET_CREATE);
status = H5Pset_filter (dcpl, (H5Z_filter_t)307,
         H5Z_FLAG_MANDATORY, (size_t)6, cd_values);
dset = H5Dcreate (file, DATASET, H5T_STD_I32LE, space,
        H5P_DEFAULT, dcpl,….);
status = H5Dwrite (dset, H5T_NATIVE_INT, H5S_ALL, H5S_ALL,
          H5P_DEFAULT, wdata[0]);
```

- Transparent on read

Plugin Example

http://svn.hdfgroup.uiuc.edu/hdf5_plugins/trunk/

- BZIP2
  - Bzip2 filter implemented in PyTables
  - Built with configure or CMake
  - Used as acceptance test for the feature
  - More plugins can be added in the future

Demo

- h5dump before and after
- h5repack

  `h5repack -f UD={ID:k; N:m; CD_VAL:[n1,…,nm]}…`
- BZIP2 example

```
h5repack -f UD={ID:307; N:1; CD_VAL:[9]} file1.h5 file2.h5
```

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Thank You!

Questions?