HDF5 Advanced Topics

Elena Pourmal
The HDF Group
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Outline

- HDF5 Datatypes
- Partial I/O

HDF5 Datatypes

Overview

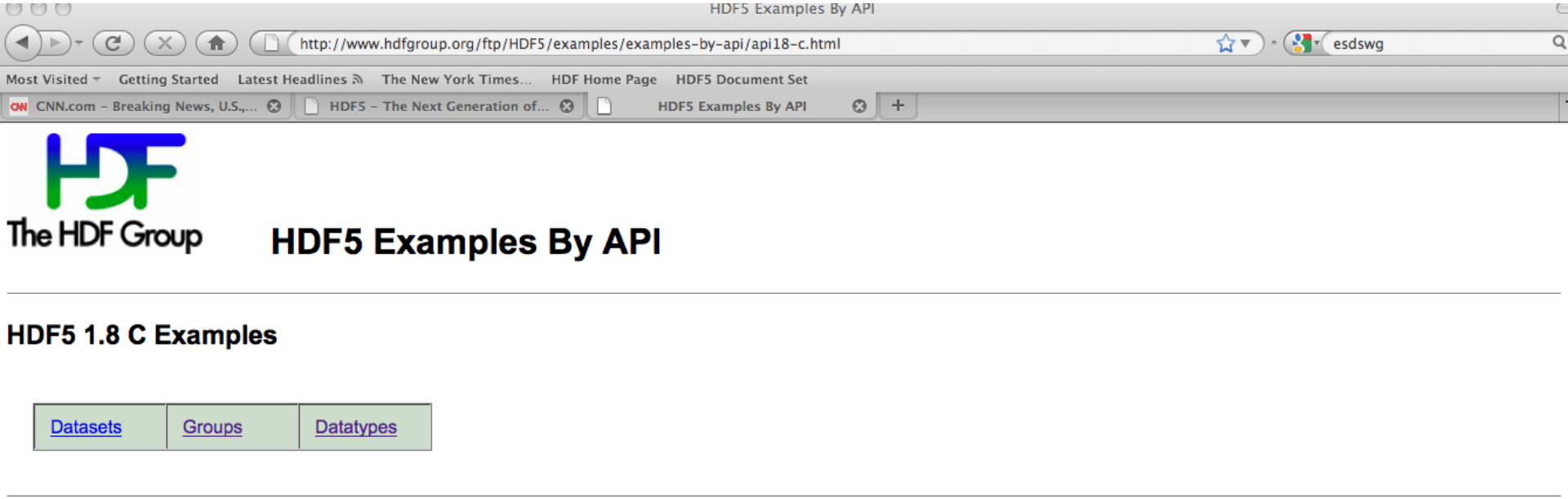
HDF5 Datatypes

- An HDF5 datatype
  - Required description of a data element
    - the set of possible values it can have
      - Example: enumeration datatype
    - the operations that can be performed
      - Example: type conversion cannot be performed on opaque datatype
    - how the values of that type are stored
      - Example: values of variable-length type are stored in a heap in a file
  - Stored in the file along with the data it describes
  - Not to be confused with the C, C++, Java and Fortran types

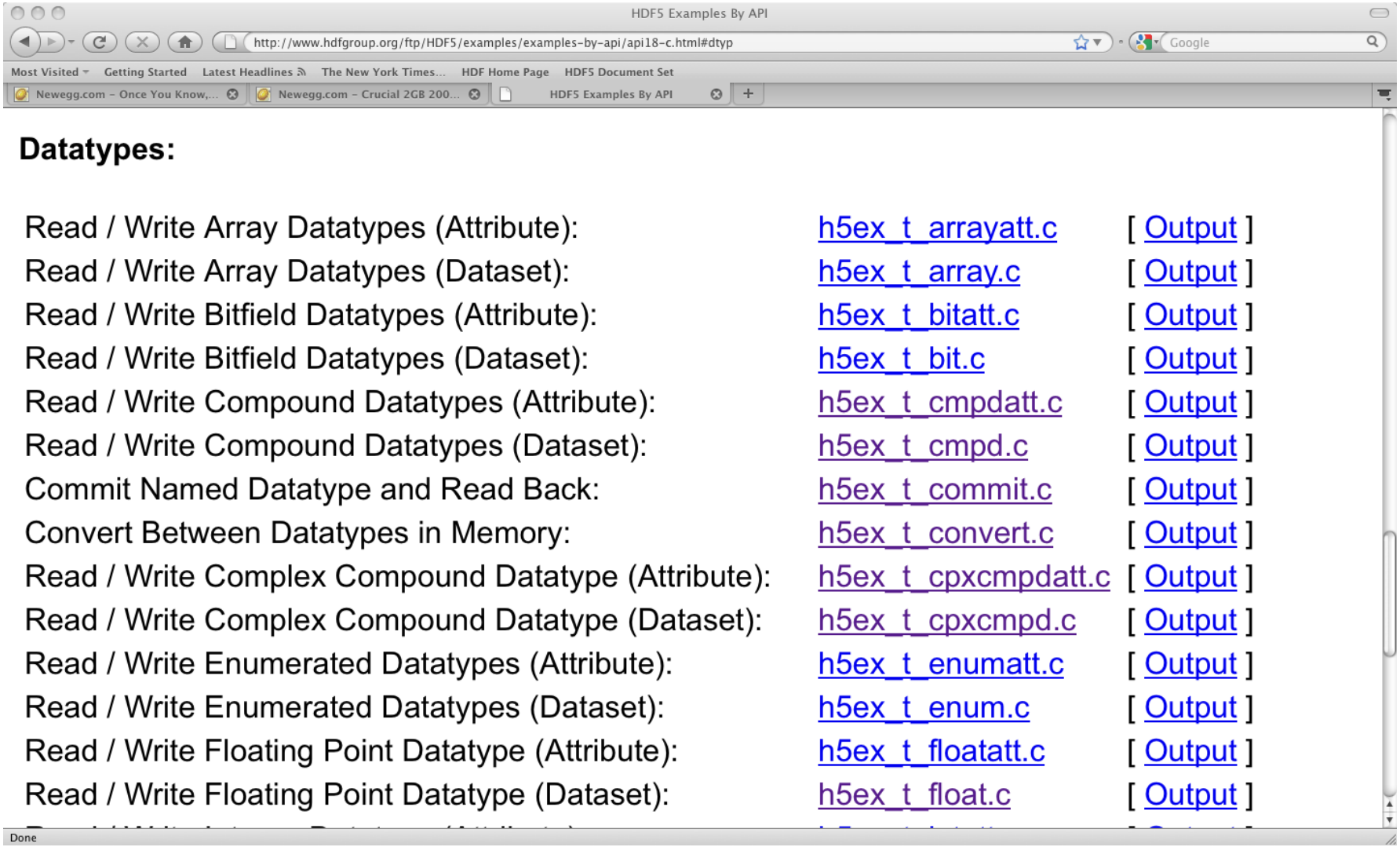
HDF5 Datatypes Examples

- We provide examples how to create, write and read data of different types

http://www.hdfgroup.org/ftp/HDF5/examples/examples-by-api/api18-c.html



HDF5 Datatypes Examples



HDF5 Datatypes

- When HDF5 Datatypes are used?
  - To describe application data in a file
    - H5Dcreate, H5Acreate calls
    - Example:
      - A C application stores integer data as 32-bit little-endian signed two's complement integer; it uses H5T_SDT_I32LE with the H5Dcreate call
      - A C applications stores double precision data "as is" in the application memory; it uses H5T_NATIVE_DOUBLE with the H5Acreate call
      - A Fortran application stores array of real numbers as 64-bit big-endian IEEE format; it uses H5T_IEEE_F64BE with h5dcreate_f call; HDF5 library will perform all necessary conversions

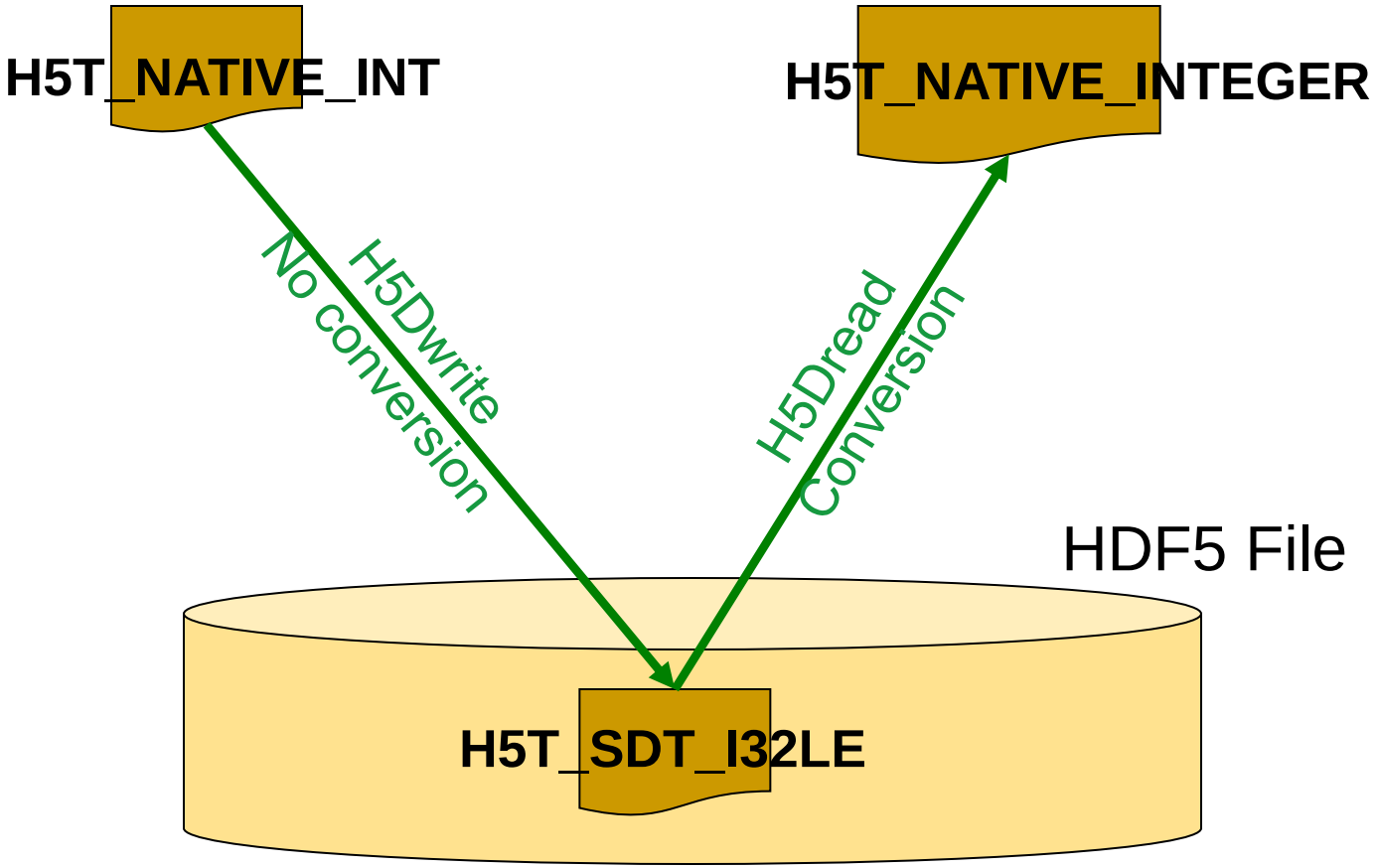
HDF5 Datatypes

- When HDF5 Datatypes are used?
  - To describe application data in memory
    - Data buffer to be written or read into with H5Dwrite/ H5Dread and H5Awrite/H5Aread calls
    - Example:
      - C application reads data from the file and stores it in an integer buffer; it uses H5T_NATIVE_INT to describe the buffer.
      - A Fortran application reads floating point data from the file and stores it an integer buffer; it uses H5T_NATIVE_INTEGER to describe the buffer;
- HDF5 library performs datatype conversion; overflow/underflow may occur.

Example

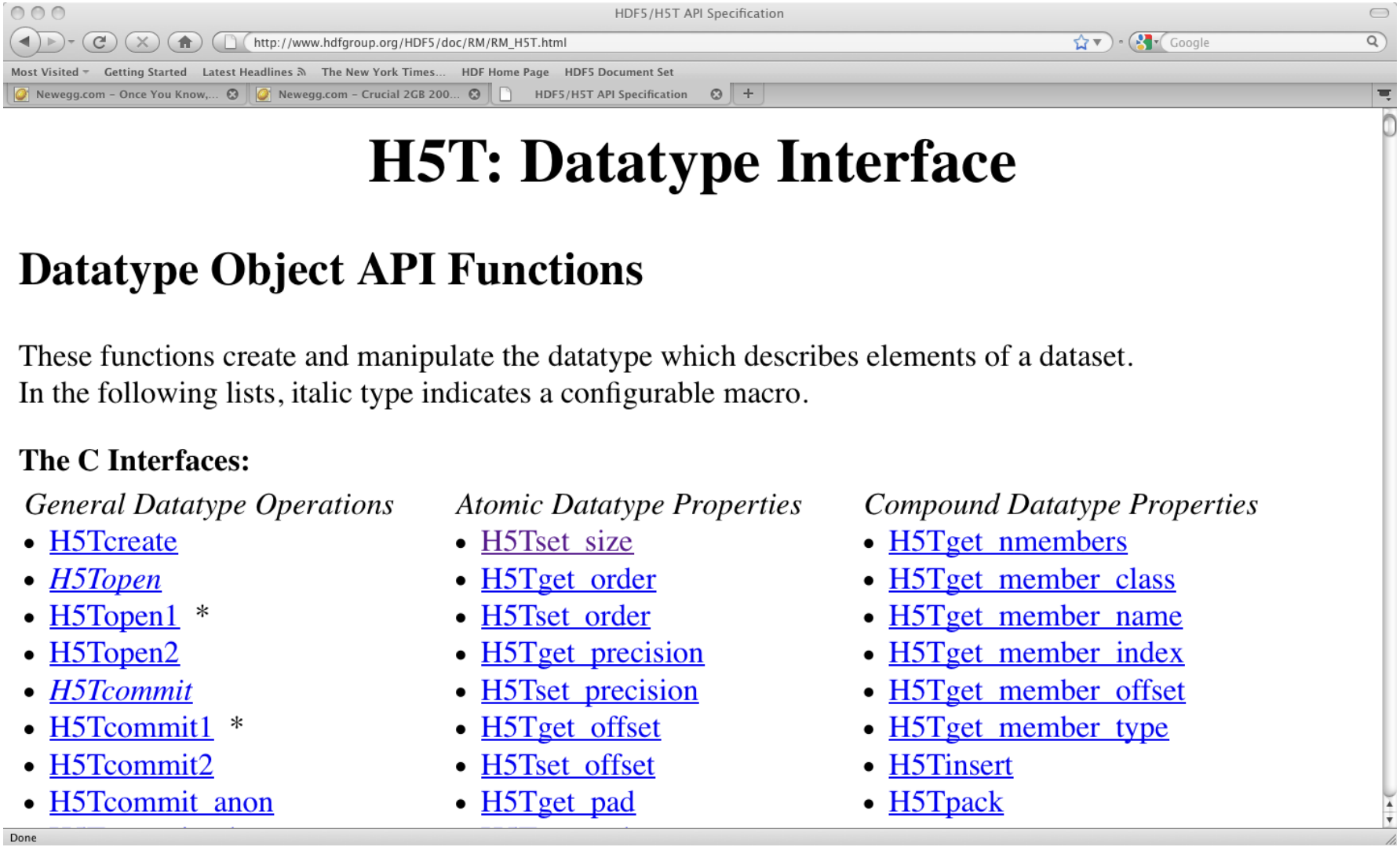
C Array of integers on Linux platform
Native integer (**H5T_NATIVE_INT**)
is little-endian, **4** bytes

Fortran Array of integers on AIX platform
Native integer (**H5T_NATIVE_INTEGER**)
is big-endian, **8** bytes



Data is stored as little-endian, converted to big-endian on read

HDF5 Datatypes



Example: Writing/reading an Array to HDF5 file

- Calls you've already seen in Intro Tutorial
  - H5LTmake_dataset
  - H5Dwrite, H5Dread
- APIs to handle specific C data type
  - H5LTmake_dataset_<*>
    - <*> is one of "char", "short", "int", "long", "float", "double", "string"
  - All data array is written (no sub-setting)
  - Data stored in a file as it is in memory
  - H5LTread_dataset, H5LTread_dataset_<*>

Example: Read data into array of longs

```
#include "hdf5.h”
#include "hdf5_hl.h”
int main( void ){
      long  *data;
      …
       /* Open file from ex_lite1.c */
      file_id = H5Fopen ("ex_lite1.h5", H5F_ACC_RDONLY,
          H5P_DEFAULT);
      /* Get information about dimensions to allocate memory buffer */
      status = H5LTget_dataset_ndims(file_id,"/dset",rank);
      status = H5LTget_dataset_info(file_id,"/dset",dims,dt_class,dt_size);
      /* Allocate buffer to read data in */
      data = (long*)malloc(…
      /* Read dataset */
      status = H5LTread_dataset_long(file_id,"/dset",data);
      /
```

Example: Read data into array of longs

```
#include hdf5.h
…
long *rdata;
….
/* Open file and dataset.  */
file_id = H5Fopen (“ex_lite1.h5”, H5F_ACC_RDONLY, H5P_DEFAULT);
dset_id = H5Dopen (file, “/dset”, H5P_DEFAULT);

 /* Get information about dimensions to allocate memory buffer */
space = H5Dget_space (dset);
rank = H5Sget_simple_extent_dims (space, dims, NULL);

status = H5Dread (dset, H5T_NATIVE_LONG, H5S_ALL, H5S_ALL,
    H5P_DEFAULT, rdata);
```

Basic Atomic HDF5 Datatypes

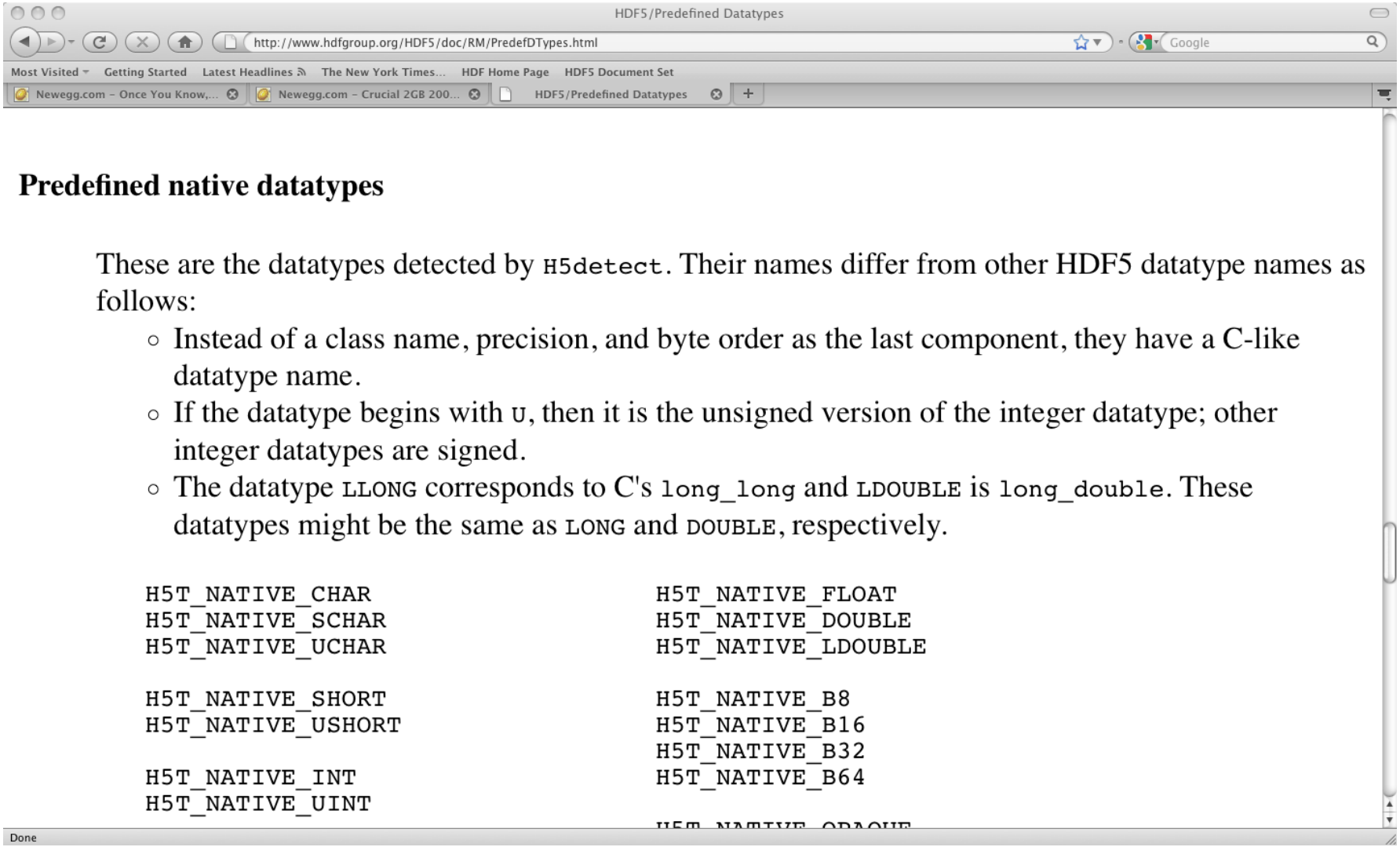
Basic Atomic Datatypes

- Integers & floats
- Strings (fixed and variable size)
- Pointers - references to objects and dataset regions
- Bitfield
- Opaque

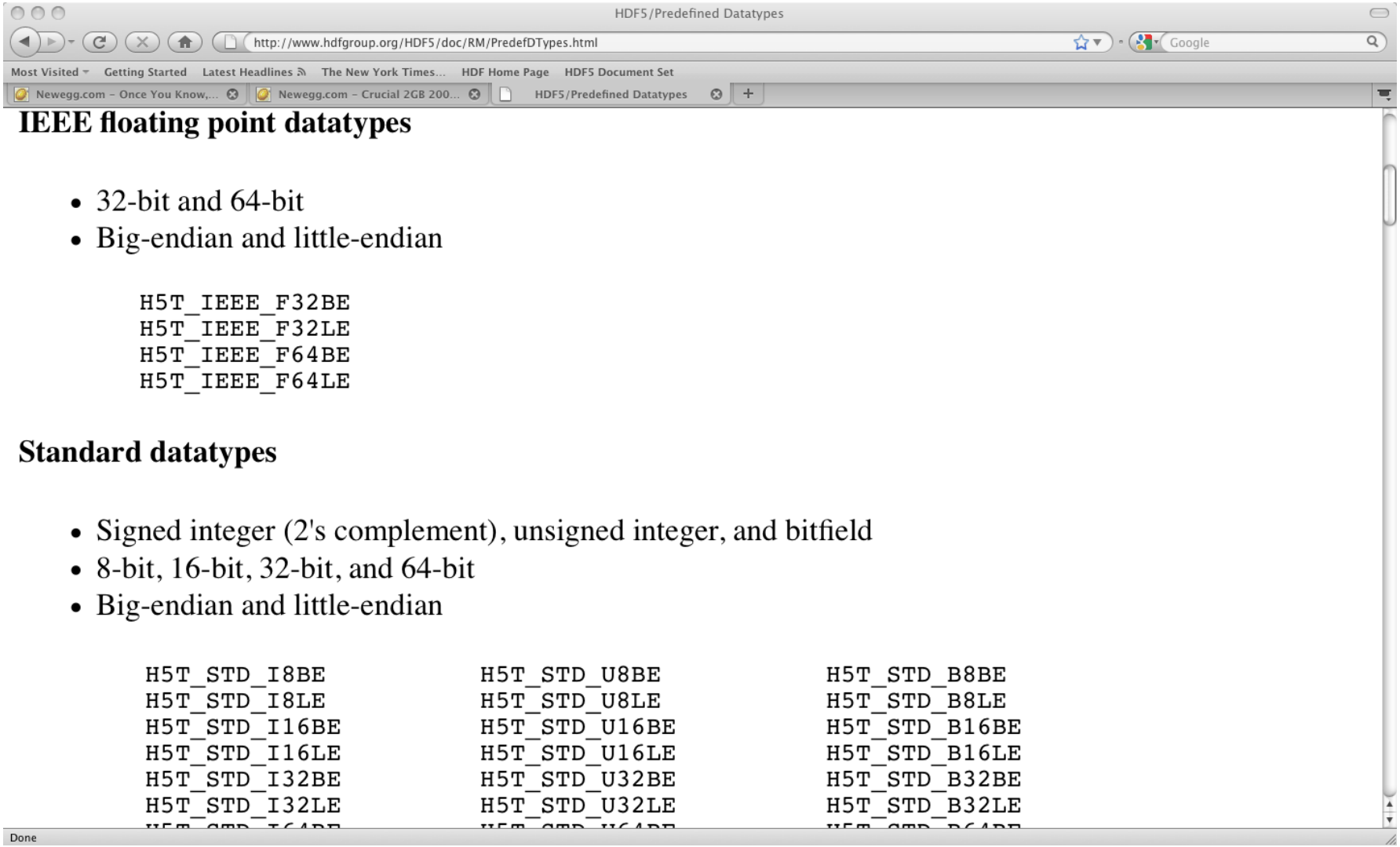
HDF5 Predefined Datatypes

- HDF5 Library provides predefined datatypes (symbols) for all basic atomic datatypes except opaque datatype
  - H5T_<arch>_<base>
  - Examples:
    - H5T_IEEE_F64LE
    - H5T_STD_I32BE
    - H5T_C_S1, H5T_FORTRAN_S1
    - H5T_STD_B32LE
    - H5T_STD_REF_OBJ, H5T_STD_REF_DSETREG
    - H5T_NATIVE_INT
- *Predefined datatypes **do not have constant values**; initialized when library is initialized*

HDF5 Pre-defined Datatypes



HDF5 Predefined Datatypes



HDF5 integer datatype

- HDF5 supports 1,2,4,and 8 byte signed and unsigned integers in memory and in the file
- Support differs by language
- C language
  - All C integer types including C99 extended integer types (when available)
  - Examples:
  - H5T_NATIVE_INT16 for int16_t
  - H5T_NATIVE_INT_LEAST64 for int_least64_t
  - H5T_NATIVE_UINT_FAST16 for uint_fast16_t

HDF5 integer datatype

- Fortran language
  - In memory supports only Fortran “integer”
    - Examples:
    - H5T_NATIVE_INTEGER for integer
  - In the file supports all HDF5 integer types
    - Example: one-byte integer has to be represented by integer in memory; can be stored as one-byte integer by creating an appropriate dataset (H5T_SDT_I8LE)
  - Next major release of HDF5 will support ANY kinds of Fortran integers

HDF5 floating-point datatype

- HDF5 supports 32 and 64-bit floating point IEEE big-endian, little-endian types in memory and in the file
- Support differs by language
- C languge
  - H5T_IEEE_F64BE and H5T_IEEE_F32LE
  - H5T_NATIVE_FLOAT
  - H5T_NATIVE_DOUBLE
  - H5T_NATIVE_LDOUBLE

HDF5 floating-point datatype

- Fortran language
  - In memory supports only Fortran “real” and “double precision” (obsolete)
    - Examples:
    - H5T_NATIVE_REAL for real
    - H5T_NATIVE_DOUBLE for double precision
  - In the file supports all HDF5 floating-point types
  - Next major release of HDF5 will support ANY kinds of Fortran reals

HDF5 string datatype

- HDF5 strings are characterized by
  - The way each element of a string type is stored in a file
    - NULL terminated (C type string)

      char *mystring[]="Once upon a time";

      HDF5 stores <Once upon a time/0>
    - Space padded (Fortran string)

      character(len=16) :: mystring='Once upon a time'

      HDF5 stores <Once upon a time> and adds spaces if required
  - The sizes of elements in the same dataset or attribute
    - Fixed-length string
    - Variable-length string

Example: Creating fixed-length string

- C Example: “Once upon a time” has 16-characters

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

- Size value have to include accommodate “/0”, i.e., size=17 for “Once upon a time” string
- Overhead for short strings, e.g., “Once” will have extra 13 bytes allocated for storage
- Compressed well

Example: Creating variable-length string

- C example:

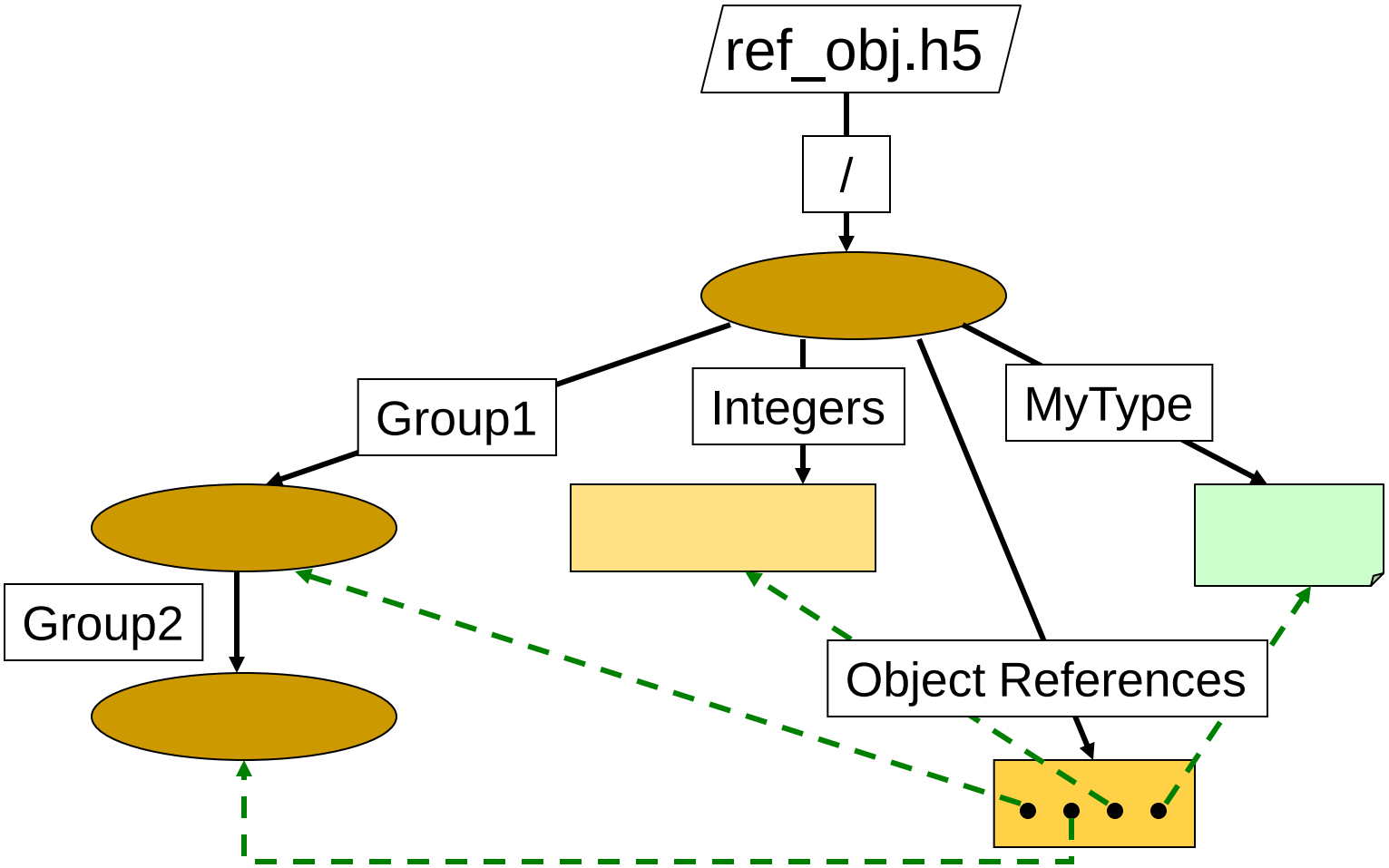
```
string_id = H5Tcopy(H5T_C_S1);
H5Tset_size(string_id, H5T_VARIABLE);
```

- Overhead to store and access data
- Cannot be compressed (may be in the future)

Reference Datatype

- Reference to an HDF5 object
  - Pointer to a group or a dataset in a file
    - Predefined datatype H5T_STD_REG_OBJ describe object references

Reference to Object



Reference to Object

h5dump –d /"object_reference" ref_obj.h5

```
DATASET "OBJECT_REFERENCES" {
      DATATYPE  H5T_REFERENCE
      DATASPACE  SIMPLE { ( 4 ) / ( 4 ) }
      DATA {
      (0): GROUP 808 /GROUP1 , GROUP 1848 /GROUP1/GROUP2 ,
      (2): DATASET 2808 /INTEGERS , DATATYPE 3352 /MYTYPE
      }
```

Reference to Object

- Create a reference to group object

```
H5Rcreate(&ref[1], fileid, "/GROUP1/GROUP2",
   H5R_OBJECT, -1);
```

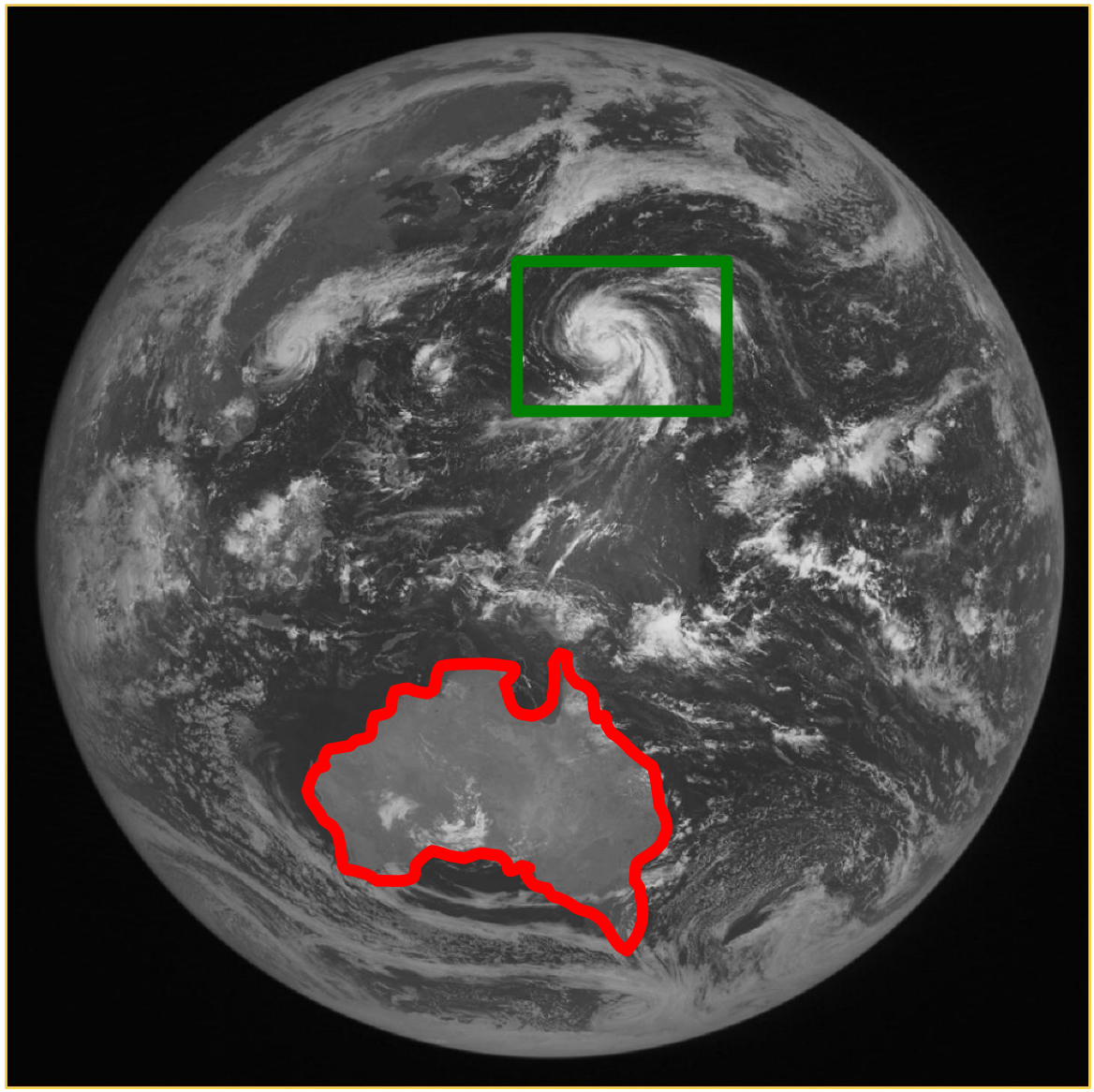
- Write references to a dataset

```
H5Dwrite(dsetr_id, H5T_STD_REF_OBJ, H5S_ALL,
   H5S_ALL, H5P_DEFAULT, ref);
```

- Read reference back with H5Dread and find an object it points to

```
type_id = H5Rdereference(dsetr_id, H5R_OBJECT,
   &ref[3]);
name_size = H5Rget_name(dsetr_id, H5R_OBJECT,
   &ref_out[3], (char*)buf, 10);
```

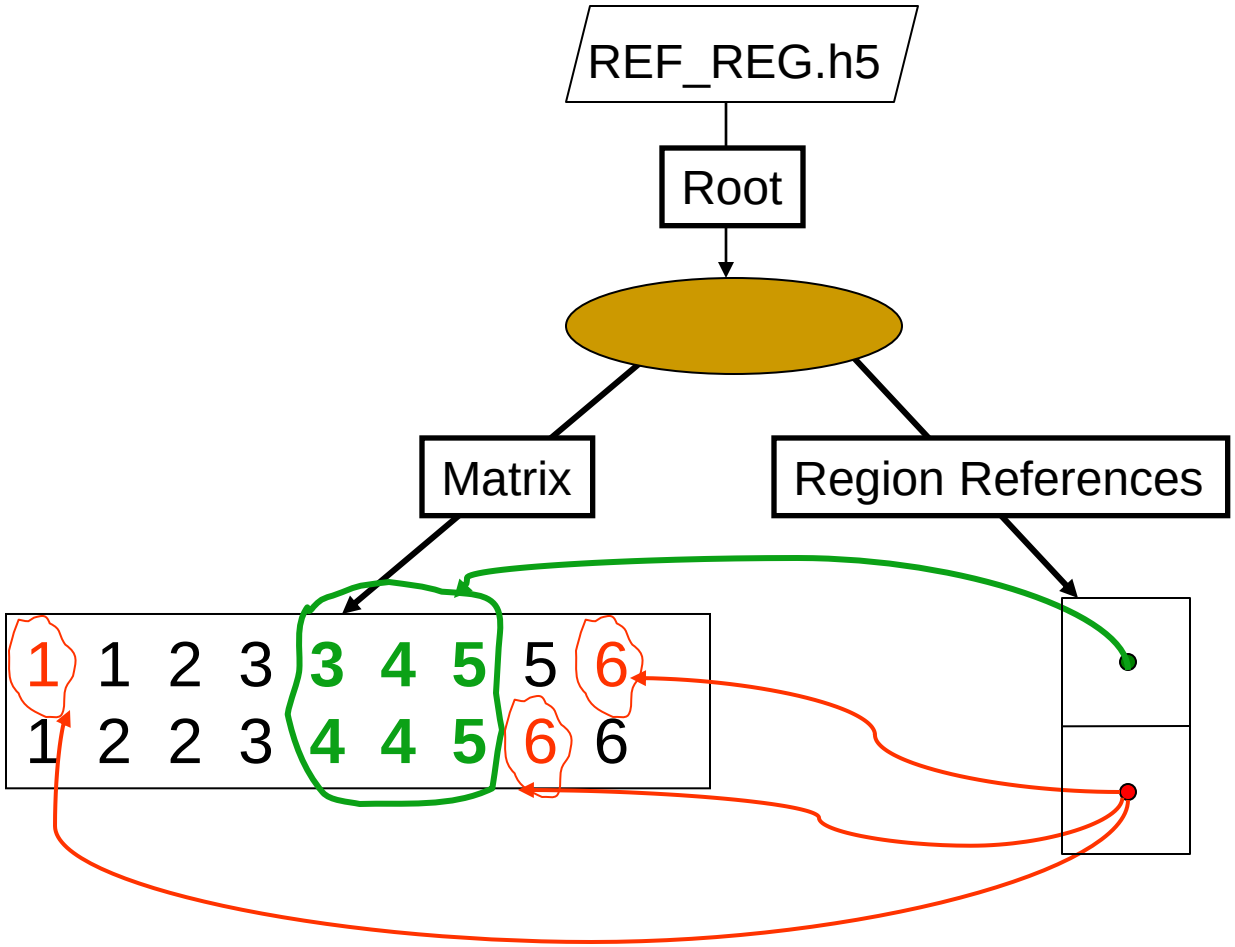
Saving Selected Region in a File



Reference Datatype

- Reference to a dataset region (or to selection)
  - Pointer to the dataspace selection
    - Predefined datatype H5T_STD_REF_DSETREG to describe regions

Reference to Dataset Region



Reference to Dataset Region

Example

```
dsetr_id = H5Dcreate(file_id,
"REGION REFERENCES", H5T_STD_REF_DSETREG,
  …);

H5Sselect_hyperslab(space_id,
          H5S_SELECT_SET, start, NULL, …);
H5Rcreate(&ref[0], file_id, "MATRIX",
H5R_DATASET_REGION, space_id);

H5Dwrite(dsetr_id, H5T_STD_REF_DSETREG,
  H5S_ALL, H5S_ALL, H5P_DEFAULT,ref);
```

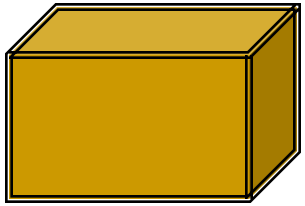
Reference to Dataset Region

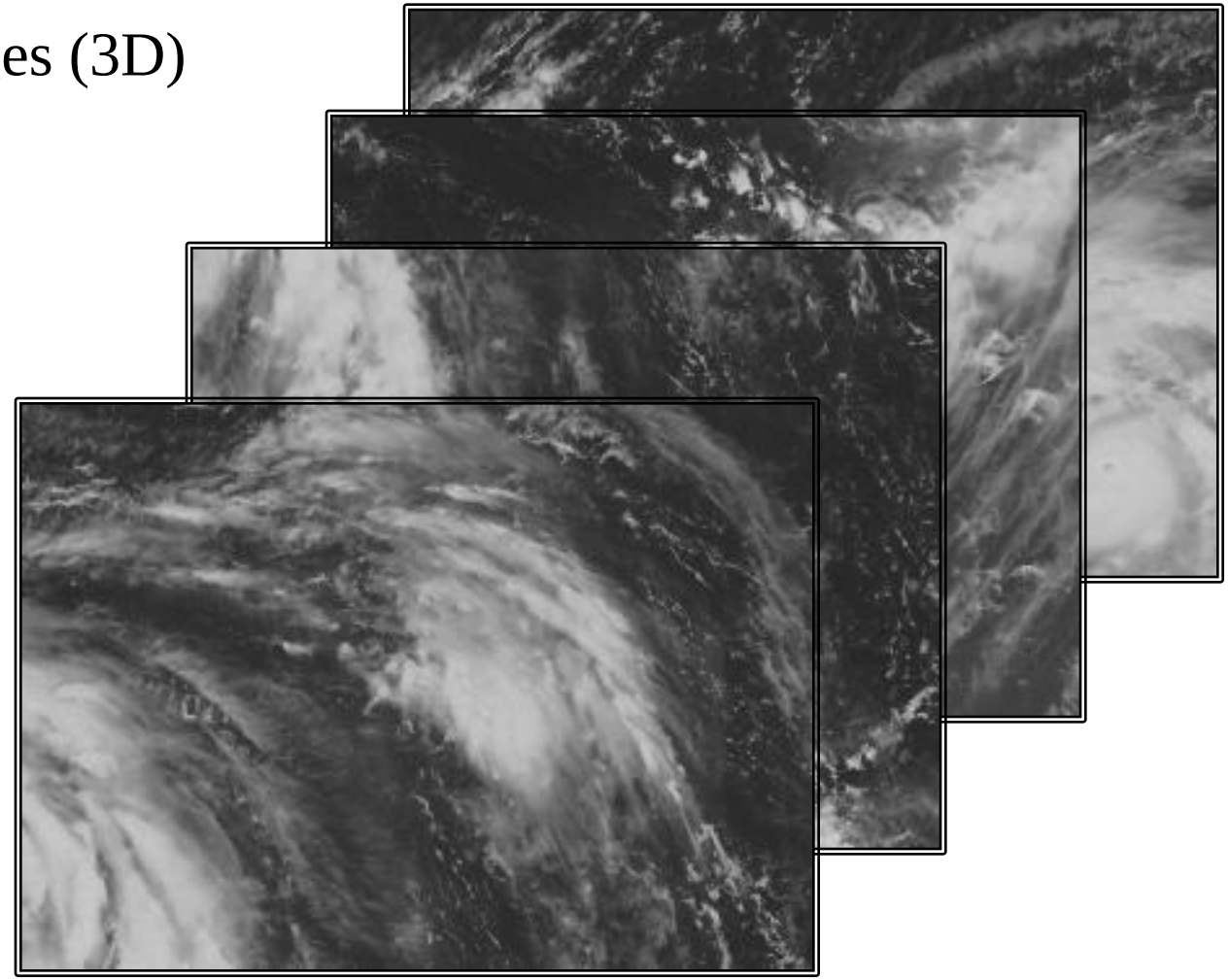
```
HDF5 "REF_REG.h5" {
GROUP "/" {
   DATASET "MATRIX" {
   ……
}
   DATASET "REGION_REFERENCES" {
      DATATYPE  H5T_REFERENCE
      DATASPACE  SIMPLE { ( 2 ) / ( 2 ) }
      DATA {
      (0): DATASET /MATRIX {(0,3)-(1,5)},
      (1): DATASET /MATRIX {(0,0), (1,6), (0,8)}
      }
   }
}
}
```

Part II
Working with subsets

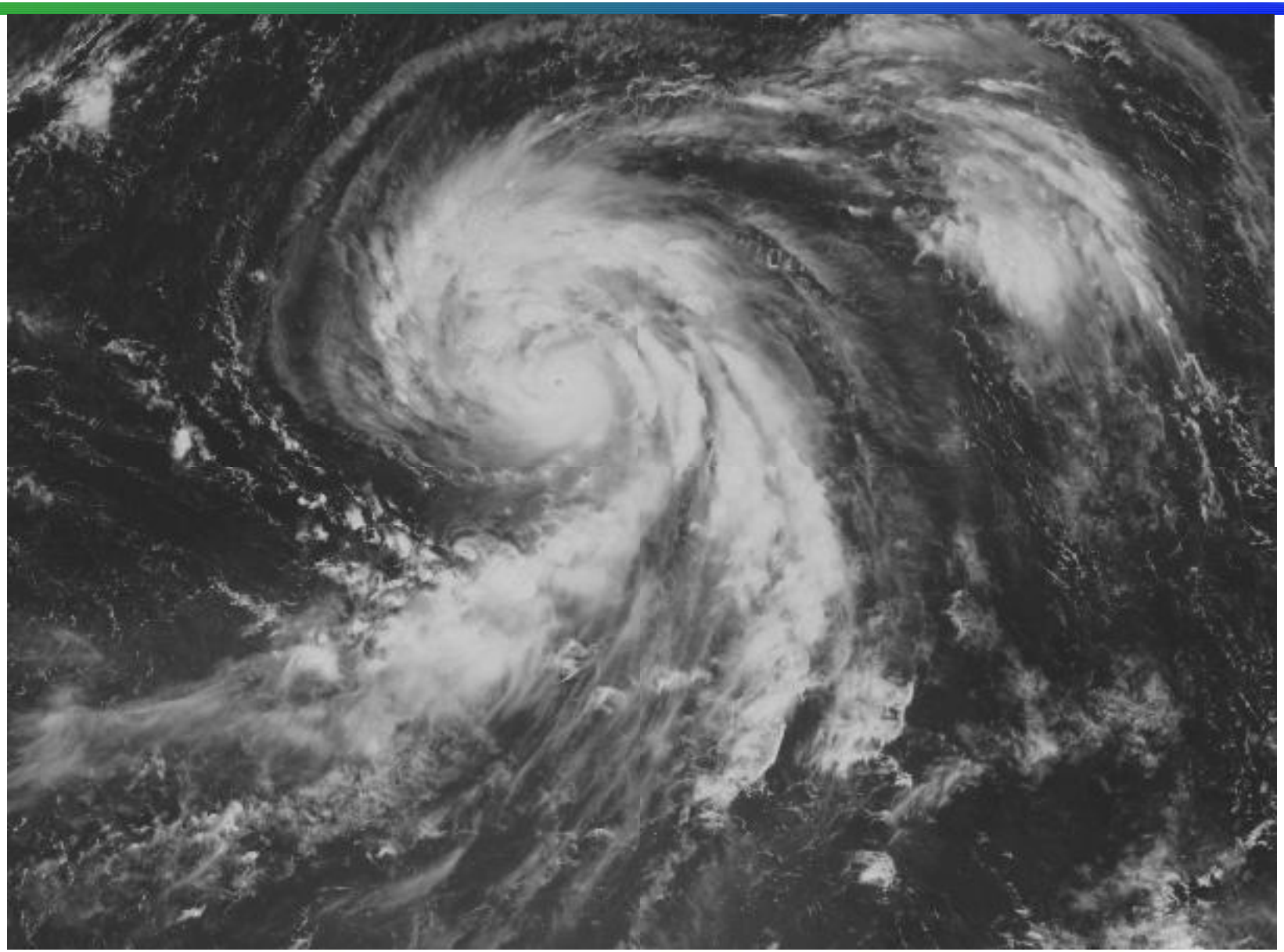
Collect data one way ….

Array of images (3D)

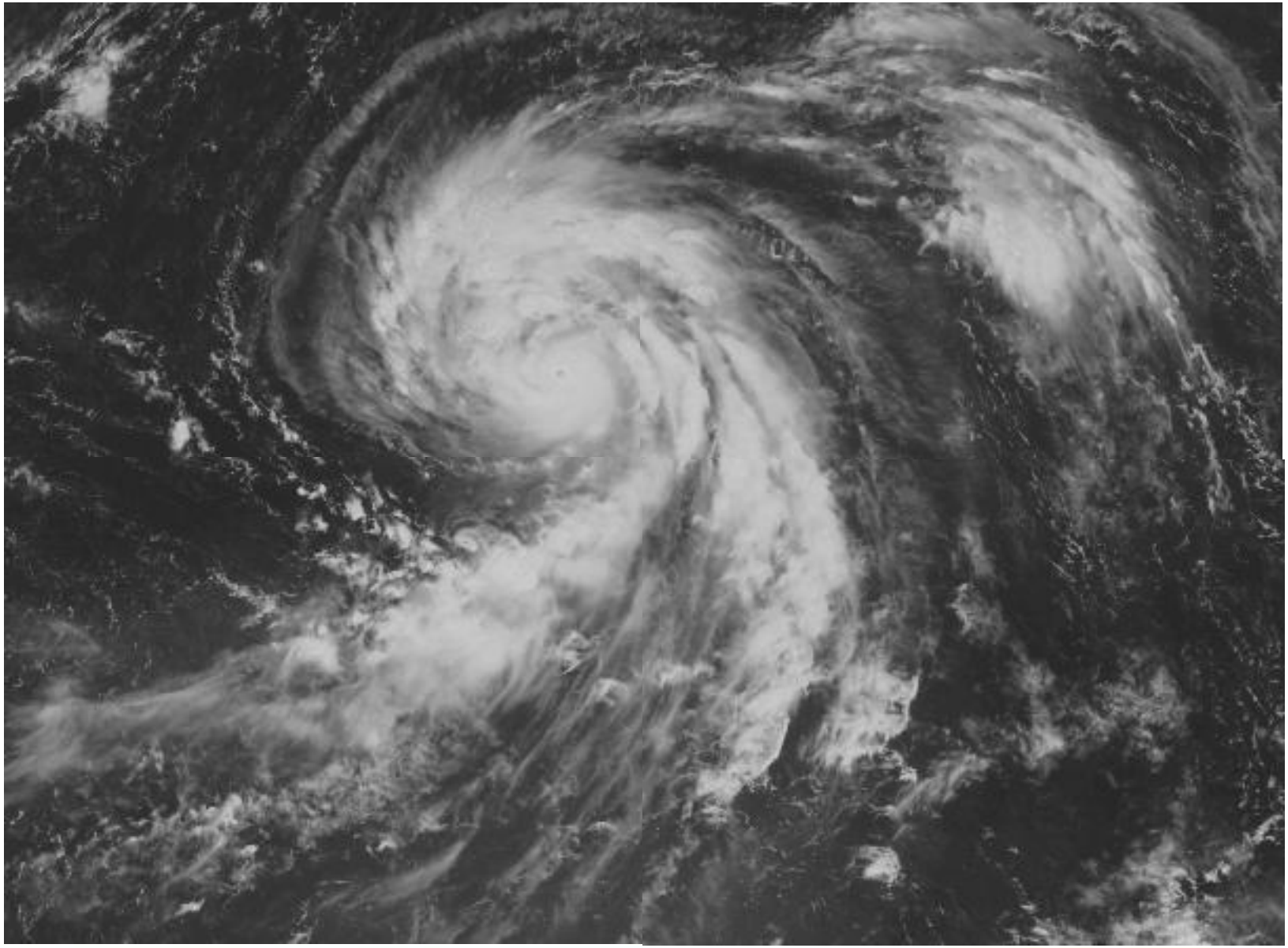




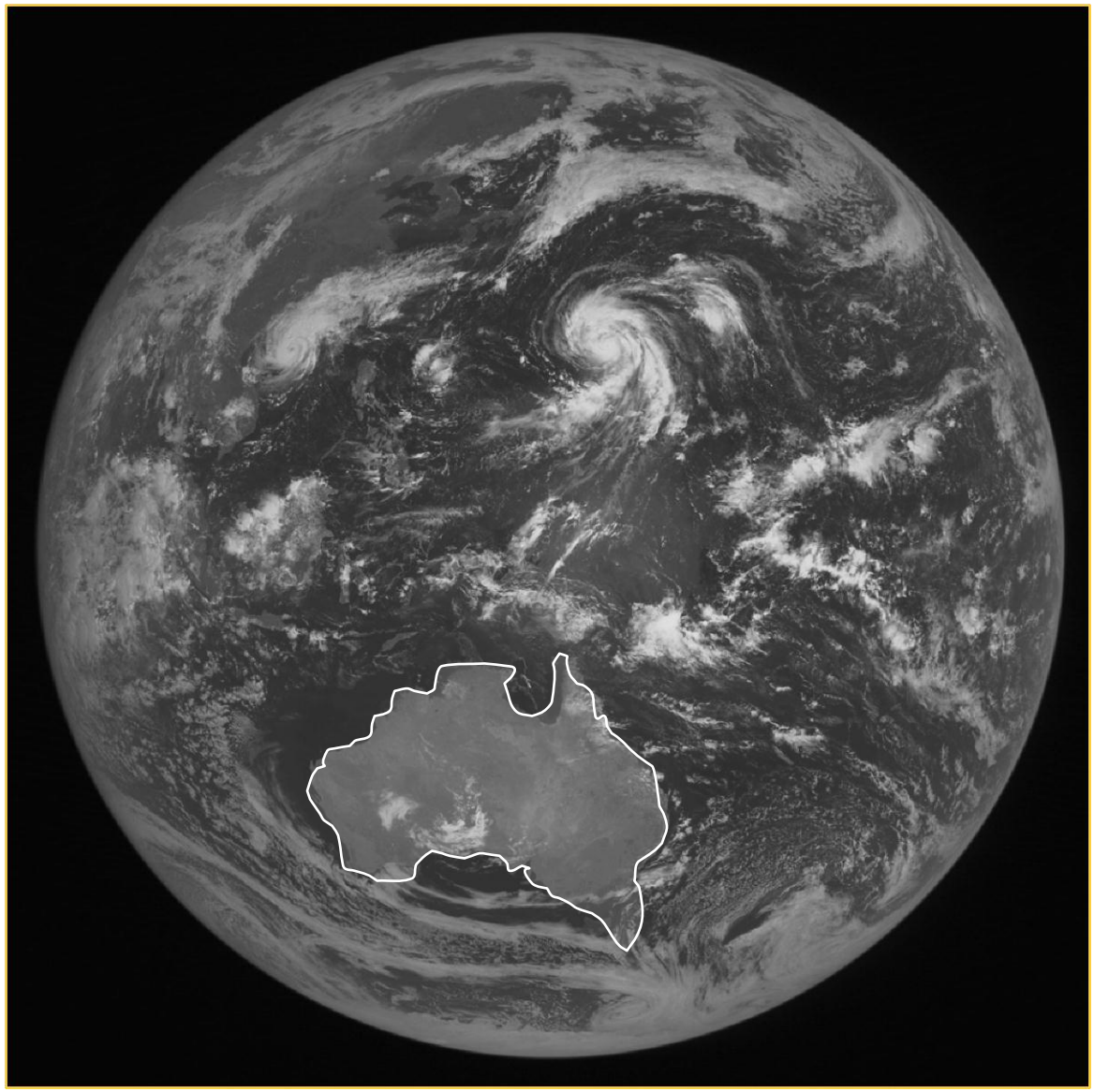
Display data another way …



Data is too big to read….



Refer to a region…



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
    - Object references
    - Region references
  - Use efficient storage mechanism to achieve good performance while writing/reading subsets of data
    - Chunking, compression

Partial I/O in HDF5

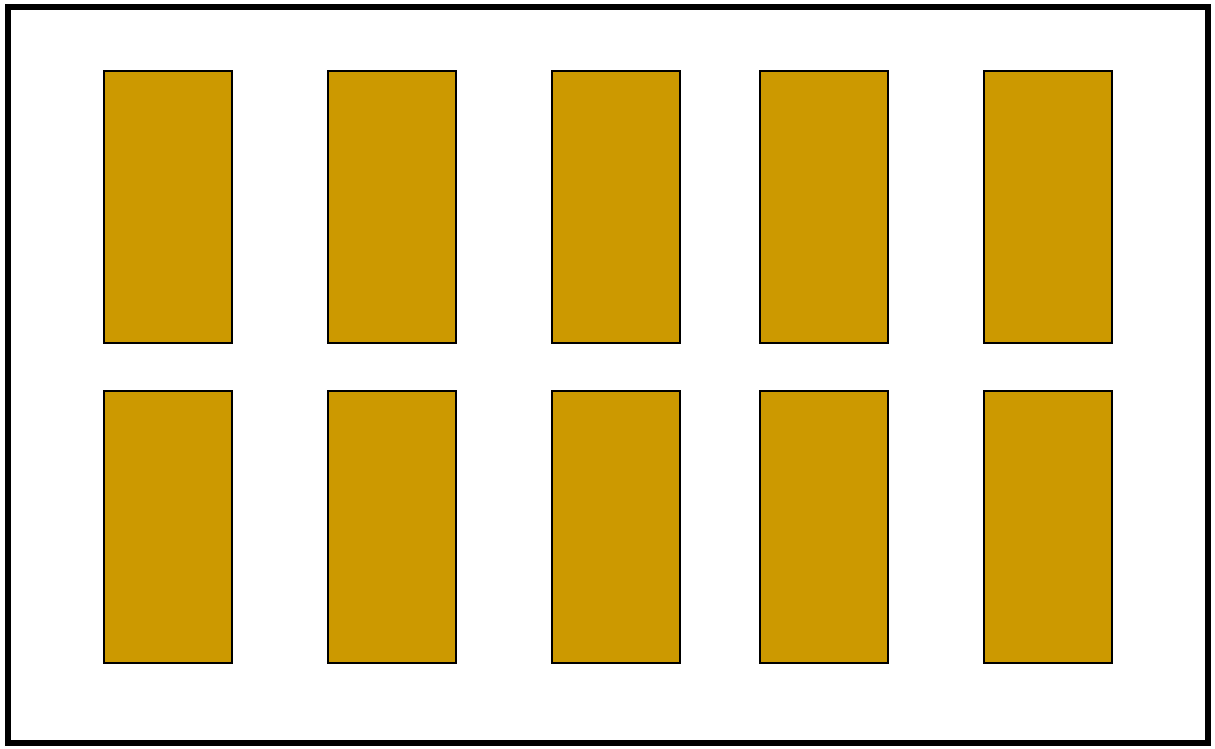
How to Describe a Subset in HDF5?

- 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 “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

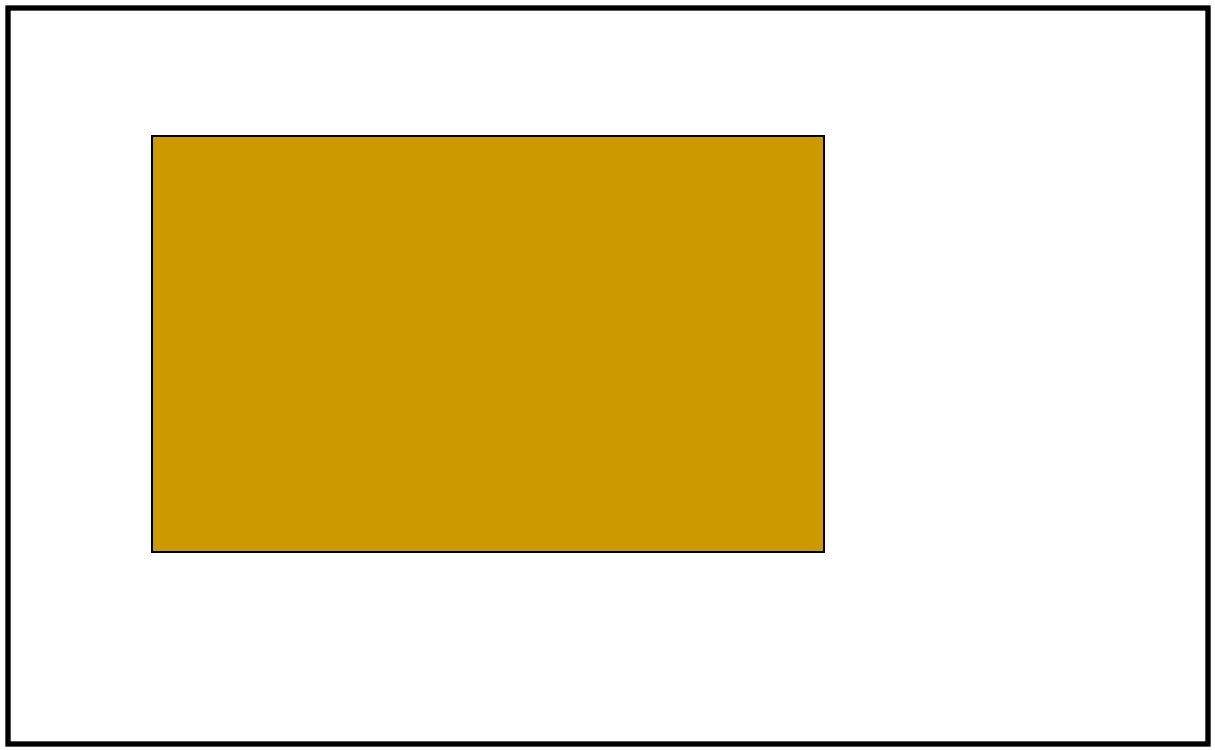
- Two types of selections
  - Hyperslab selection
    - Regular hyperslab
    - Simple hyperslab
    - Result of set operations on hyperslabs (union, difference, …)
  - Point selection
- Hyperslab selection is especially important for doing parallel I/O in HDF5 (See Parallel HDF5 Tutorial)

Regular Hyperslab



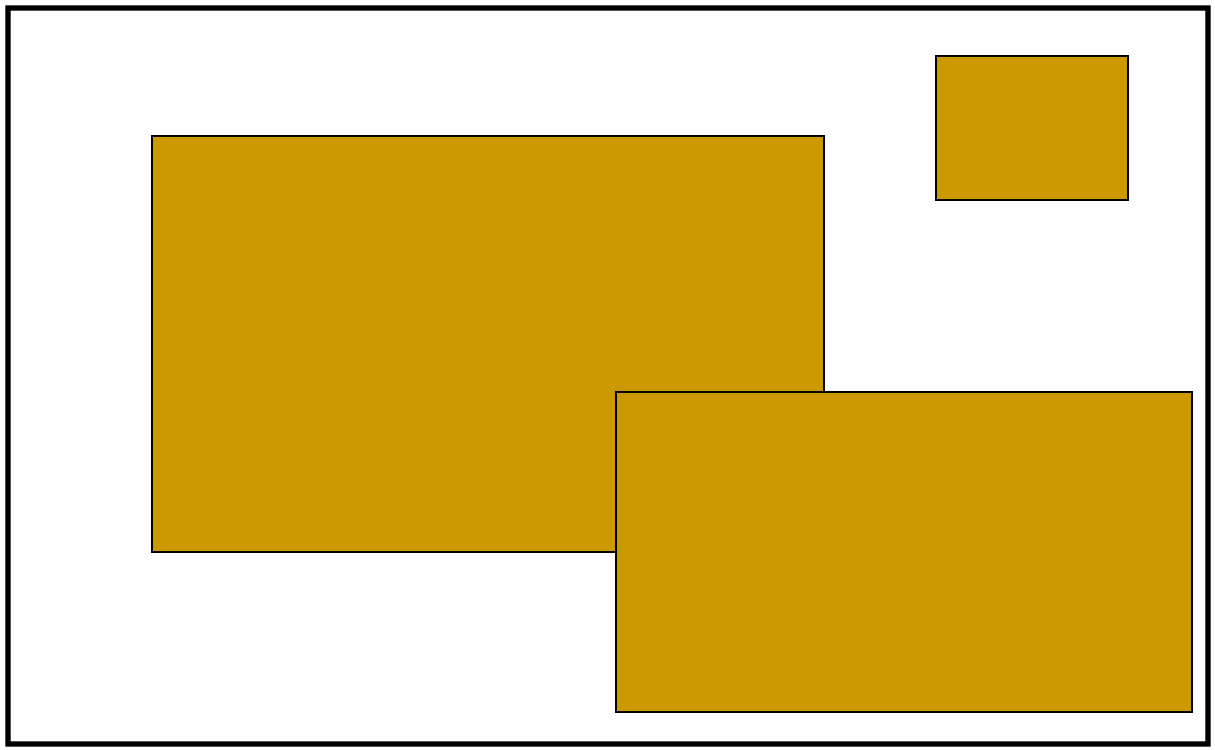
Collection of regularly spaced blocks of equal size

Simple Hyperslab



Contiguous subset or sub-array

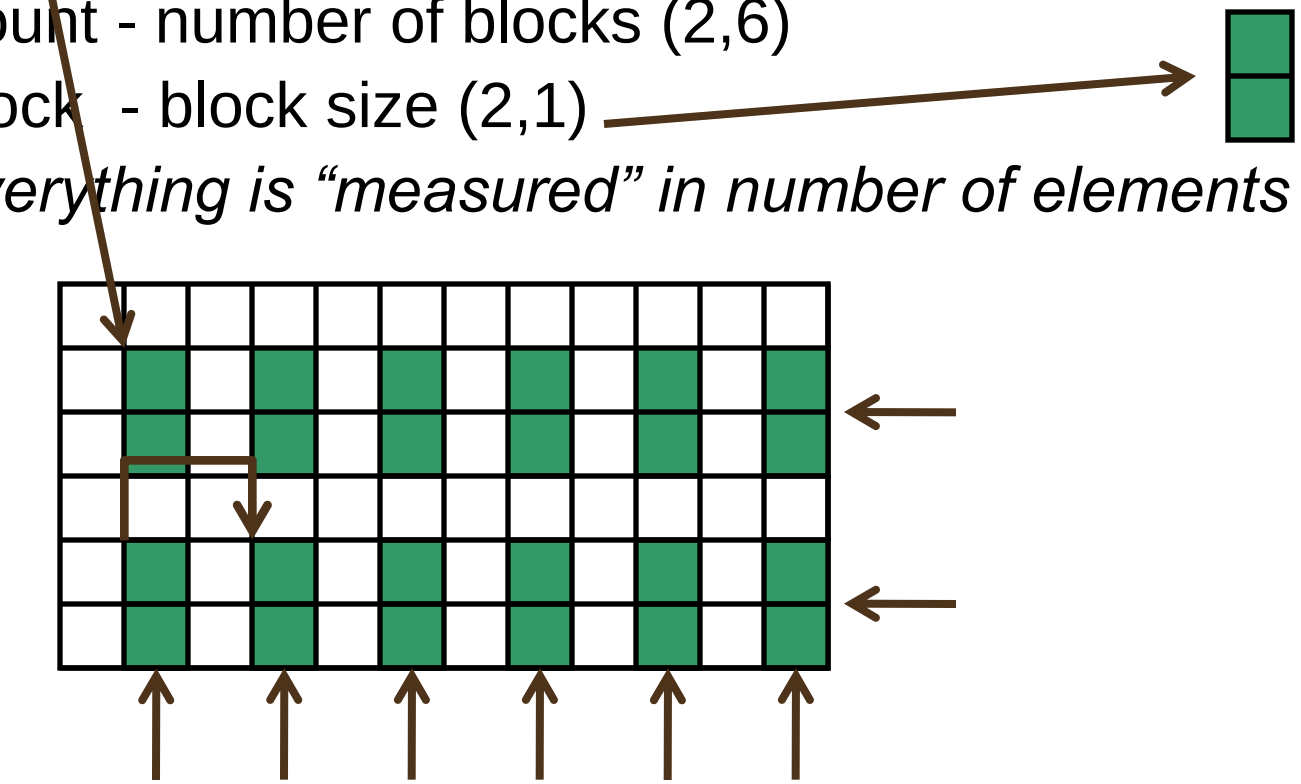
Hyperslab Selection



Result of union operation on three simple hyperslabs

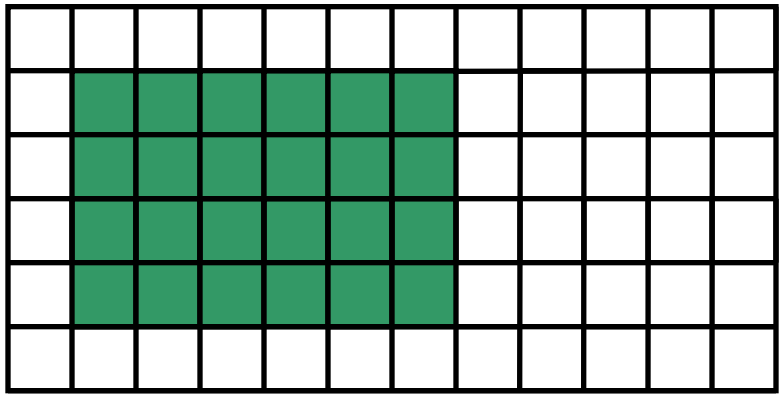
Hyperslab Description

- Start - 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 – (2,6)**
  - Block – (2,1)
- As *one* block
  - Stride – (1,1)
  - Count – (1,1)
  - **Block – (4,6)**



No performance penalty for one way or another

H5Sselect_hyperslab Function

space_id	Identifier of dataspace
op	Selection operator H5S_SELECT_SET or H5S_SELECT_OR
start	Array with starting coordinates of hyperslab
stride	Array specifying which positions along a dimension to select
count	Array specifying how many blocks to select from the dataspace, in each dimension
block	Array specifying size of element block (NULL indicates a block size of a single element in a dimension)

Reading/Writing Selections

Programming model for reading from a dataset in a file

1. Open a dataset.
2. Get file dataspace handle of the dataset and specify subset to read from.
   a. **`H5Dget_space`** returns file dataspace handle
      a. File dataspace describes array stored in a file (number of dimensions and their sizes).
   b. **`H5Sselect_hyperslab`** selects elements of the array that participate in I/O operation.
3. Allocate data buffer of an appropriate shape and size

Reading/Writing Selections

Programming model (continued)

4. Create a memory dataspace and specify subset to write to.
    1. Memory dataspace describes data buffer (its rank and dimension sizes).
    2. Use **H5Screate_simple** function to create memory dataspace.
    3. Use **H5Sselect_hyperslab** to select elements of the data buffer that participate in I/O operation.
5. Issue **H5Dread** or **`H5Dwrite`** to move the data between file and memory buffer.
6. Close file dataspace and memory dataspace when done.

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

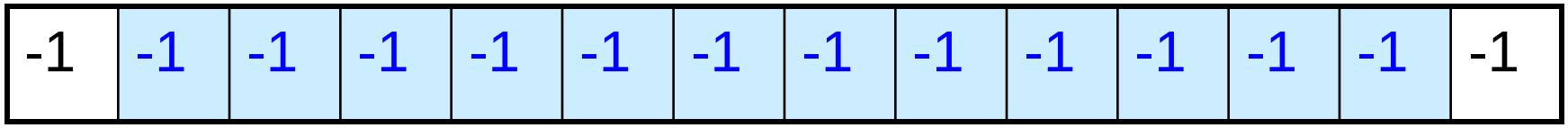
1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

```
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}
```




```
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; *avoid* choosing *subsets* that have *different ranks* (as in example above)
- *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.

Thank You!

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Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author[s] and do not necessarily reflect the views of the National Aeronautics and Space Administration.

Questions/comments?