Introduction to HDF5

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The HDF Group

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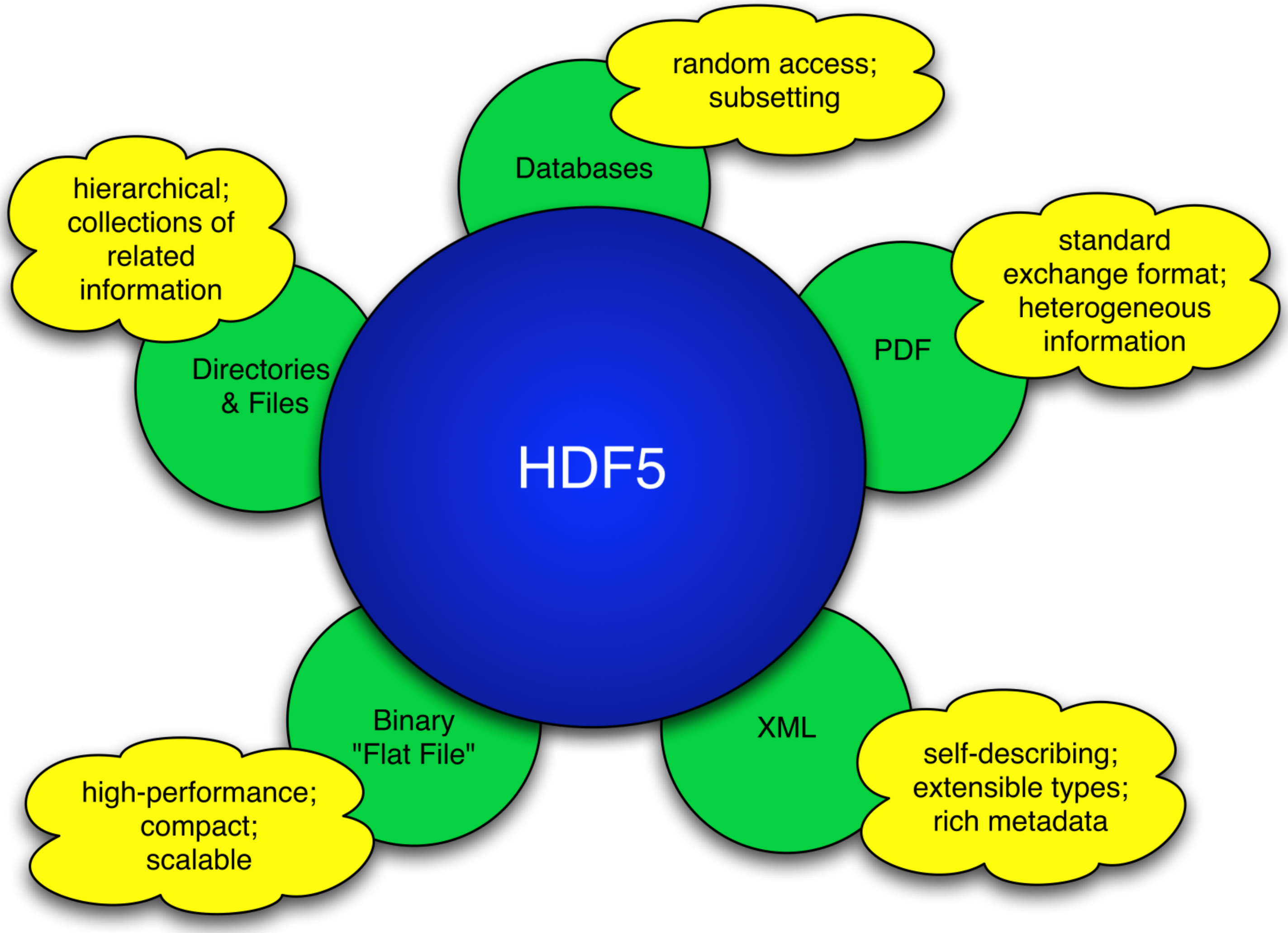
What is HDF5?

- Open **file format**
  - Designed for high volume or complex data
- Open source **software**
  - Works with data in the format
- A **data model**
  - Structures for data organization and specification

HDF = Hierarchical Data Format

- HDF4 is the first HDF
  - Originally called HDF; last major release was version 4
- HDF5 benefits from lessons learned with HDF4
  - Changes to file format, software, and data model
  - HDF5 and HDF4 are *different*
- No plans for an HDF6!

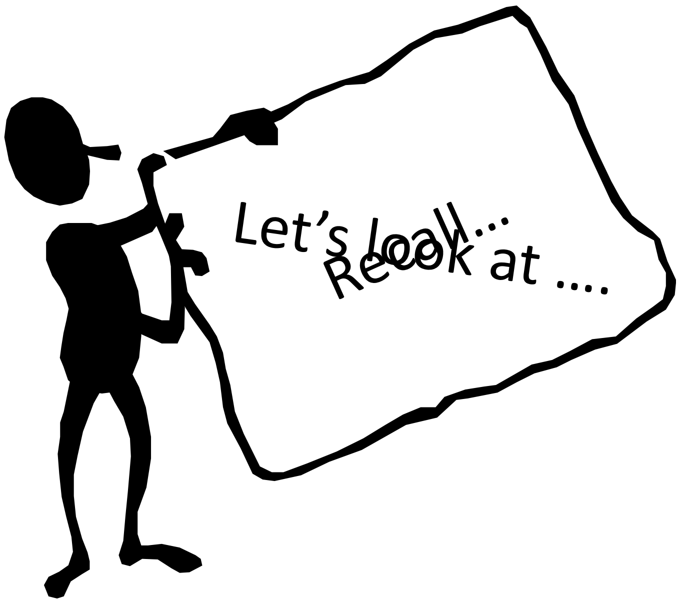
HDF5 is like …


HDF5
Databases
random access; subsetting
Directories & Files
hierarchical; collections of related information
PDF
standard exchange format; heterogeneous information
Binary "Flat File"
high-performance; compact; scalable
XML
self-describing; extensible types; rich metadata

HDF5 is designed …

- for high volume and/or complex data
- for every size and type of system (portable)
- for flexible, efficient storage and I/O
- to enable applications to evolve in their use of HDF5 and to accommodate new models
- to support long-term data preservation

HDF5 Technology Platform



- HDF5 **data model**
  - The "building blocks" for data organization and specification
- HDF5 **software**
  - Library, language interfaces, tools
- HDF5 **file format**
  - Bit-level organization of HDF5 file

HDF5 Data Model

Dataset

Group

Attribute

HDF5 Objects

Link

Datatype

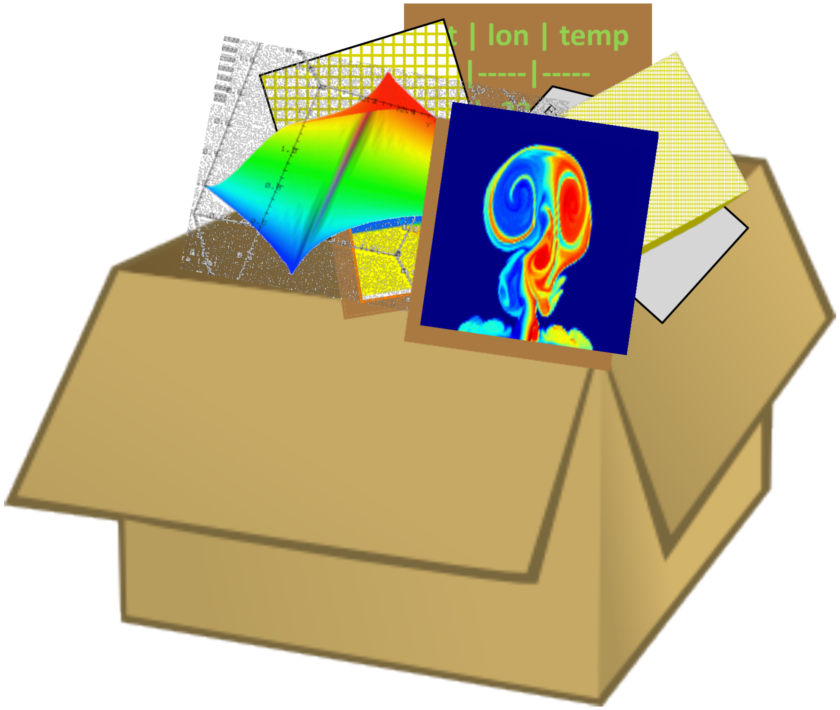
Dataspace

File

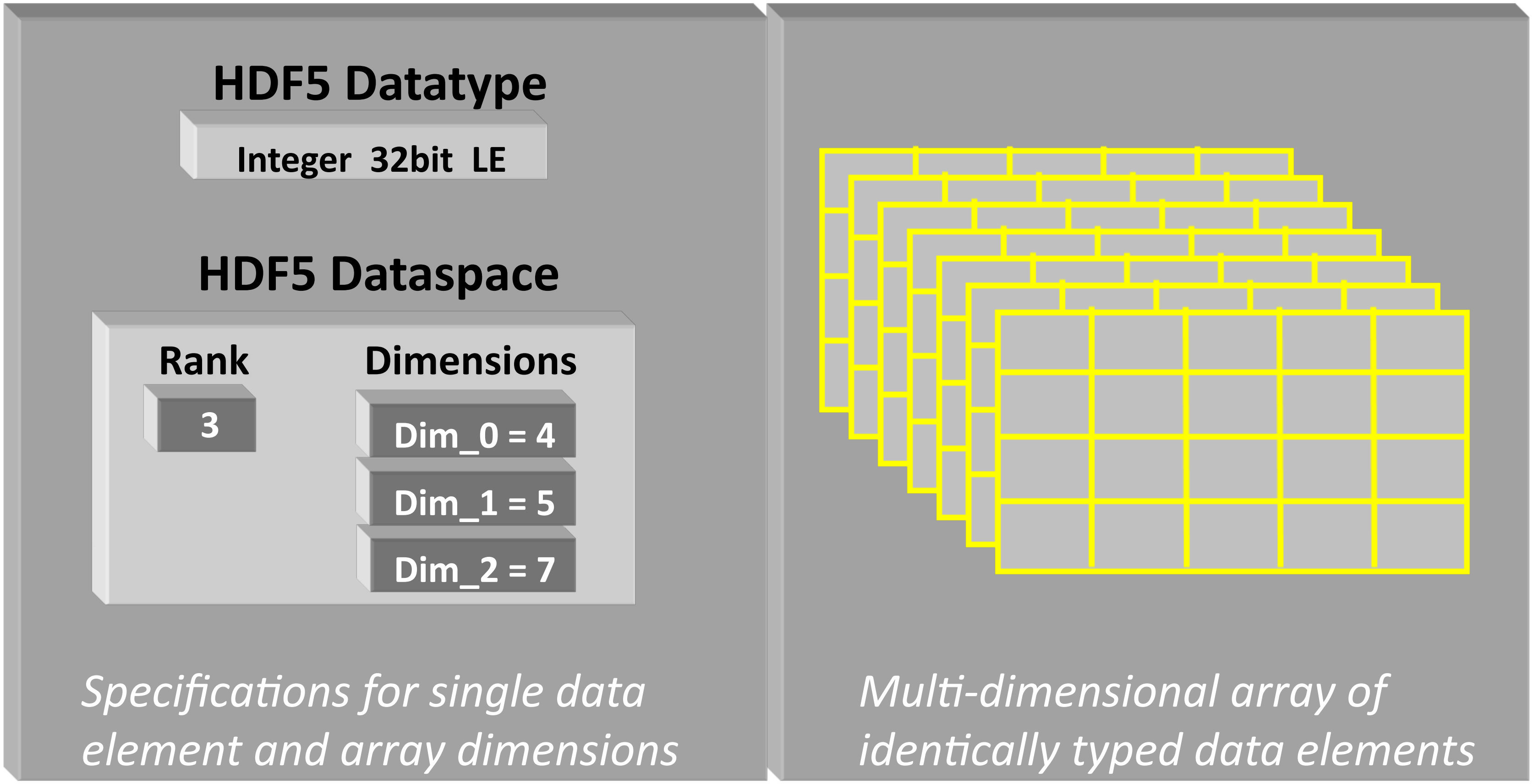
a.k.a. HDF5 Abstract Data Model
a.k.a. HDF5 Logical Data Model

HDF5 File

An HDF5 file is a **container** that holds data objects.



HDF5 Dataset



HDF5 Datatype

Integer 32bit LE

HDF5 Dataspace

Rank

3

Dimensions

Dim_0 = 4

Dim_1 = 5

Dim_2 = 7

Specifications for single data element and array dimensions

Multi-dimensional array of identically typed data elements

- HDF5 datasets **organize and contain** “raw data values”.
  - HDF5 datatypes describe individual data elements.
  - HDF5 dataspaces describe the logical layout of the data elements.

HDF5 Dataspaces

- Describe the logical layout of the elements in an HDF5 dataset
  - NULL
    - no elements
  - Scalar
    - single element
  - Simple array (*most common*)
    - multiple elements organized in a rectangular array
      - rank = number of dimensions
      - dimension sizes = number of elements in each dimension
      - maximum number of elements in each dimension
        - may be fixed or unlimited

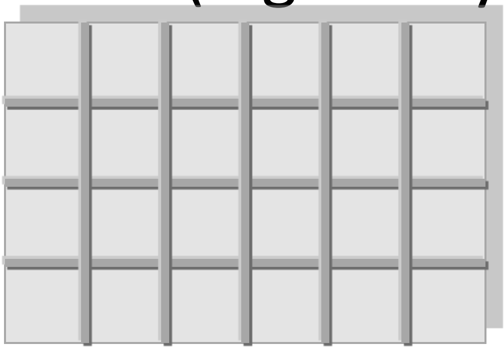
HDF5 Dataspaces

Two roles:

Dataspace contains spatial information (logical layout) about a dataset

stored in a file

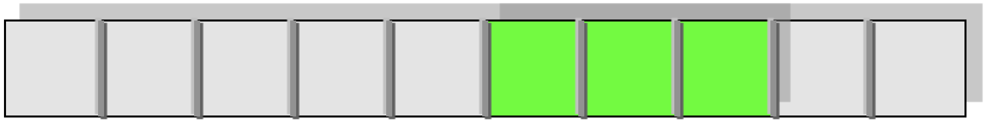
- Rank and dimensions
- Permanent part of dataset definition



Rank = 2

Dimensions = 4x6

Partial I/0: Dataspace describes application's data buffer and data elements participating in I/O



Rank = 1

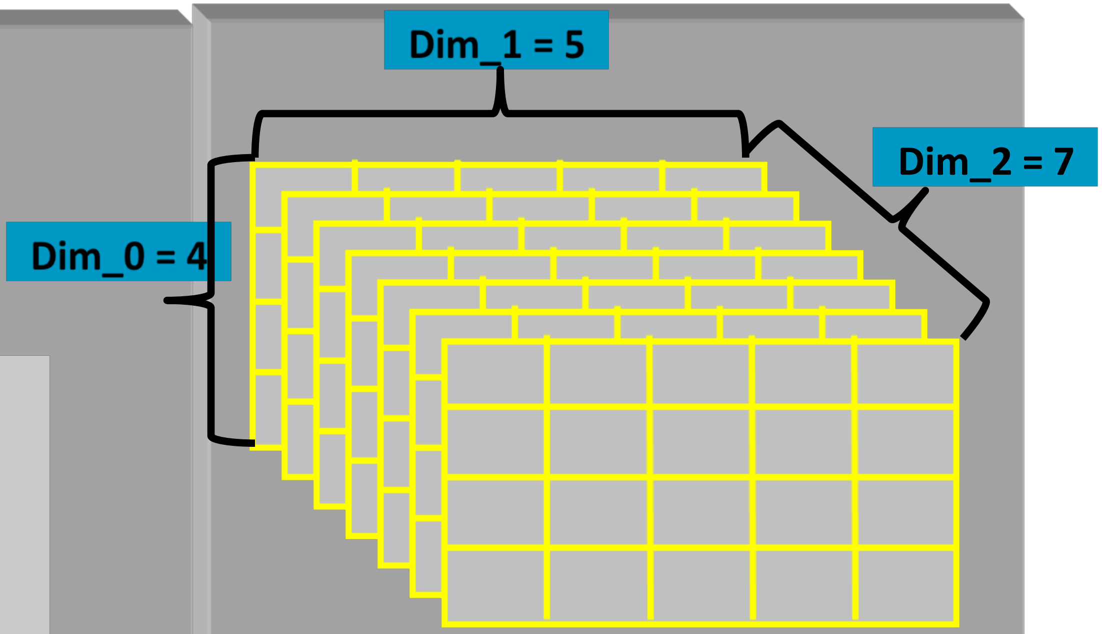
Dimension = 10

HDF5 Dataset & Dataspace

HDF5 Dataspace

Rank	Dimensions
3	Dim_0 = 4
	Dim_1 = 5
	Dim_2 = 7

Specifications for array dimensions



Multi-dimensional array of identically typed data elements

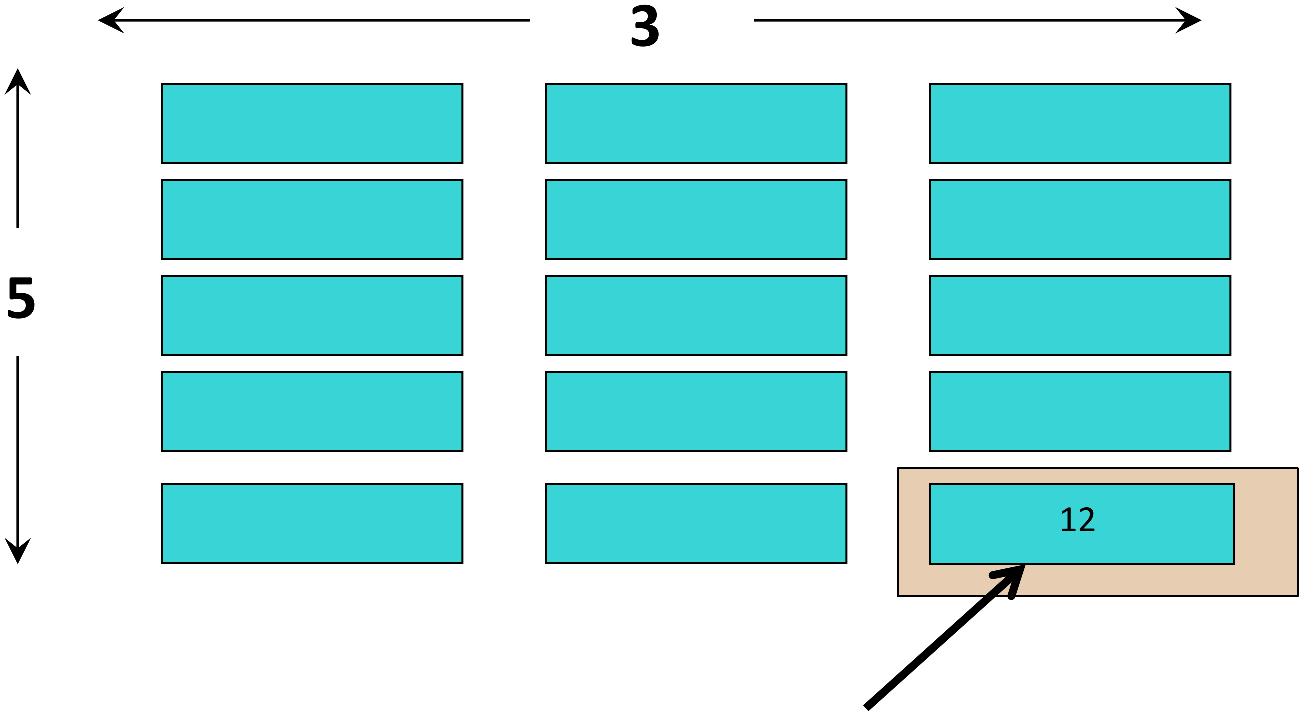
- HDF5 datasets organize and contain “raw data values”.

  - HDF5 dataspaces **describe the logical layout of the data elements**.

HDF5 Datatypes

- Describe individual data elements in an HDF5 dataset
- Wide range of datatypes supported
  - Signed/unsigned Integer
  - Float
  - User-defined (e.g., 13-bit integer)
  - Fixed and variable-length strings
  - Variable length sequences
  - Arrays
  - Compound (similar to C structs)
  - Enumerated
  - Many more …

HDF5 Dataset

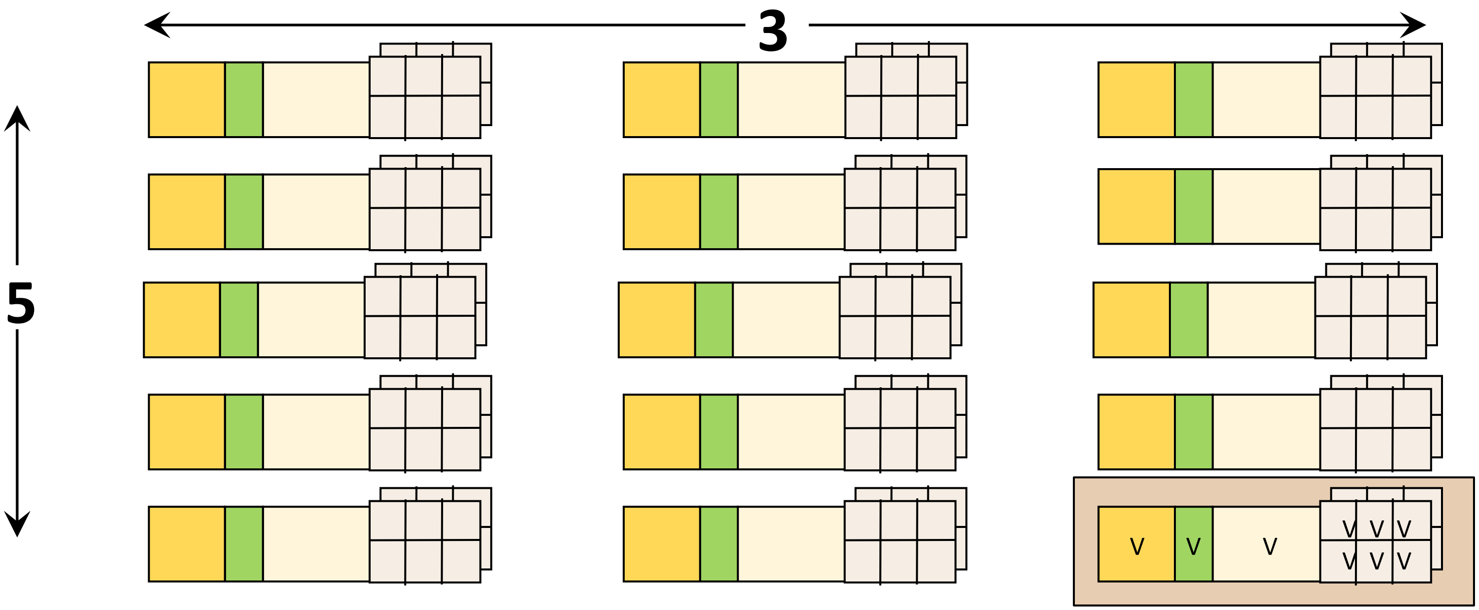


Datatype: **32-bit Integer**

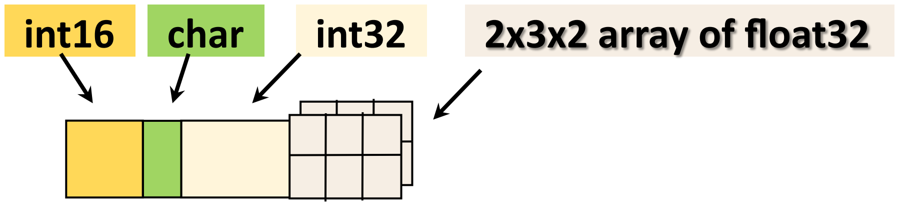
Dataspace: **Rank = 2**

Dimensions = 5 x 3

HDF5 Dataset with Compound Datatype



Compound Datatype:


int16

char

int32

2x3x2 array of float32

Dataspace: **Rank = 2**

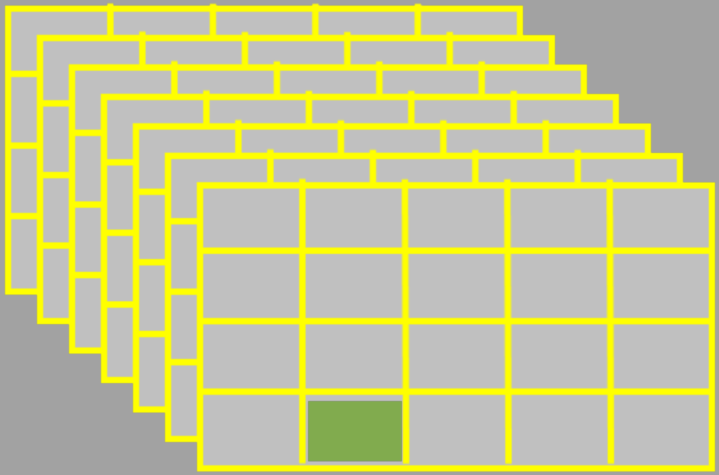
Dimensions = 5 x 3

HDF5 Dataset & Datatype

HDF5 Datatype

Integer 32bit LE

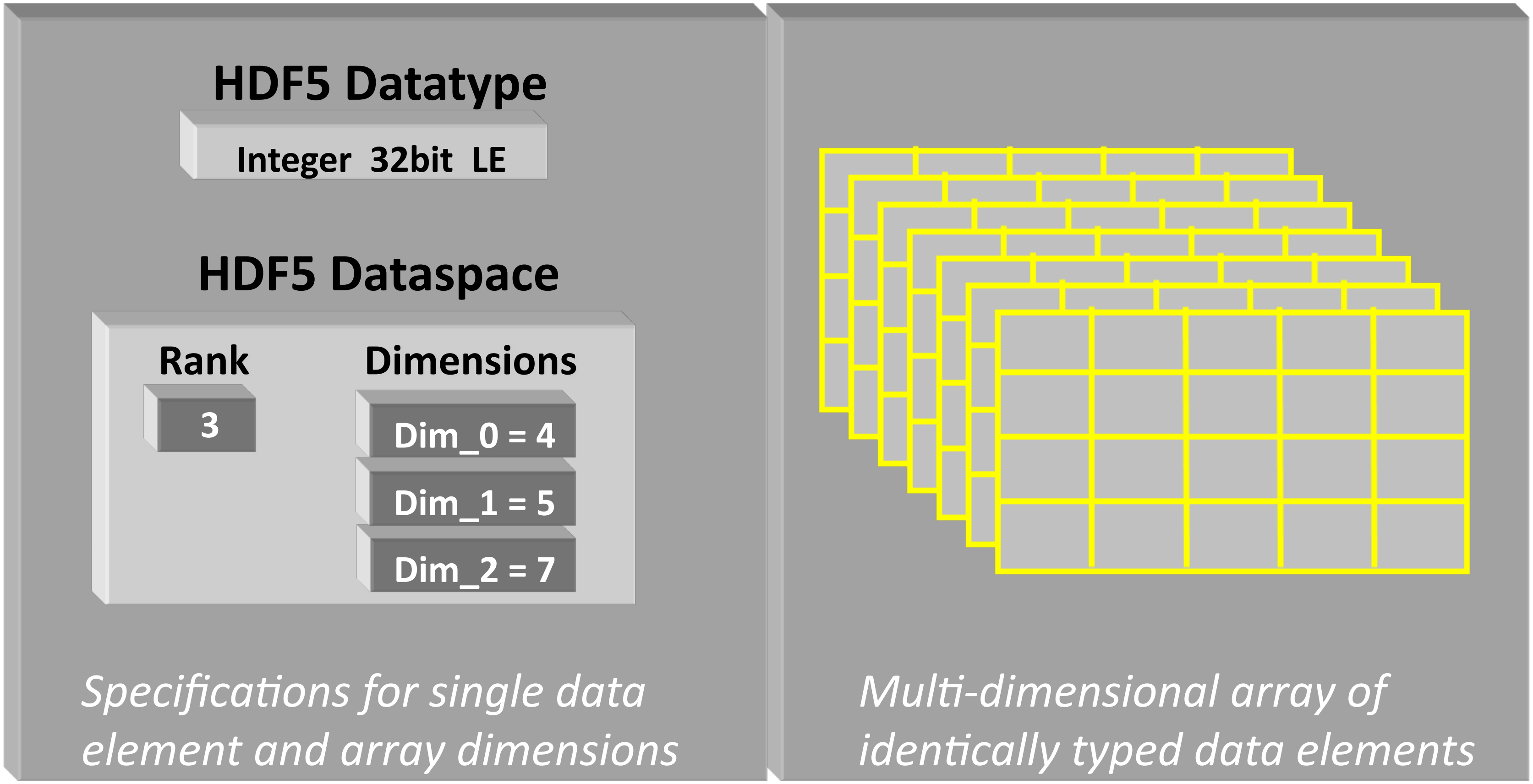
Specifications for single data element



Multi-dimensional array of identically typed data elements

- HDF5 datasets organize and contain “raw data values”.
  - HDF5 datatypes **describe individual data elements.**

HDF5 Dataset



HDF5 Datatype

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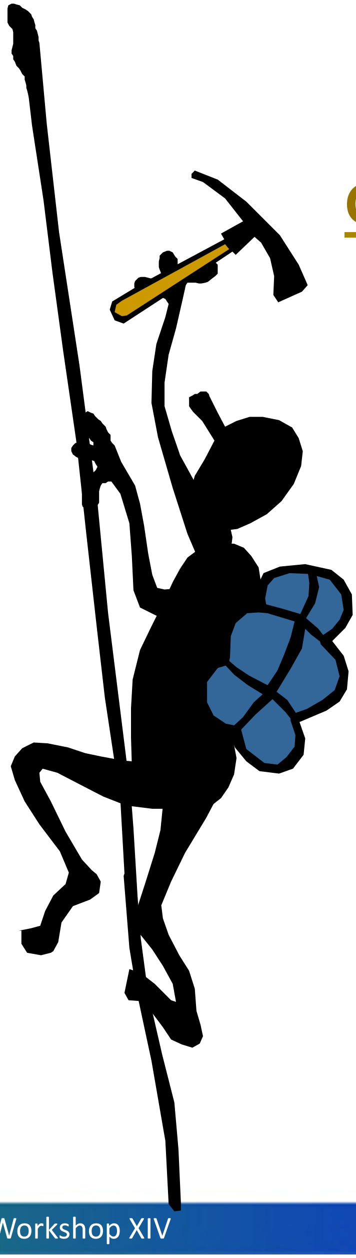
Specifications for single data element and array dimensions

Multi-dimensional array of identically typed data elements

- HDF5 datasets organize and contain “raw data values”.
    - HDF5 datatypes describe individual data elements.
    - HDF5 dataspaces describe the logical layout of the data elements.

HDF5 Data Model: Are we there yet?

HDF5 Objects



Group and **Link**

Attribute

Dataspace ✓

Datatype ✓

Dataset ✓

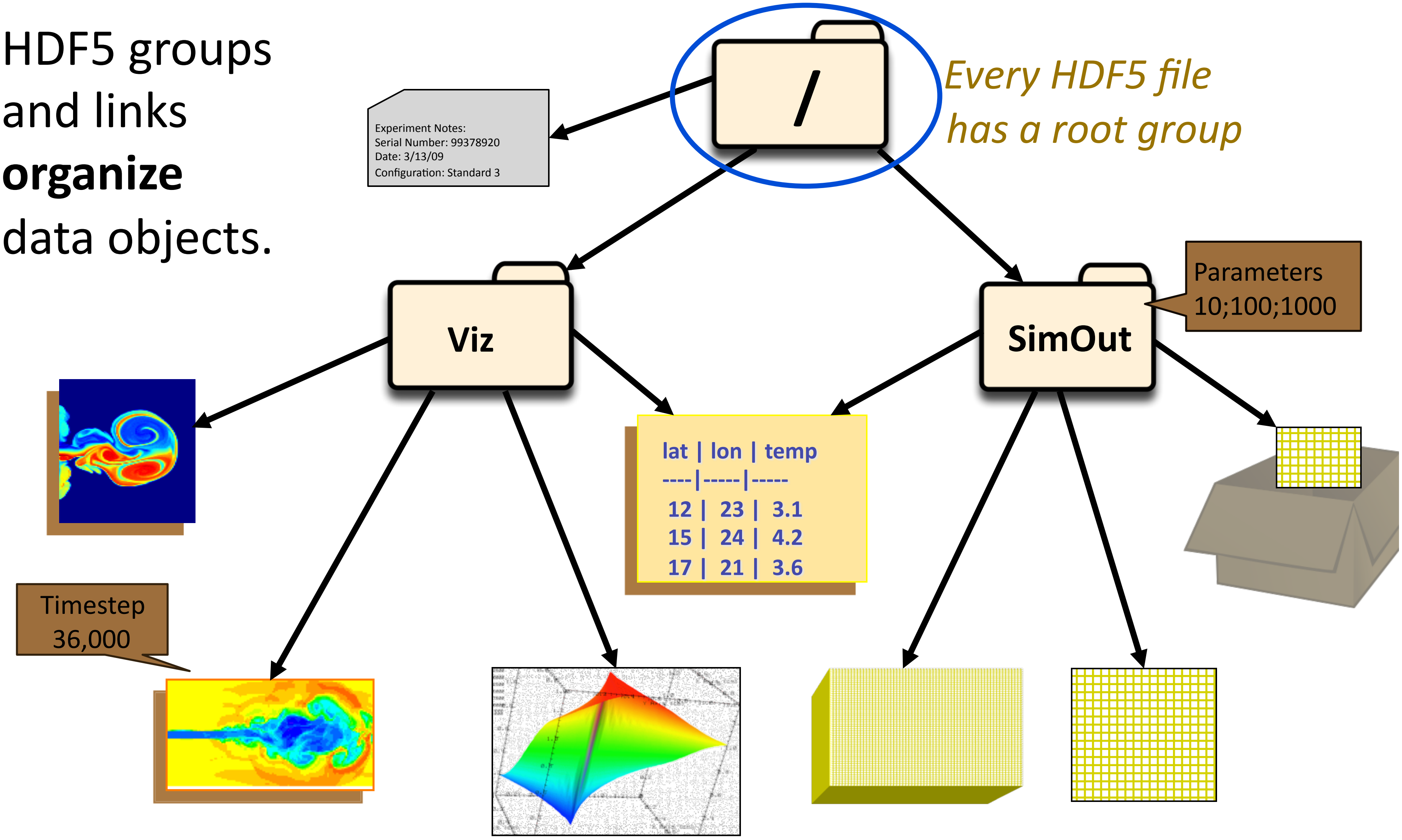
File ✓

HDF5 Attributes

- Typically contain user metadata
- Have a <u>name</u> and a <u>value</u>
- Are associated with HDF5 objects.
- Value is described by a datatype and a dataspace
    - analogous to a dataset

HDF5 Groups and Links

HDF5 groups and links **organize** data objects.



Every HDF5 file has a root group

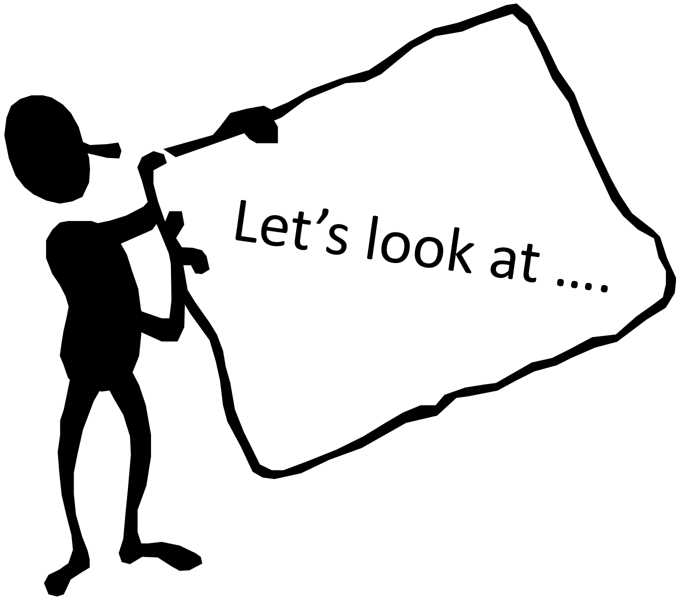
Experiment Notes:
Serial Number: 99378920
Date: 3/13/09
Configuration: Standard 3

Parameters
10;100;1000

Timestep
36,000

lat	lon	temp
12	23	3.1
15	24	4.2
17	21	3.6

HDF5 Technology Platform



- HDF5 **data model**
  - The "building blocks" for data organization and specification
- HDF5 **software**
  - Library, language interfaces, tools

HDF5 Home Page

HDF5 home page: http://hdfgroup.org/HDF5/

- Latest release: HDF5 1.8.5 (1.8.6 coming in November!)

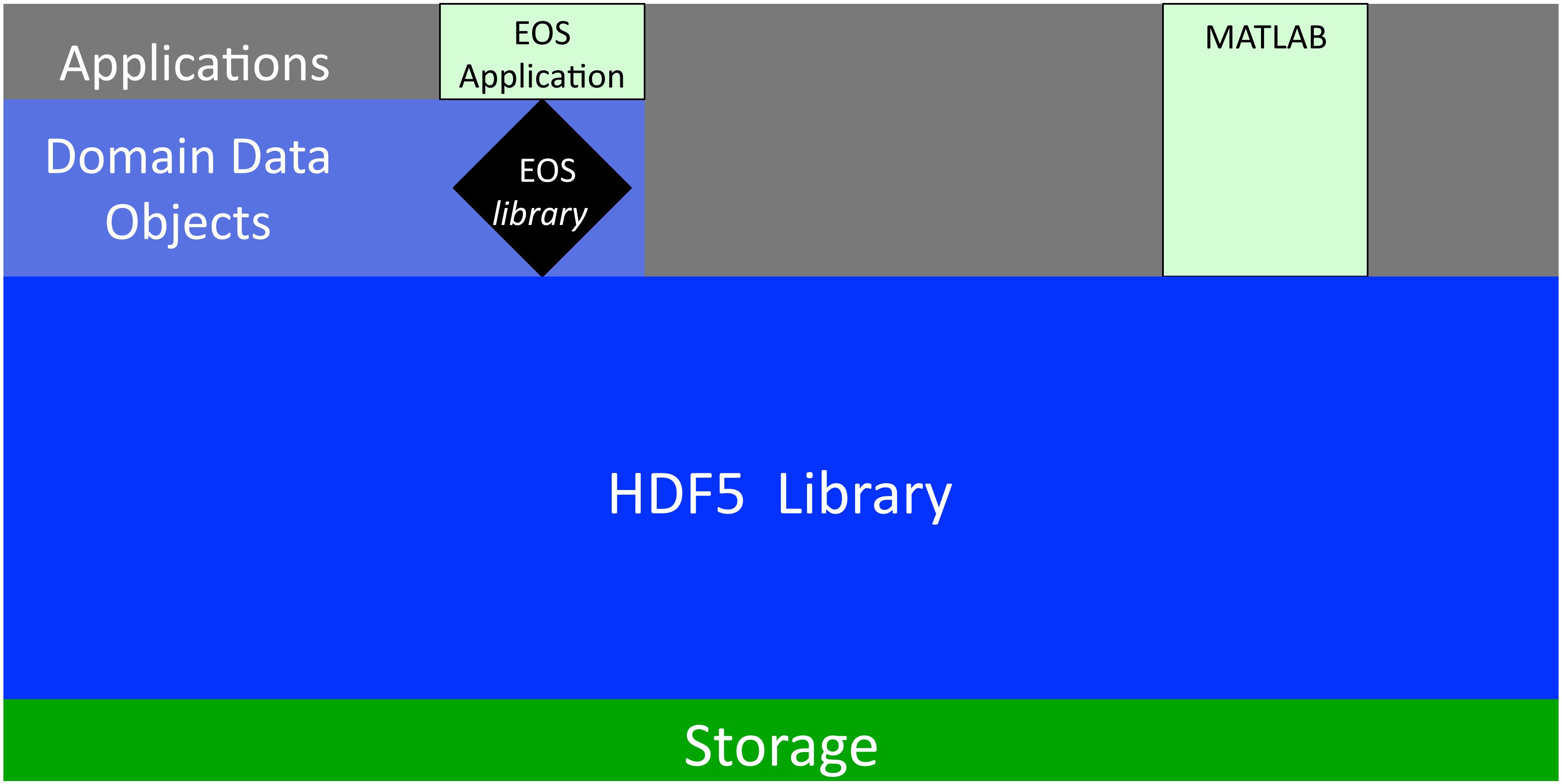
HDF5 source code:

- Written in C, and includes optional C++, Fortran 90 APIs, and High Level APIs
- Contains command-line utilities (h5dump, h5repack, h5diff, ..) and compile scripts

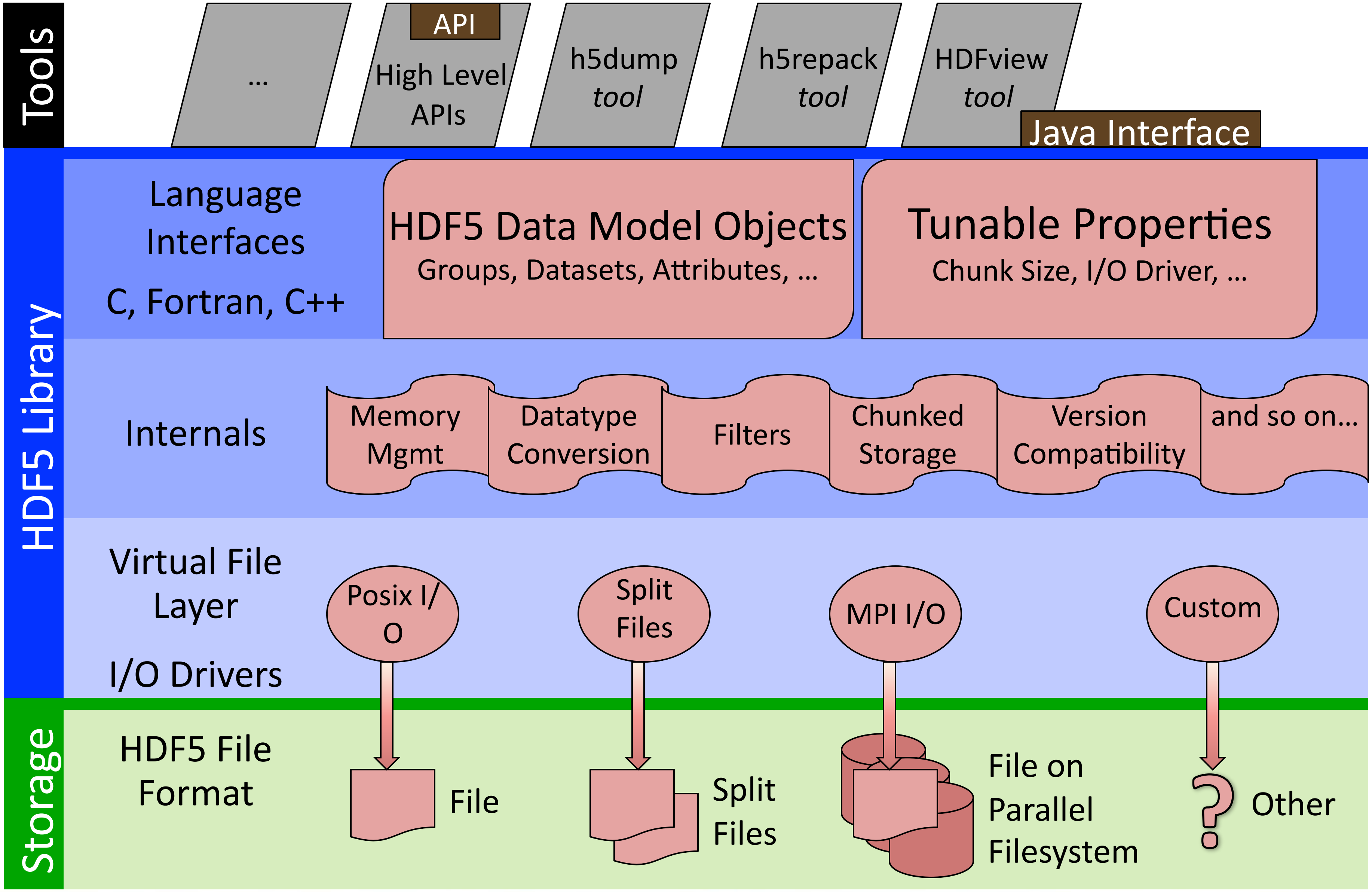
HDF5 pre-built binaries:

- When possible, include C, C++, F90, and High Level libraries. Check ./lib/libhdf5.settings file.
- Built with and require the SZIP and ZLIB external libraries

HDF5 API and Applications



HDF5 Software Layers & Storage



Useful Tools For New Users

h5dump:

Tool to “dump” or display contents of HDF5 files

h5cc, h5c++, h5fc:

Scripts to compile applications

HDFView:

Java browser to view HDF4 and HDF5 files

http://www.hdfgroup.org/hdf-java-html/hdfview/

Introduction to HDF5 Programming Model and APIs

General Programming Paradigm

- Object is opened or created
- Object is accessed, possibly many times
- Object is closed

- Properties of object are <u>optionally</u> defined
  - ✓Creation properties
  - ✓Access properties

Order of Operations

- An order is imposed on operations by argument dependencies

  For Example:

  A file must be opened before a dataset

  -because-

  the dataset open call requires a file handle as an argument.

- Objects can be closed in any order.

The General HDF5 API

- Currently C, Fortran 90, Java, and C++ bindings.
- C routines begin with prefix H5*?*

  ? is a character corresponding to the type of object the function acts on

Example Functions:

H5D :	**D**ataset interface	*e.g.,* **H5Dread**
H5F :	**F**ile interface	*e.g.,* **H5Fopen**
H5S :	data**S**pace interface	*e.g.,* **H5Sclose**

HDF5 Defined Types

For portability, the HDF5 library has its own defined types:

hid_t: object identifiers (native *integer*)

hsize_t: size used for dimensions (*unsigned long* or *unsigned long long*)

herr_t: function return value

hvl_t: variable length datatype

Note: This is not an exhaustive list!

For **C**, include hdf5.h in your HDF5 application.

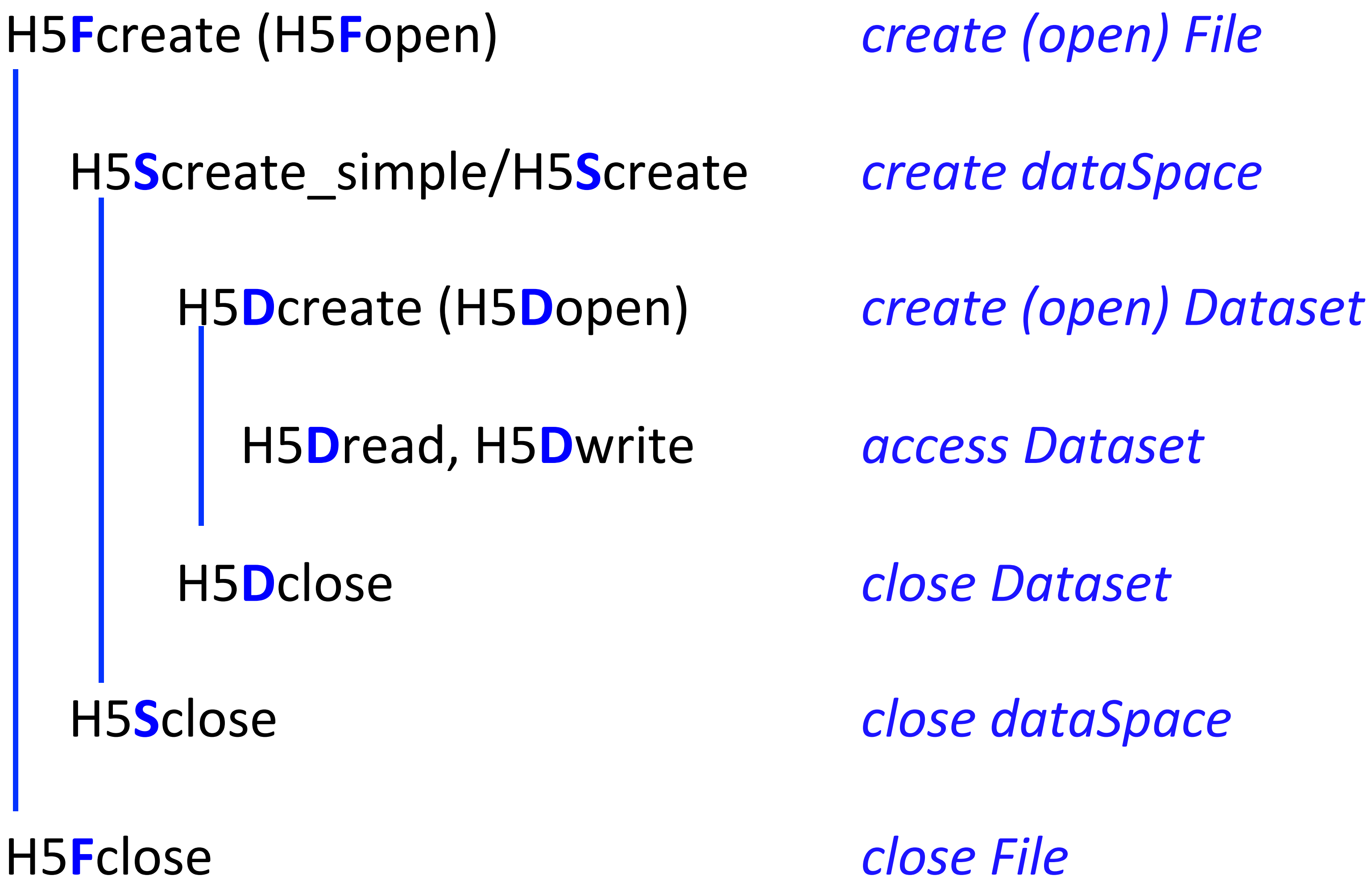
The HDF5 API

- For flexibility, the API is extensive
  - ✓ 300+ functions

Victronix
Swiss Army
Cybertool 34

- This can be daunting… but there is hope
  - ✓A few functions can do a lot
  - ✓Start simple
  - ✓Build up knowledge as more features are needed

Basic Functions



H5**F**create (H5**F**open)	*create (open) File*
H5**S**create_simple/H5**S**create	*create dataSpace*
H5**D**create (H5**D**open)	*create (open) Dataset*
H5**D**read, H5**D**write	*access Dataset*
H5**D**close	*close Dataset*
H5**S**close	*close dataSpace*
H5**F**close	*close File*

Other Common Functions

DataSpaces:	H5Sselect_hyperslab (Partial I/O) H5Sselect_elements (Partial I/O) H5Dget_space
Groups:	H5Gcreate, H5Gopen, H5Gclose
Attributes:	H5Acreate, H5Aopen_name, H5Aclose, H5Aread, H5Awrite
Property lists:	H5Pcreate, H5Pclose H5Pset_chunk, H5Pset_deflate

High Level APIs

- Included along with the HDF5 library
- Simplify steps for creating, writing, and reading objects.
- Do not entirely ‘wrap’ HDF5 library

Example HDF5 Code

Steps to Create a File

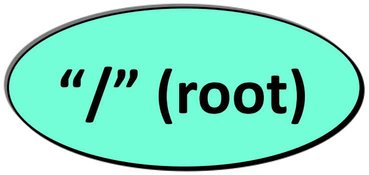
1. Decide on properties the file should have and create them if necessary:
   - Creation properties
   - Access properties
   - We will use Default properties.

2. Create the file

3. Close the file and the property lists, as needed

Code: Create a File

```
hid_t       file_id;
herr_t      status;

file_id = H5Fcreate("file.h5", H5F_ACC_TRUNC,
                    H5P_DEFAULT, H5P_DEFAULT);

status = H5Fclose (file_id);
```



“/” (root)

Note: Return codes not checked for errors in code samples.

Steps to Create a Dataset

1. Define dataset characteristics

   a) Datatype – integer

   b) Dataspace - 4x6

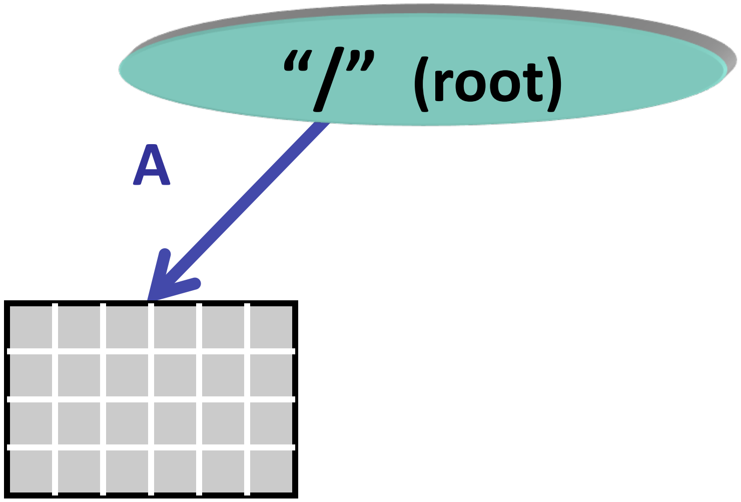
   c) Properties if needed, or use H5P_DEFAULT

2. Decide where to put it

   2. Group or root group

3. Create dataset in file

4. Close everything



HDF5 Pre-defined Datatype Identifiers

HDF5 defines* set of Datatype Identifiers per HDF5 session.

For example:

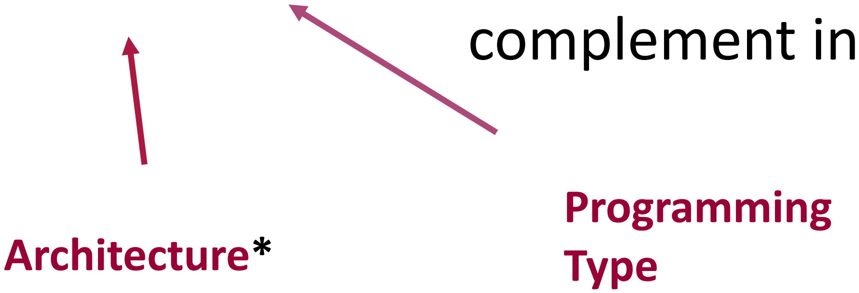
C Type	HDF5 File Type	HDF5 Memory Type
int	H5T_STD_I32BE H5T_STD_I32LE	H5T_NATIVE_INT
float	H5T_IEEE_F32BE H5T_IEEE_F32LE	H5T_NATIVE_FLOAT
double	H5T_IEEE_F64BE H5T_IEEE_F64LE	H5T_NATIVE_DOUBLE

*** Value of datatype is NOT fixed**

Pre-defined File Datatype Identifiers

Examples:

H5T_IEEE_F64LE	Eight-byte, little-endian, IEEE floating-point
H5T_STD_I32LE	Four-byte, little-endian, signed two's complement integer



Architecture*

Programming Type

NOTE: What you see in the file. Name is the same everywhere and explicitly defines a datatype.

***STD= "An architecture with a semi-standard type like 2's complement integer, unsigned integer…"**

Pre-defined Native Datatypes

Examples of predefined native types in C:

H5T_NATIVE_INT	(int)
H5T_NATIVE_FLOAT	(float)
H5T_NATIVE_UINT	(unsigned int)
H5T_NATIVE_LONG	(long)
H5T_NATIVE_CHAR	(char)

NOTE: **Memory types.**
Different for each machine.
Used for reading/writing.

Code: Create a Dataset

```
hid_t         dataspace_id;
hsize_t       dims[2];

.
.
.
dims[0] = 4;
dims[1] = 6;
dataspace_id = H5Screate_simple (2, dims, NULL);
```

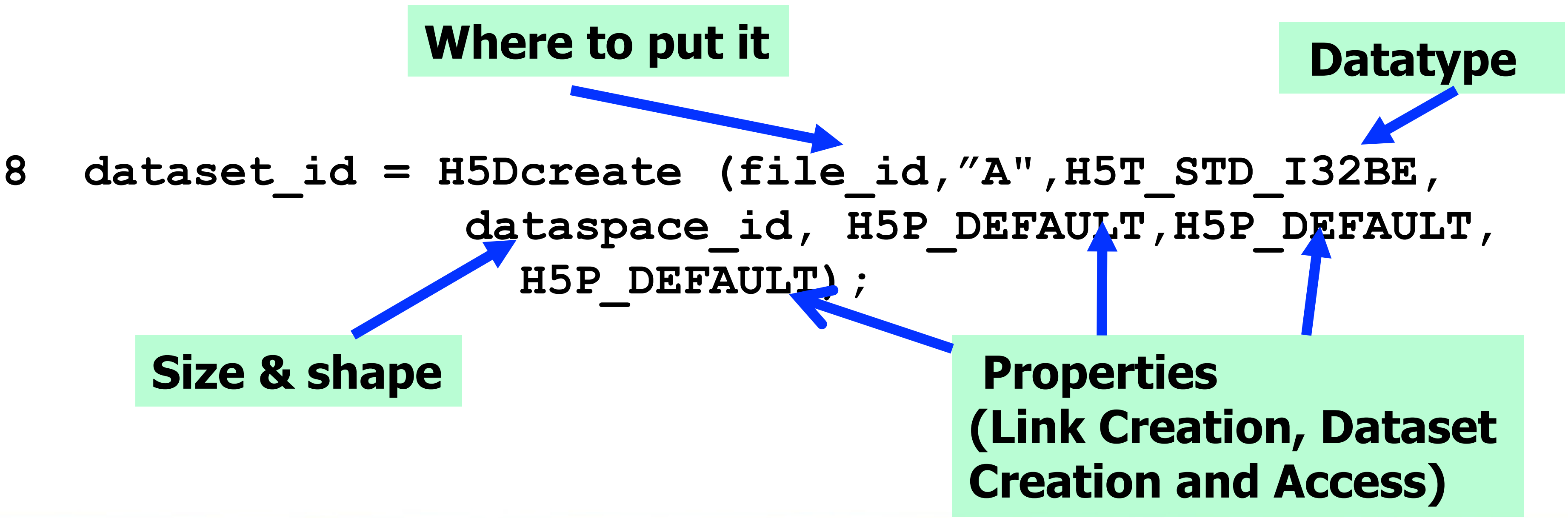
Define a dataspace

rank

current dims

Code: Create a Dataset

```
hid_t        file_id, dataset_id, dataspace_id;
.
.
.
```



```
dataset_id = H5Dcreate (file_id,”A",H5T_STD_I32BE,
               dataspace_id, H5P_DEFAULT,H5P_DEFAULT,
                 H5P_DEFAULT);
```

Where to put it

Datatype

Size & shape

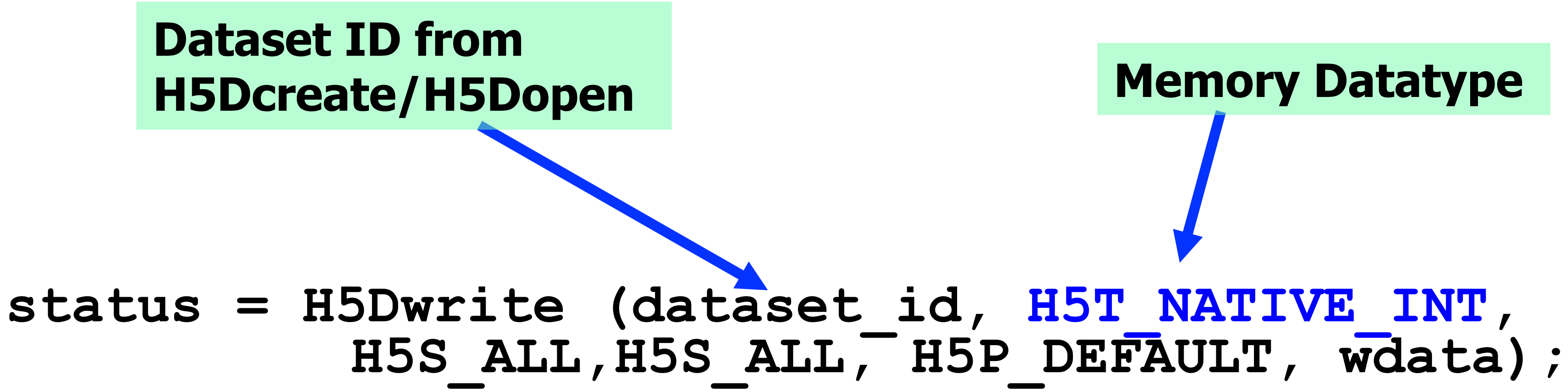
Properties
(Link Creation, Dataset Creation and Access)

Code: Create a Dataset

```
hid_t            file_id, dataset_id, dataspace_id;
hsize_t          dims[2];
herr_t           status;

file_id = H5Fcreate (”file.h5", H5F_ACC_TRUNC,
                     H5P_DEFAULT, H5P_DEFAULT);

dims[0] = 4;
dims[1] = 6;
dataspace_id = H5Screate_simple (2, dims, NULL);

dataset_id = H5Dcreate (file_id,”A",H5T_STD_I32BE,
                dataspace_id, H5P_DEFAULT, H5P_DEFAULT,
                H5P_DEFAULT);

status = H5Dclose (dataset_id);
status = H5Sclose (dataspace_id);
status = H5Fclose (file_id);
```

Terminate access to dataspace, dataset, file

Example Code - H5Dwrite



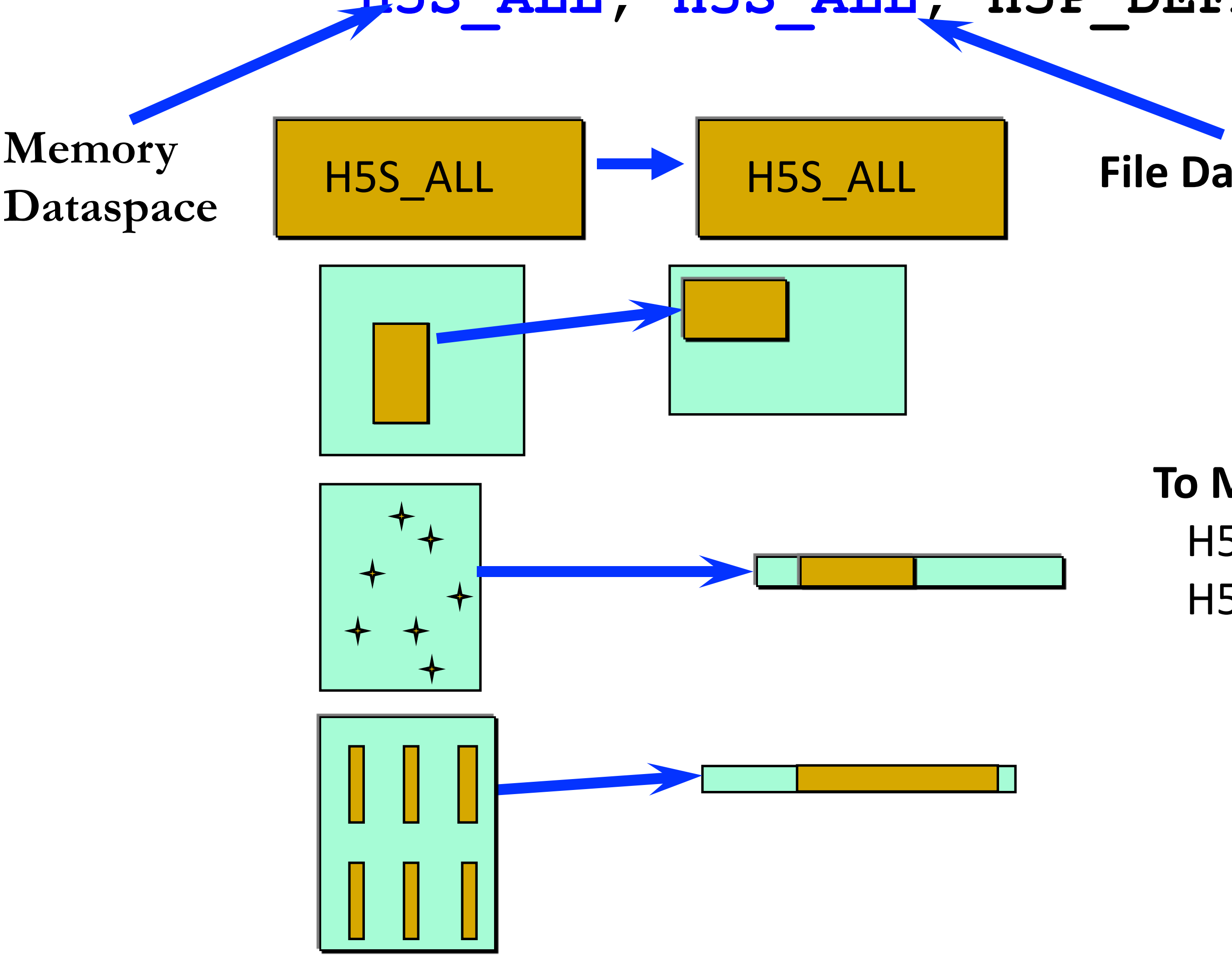
Dataset ID from H5Dcreate/H5Dopen

Memory Datatype

```
status = H5Dwrite (dataset_id, H5T_NATIVE_INT,
                   H5S_ALL,H5S_ALL, H5P_DEFAULT, wdata);
```

Partial I/O

```
status = H5Dwrite (dataset_id, H5T_NATIVE_INT,
             H5S_ALL, H5S_ALL, H5P_DEFAULT,wdata);
```



File Dataspace (disk)

To Modify Dataspace:

H5Sselect_hyperslab
H5Sselect_elements

Example Code – H5Dwrite

```
status = H5Dwrite (dataset_id, H5T_NATIVE_INT,
           H5S_ALL, H5S_ALL, H5P_DEFAULT, wdata);
```

Data Transfer Property List (MPI I/O, Transformations,…)

Example Code – H5Dread

```
status = H5Dread (dataset_id, H5T_NATIVE_INT,
          H5S_ALL, H5S_ALL, H5P_DEFAULT, rdata);
```

High Level APIs: HDF5 Lite (H5LT)

```
#include “hdf5_hl.h“
.
.

  file_id = H5Fcreate(“file.h5",H5F_ACC_TRUNC,
                      H5P_DEFAULT, H5P_DEFAULT);

  status = H5LTmake_dataset (file_id,“A",2,dims,
                      H5T_STD_I32BE, data);

  status = H5Fclose (file_id);
```

High Level APIs

- HDF5 Lite
- HDF5 Image
- HDF5 Table
- HDF5 Dimension Scales
- HDF5 Packet Table

Steps to Create a Group

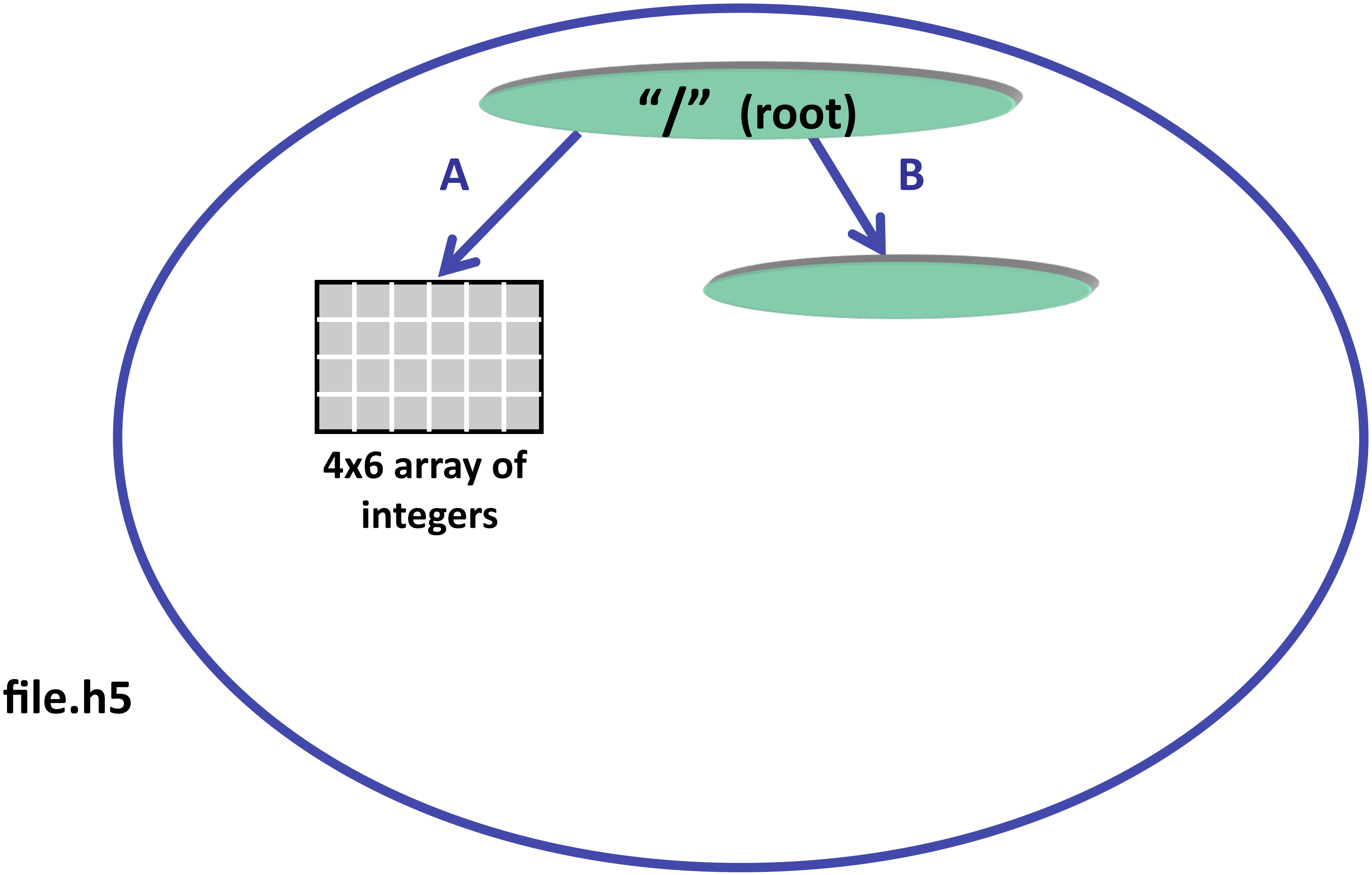
1. Decide where to put it – “root group”

2. Define properties or use H5P_DEFAULT

5. Create group in file.

4. Close the group.

Example: Create a Group



Code: Create a Group

```
hid_t file_id, group_id;
...
/* Open “file.h5” */
file_id = H5Fopen (“file.h5”, H5F_ACC_RDWR,
                         H5P_DEFAULT);

/* Create group "/B" in file. */
group_id = H5Gcreate (file_id,"B", H5P_DEFAULT,
                      H5P_DEFAULT, H5P_DEFAULT);

/* Close group and file. */
status = H5Gclose (group_id);
status = H5Fclose (file_id);
```

HDF5 Tutorial and Examples

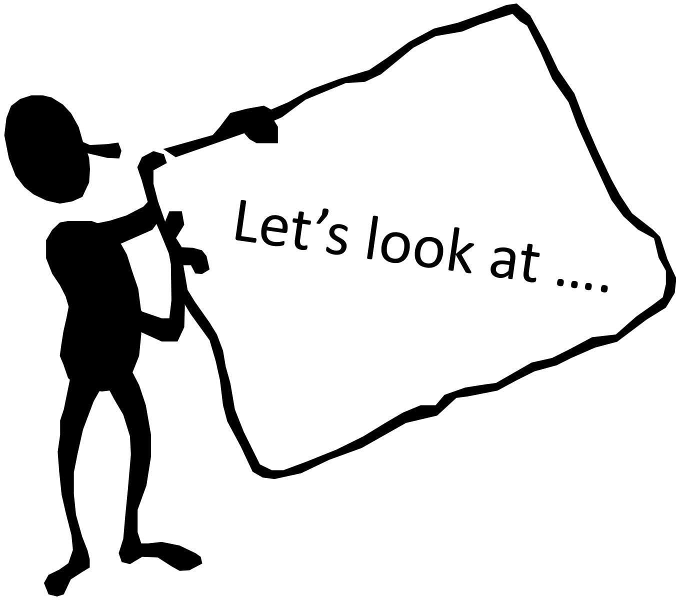
HDF5 Tutorial:

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

HDF5 Example Code:

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

HDF5 Technology Platform



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- HDF5 **file format**
  - Bit-level organization of HDF5 file

HDF5 File Format

- Defined by the *HDF5 File Format Specification.*

  http://www.hdfgroup.org/HDF5/doc/H5.format.html

- Specifies the bit-level organization of an HDF5 file on storage media.

- HDF5 library adheres to the File Format, so for the most part basic users do not need to know the guts of this information.

HDF5 Technology Platform

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Thank You!

Questions/comments?