A New XML Representation for HDF5 (First Draft)

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Abstract:

In this document, a brief overview of a new XML representation of HDF5 is given. Its purpose is to rekindle the discussion about different XML representations of HDF5, and to arrive at a solution that will serve our users well for the next decade.

Motto:

Ein neues Lied, ein besseres Lied,
O Freunde, will ich euch dichten! [1]

Heinrich Heine

1 Introduction

The idea of an XML representation of HDF5 is probably almost as old as HDF5 itself. HDF5 wraps something that is structurally rich into an opaque container and creates a demand for *introspection* – for looking under the surface. However, with the possible exception of data archival **[7]**, this curiosity doesn't extend all the way down to the byte level.

Technically, the HDF5 library provides all the facilities for introspection and the tool `h5dump` **[8]** can produce textual renderings (in Backus-Naur Form **[1]**). Despite these capabilities, the library leaves the definition of a description largely to the user and BNF is probably too esoteric of a choice when it comes to tool support and interoperability. Creating an XML representation of HDF5 opens data stored in HDF5

[1] *"A novel song, a better song, my friends, I'll have you try!"* Germany – A Winter's Tale (translation by Walter W. Arndt)

up to the formidable machinery built around W3C standards such as XML schema **[9]**, XSLT **[10]**, and XQuery **[11]**.

The genesis of the existing XML representation for HDF5 **[16]** can be summarized as follows: In the beginning there was the HDF5 BNF grammar **[1]** that was paraphrased to become an HDF5 DTD that was later "converted" and enhanced to become the current HDF5 XML schema. A conscious decision was made to adopt the "hybrid approach" already present in the BNF representation: *For HDF5 objects that may be shared (Groups, Datasets, Named Datatypes) the XML element is defined to be either a description of the object or a "pointer" to an element that describes the object. A shared object should be described in exactly one element, and all other instances should point to that element.* **[19]**

While the choices made appear to result in an XML representation that provides improved readability and a natural representation of the HDF5 structure, they also result in a de-normalized representation, a substantial increase in XML processing complexity, and make ad hoc querying rather difficult because of a priori knowledge requirements. Seen in hindsight, the "hybrid approach" was a questionable decision.

The requirements and use case analysis given in **[19]** are still valid and illuminating today. In fact, the "new" HDF5/XML schema was discussed as an alternative in **[19]**. In meeting notes from February 2000 **[21]**, it was characterized as 'elegant' and deemed to represent *the actual way that HDF5 works.* Despite this, it was ultimately rejected in favor of the hybrid solution.

We cannot ignore a decade of advances in XML technology that lets yesterday's challenges appear in a different light and that urges us to review earlier decisions. As the use of the indefinite article in the title of this document suggests, there is no canonical XML representation of HDF5.

The choices and design decisions made in the development of the new HDF5 XML schema (HDF5/XML) were driven by the aspects of HDF5 that are to be represented and by the intended consumers. With that in mind, the representation should meet these requirements:

1) Reflect the simplicity of the HDF5 data model,

   The HDF5 data model is of the utmost simplicity: a collection of HDF5 datasets, a *database*, is logically structured via a collection of HDF5 groups, a *linkbase*. Together these define a global structure that can be navigated starting from a *root*.

2) Offer a sufficient degree of fidelity to the "real thing" (HDF5).

   The BNF representation (and the current XML representation) gives a distorted view of the original in its attempt to create the fiction of object names. This obscures the simplicity of HDF5 and has unintended side-effects, which we would like to avoid.

3) Be neutral with respect to application domains.

   Not only should the representation be neutral with respect to application domains, it must not limit its own applicability by constraining potential applications in any shape or form.

4) Be durable and capable of absorbing peripheral changes to HDF5.

The durability requirement is necessary in order for the representation to be a sound investment.

Let HDF5/XML be an XML schema that satisfies these requirements. As a domain expert, you might ask of what, if any, value such a representation may be to your domain. The answer can range from “none at all” to “one less thing to think about”. In case you are contemplating the creation of an XML-based description for your domain, HDF5/XML provides a stable target that lets you “factor out” the HDF5 side of things. You are more than welcome to reuse the type definitions from HDF5/XML in your own XML schema. Alternatively, you may provide XSL or XQuery transformations that map parts of your domain XML into HDF5/XML. Finally, although this appears to be the least common scenario, you may represent your domain directly in HDF5/XML. No matter what approach you take, as HDF5 tools are extended to support HDF5/XML, you can utilize them for your domain.

This document is neither an HDF5/XML specification nor a primer. We assume that you have a working knowledge of HDF5 and XML schema, XPath, XLink **[12]**, and preferably XSLT or XQuery. This is a request for comments. If you are interested in the synergy between HDF5 and XML, we would like to hear from you. Please contact us by email or, even better, share your comments, criticisms, suggestions, and thoughts with the community on the HDF forum hdf-forum@hdfgroup.org.

2 HDF5/XML High-Level Structure

All XML information items defined by the HDF5/XML schema are identified by the namespace URI

```
http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11
```

The schema uses the following prefixes:

Prefix	Namespace
h5	http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11
xs	http://www.w3.org/2001/XMLSchema
xlink	http://www.w3.org/1999/xlink

The schema can be found at the namespace URI which happens to be a URL.

Many elements in instance documents are identified by universally unique identifiers (UUID) **[13]**:

```
<xs:simpleType name="uuidT">
  <xs:restriction base="xs:anyURI">
    <xs:pattern value="[a-f0-9]{8}-[a-f0-9]{4}-[a-f0-9]{4}-[a-f0-9]{4}-[a-f0-9]{12}"/>
  </xs:restriction>
</xs:simpleType>
```

The HDF5/XML schema defines a single global element of type `h5:domainT`. All other elements are local elements. The type `h5:domainT` is defined as follows:

```
<xs:complexType name="domainT">
    <xs:sequence>
        <xs:element name="root" type="xlink:simple" minOccurs="1" maxOccurs="1"/>

        <xs:element name="linkbase" type="h5:linkbaseT" minOccurs="1" maxOccurs="1"/>

        <xs:element name="database" type="h5:databaseT" minOccurs="1" maxOccurs="1"/>

        <xs:element name="encodingbase" type="h5:encodingbaseT"
                    minOccurs="1" maxOccurs="1"/>
    </xs:sequence>
    <xs:attribute name="id" type="h5:uuidT" use="required"/>
    <xs:attribute name="created" type="xs:dateTime" use="required"/>
    <xs:attribute name="last-modified" type="xs:dateTime" use="required"/>
</xs:complexType>
```

Conceptually, an HDF5 domain consists of a collection of HDF5 datasets (a database), a collection of HDF5 groups and links (a linkbase), and a designated HDF5 root group (the root). The linkbase tracks how HDF5 datasets and groups are organized and the root tells us “where to start”:

```
<xs:complexType name="linkbaseT">
    <xs:sequence>
        <xs:element name="group" type="h5:groupT" minOccurs="1" maxOccurs="unbounded"/>
    </xs:sequence>
</xs:complexType>

<xs:complexType name="groupT">
    <xs:sequence>
        <xs:element name="attribute" type="h5:attributeT" minOccurs="0"
                    maxOccurs="unbounded"/>
        <xs:element name="participant" type="h5:participantT" minOccurs="0"
                    maxOccurs="unbounded"/>
    </xs:sequence>
    <xs:attribute name="id" type="h5:uuidT" use="required"/>
    <xs:attribute ref="xlink:type" fixed="extended" use="required"/>
</xs:complexType>

<xs:complexType name="participantT">
    <xs:complexContent>
        <xs:extension base="xlink:locatorType">
            <xs:attribute name="corder" type="xs:long" use="optional"/>
            <xs:attribute name="cencoding" type="h5:cencodingT" use="optional"/>
        </xs:extension>
    </xs:complexContent>
</xs:complexType>
```

HDF5 groups can be viewed as collections of named single source/single destination, unidirectional links. This is a special case of XLink extended links **[12]** which we use in HDF5/XML to model HDF5 groups. What XLink refers to as ‘link participants’ is equivalent to what HDF5 refers to as ‘members of an HDF5 group’. A group member is represented by an element of type `xlink:locatorType` with XML attributes `xlink:title` for the link name and `xlink:href` for the link target.

The database is just a collection of HDF5 datasets that is modeled as follows:

```
<xs:complexType name="databaseT">
    <xs:sequence>
        <xs:element name="dataset" type="h5:datasetT" minOccurs="0"
                    maxOccurs="unbounded"/>
    </xs:sequence>
</xs:complexType>

<xs:complexType name="datasetT">
    <xs:sequence>
        <xs:element name="attribute" type="h5:attributeT" minOccurs="0"
```

```
                    maxOccurs="unbounded"/>

        <xs:group ref="h5:functionGraphG"/>

        <xs:element name="layout" type="h5:layoutT" minOccurs="1" maxOccurs="1"/>
        <xs:element name="fill-value" type="xs:string" minOccurs="0" maxOccurs="1"/>
        <xs:element name="fill-time" type="h5:fillTimeT" minOccurs="0" maxOccurs="1"/>
        <xs:element name="allocation-time" type="h5:allocationTimeT" minOccurs="0"
                    maxOccurs="1"/>
        <xs:element name="filters" type="h5:filterPipelineT" minOccurs="0"
                    maxOccurs="1"/>
        <xs:element name="storage" type="h5:storageT" minOccurs="0" maxOccurs="1"/>
    </xs:sequence>
        <xs:attribute name="id" type="h5:uuidT" use="required"/>
</xs:complexType>

<xs:group name="functionGraphG">
    <xs:sequence>
       <xs:element name="type" type="xlink:simple" minOccurs="1" maxOccurs="1"/>
       <xs:element name="shape" type="h5:dataspaceT" minOccurs="1" maxOccurs="1"/>
       <xs:element name="value" type="h5:valueT" minOccurs="0" maxOccurs="1"/>
    </xs:sequence>
</xs:group>
```

HDF5 datasets (and attributes) can be viewed as array variables. Their defining characteristics are:

1) A *shape* - a multidimensional lattice (HDF5 dataspace)

2) An array element *type* (HDF5 datatype)

3) The *value* of the array variable (an actual array of data elements)

This "trinity" is modeled with an XML `group` element called `functionGraphG`. (The value of an HDF5 dataset or attribute is the graph of an HDF5 datatype-valued function defined on an HDF5 dataspace.) The `type` child element is a simple link that refers to an HDF5 datatype encoding in the `encodingbase` which is the one-stop shop for the various datatype encodings in an HDF5 domain.

That's all. There are of course many more XML schema datatypes and local elements dealing with the details that fully describe dataset layout, filter pipelines, HDF5 attributes etc., but in terms of the high-level structure this is all there is. Remember, an HDF5 domain is nothing but a database held together by a linkbase with a designated entry point (root).

See Appendix B for a sample XML instance.

3 Examples

Throughout the discussion we will use an imaginary HDF5 file whose (multi-graph) structure is shown in Figure 1. Circles symbolize HDF5 groups (root = blue circle), rectangles symbolize HDF5 datasets, and triangles symbolize HDF5 datatypes. An HDF5/XML representation, `sample.xml`, can be found in Appendix B.

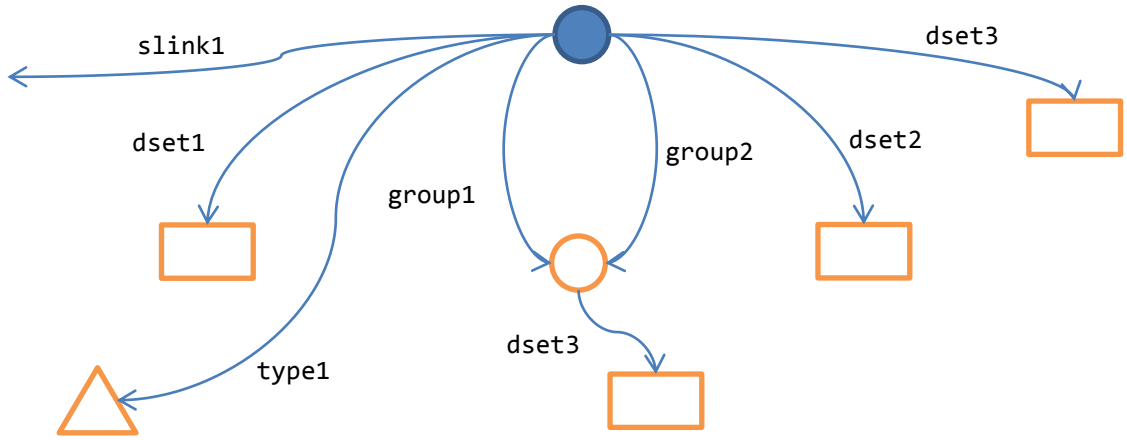

Figure 1. A schematic of the HDF5 domain from Appendix B.

XPath, XSLT, and XQuery are the main workhorses when dealing with HDF5/XML representations. HDF5/XML-style introspection doesn't require any C programming. Below are a few simple examples that may give you an idea of what's involved. Use your favorite XSLT/XQuery processor (e.g., SAXON **[14]** or Zorba **[15]**) to play along!

3.1 XPath

Example: Dataset Count

Return the total number of datasets.

```
=> count(/domain/database/dataset)
4
```

Example: Group Member Count

For each group return its member count.

```
=> for $g in /domain/linkbase/group return count($g/participant)

7
1
```

Example: IDs of Leaf Elements

Display the UUIDs of all leaf elements, i.e., all elements that represent HDF5 objects that have no members (groups without members, datasets and committed datatypes).

```
=>/domain/(linkbase|database|encodingbase)/(dataset|group[empty(./participant)]|datatype
[./@id=/domain/linkbase/group/participant/@xlink:href])/@id

30292613-8d2a-4dc4-a277-b9d59d5b0d20
0a68caca-629a-44aa-9f37-311e7ffb8417
4b43748e-817f-44c6-a9f1-16e242fd374b
42f5e3a2-5e70-4faf-9893-fd216257a0d9
```

```
a93ff089-d466-44e7-b3f0-09db34ec2ef5
```

Example: Reference Count

Return the reference counts of all linked objects.

```
=> for $n in
/domain/(linkbase|database|encodingbase)/(group|dataset|datatype[./@id=/domain/linkbase/
group/participant/@xlink:href])
return concat(string($n/@id), ' : ',
       string(count(/domain/linkbase/group/participant[@xlink:href=$n/@id])))

be8dcb22-b411-4439-85e9-ea384a685ae0 : 2
903d1d75-e617-4767-a3bf-0cb3ee509027 : 0
30292613-8d2a-4dc4-a277-b9d59d5b0d20 : 1
0a68caca-629a-44aa-9f37-311e7ffb8417 : 1
4b43748e-817f-44c6-a9f1-16e242fd374b : 1
42f5e3a2-5e70-4faf-9893-fd216257a0d9 : 1
a93ff089-d466-44e7-b3f0-09db34ec2ef5 : 1
```

Example: Attribute Search

Return the identifiers of all datasets and groups that have an attribute starting with an ‘a’.

```
=> //(dataset|group)[./attribute[matches(@name,"a*")]]/@id

903d1d75-e617-4767-a3bf-0cb3ee509027
```

3.2 XSLT

Converting XML documents from the older XML schema for HDF5 into HDF5/XML is a standard XML-to-XML translation task and can be easily accomplished using an XSLT stylesheet. Shown below is an excerpt from an XSLT stylesheet that generates the HDF5/XML `<domain>` element.

```
<xsl:stylesheet xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
    xmlns:xlink="http://www.w3.org/1999/xlink"
    xmlns:hdf5="http://hdfgroup.org/HDF5/XML/schema/HDF5-File" version="2.0">

    <xsl:output method="xml" version="1.0" encoding="UTF-8" indent="yes"/>

    <!-- datetimes need to be supplied via external parameters -->
    <xsl:param name="created"/>
    <xsl:param name="last-modified"/>

    <xsl:template match="/hdf5:HDF5-File">

        <domain xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11"
            xmlns:xlink="http://www.w3.org/1999/xlink"
            xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
            xsi:schemaLocation="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11
                                http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">

            <xsl:attribute name="id">
                <xsl:value-of select="generate-id(.)"/>
            </xsl:attribute>
            <xsl:attribute name="created">
                <xsl:value-of select="$created"/>
            </xsl:attribute>
            <xsl:attribute name="last-modified">
                <xsl:value-of select="$last-modified"/>
```

```
            </xsl:attribute>

            <root xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">
                <xsl:attribute name="href" namespace="http://www.w3.org/1999/xlink">
                    <xsl:value-of select="/hdf5:HDF5-File/hdf5:RootGroup/@OBJ-XID"/>
                </xsl:attribute>
            </root>

            <linkbase xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">
                <xsl:apply-templates select="//hdf5:Group|hdf5:RootGroup[@OBJ-XID]"/>
            </linkbase>

            <database xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">
                <xsl:apply-templates select="//hdf5:Dataset"/>
            </database>

            <encodingbase xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">
                <xsl:apply-templates
                     select="//hdf5:DataType[not(ancestor::hdf5:DataType)]"/>
            </encodingbase>

        </domain>

    </xsl:template>

    ...
</xsl:stylesheet>
```

This way, for example, the XML generated by `h5dump` can be easily converted into HDF5/XML.

3.3 XQuery

Where did the HDF5 path names go? The linkbase contains all the information that's needed to generate them. The path names can be obtained by traversing the linkbase from the HDF5 root group and concatenating link names (the `xlink:title` XML attributes of `member` elements) interspersed with slashes. This is what the XQuery function `h5xq:pathnames` does. Given an HDF5 group and an initial path it iterates over all group members and recursively descends into member groups that aren't empty. (The function is guarded against infinite recursion through a maximum recursion depth parameter.)

```
xquery version "1.0" encoding "UTF-8";

declare namespace h5xq = "http://www.hdfgroup.org/HDF5/XML/xquery";
declare namespace xlink = "http://www.w3.org/1999/xlink";

import schema namespace h5 =
  "http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11"
  at http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11";

declare function h5xq:pathnames(
  $domain       as element(h5:domain,h5:domainT),
  $group        as element(h5:group,h5:groupT),
  $path         as xs:string,
  $maxRecDepth  as xs:integer
  ) as xs:string*
{
  let $depth := $maxRecDepth - 1
  return
    if ($depth ge 0) (: maximum recursion depth ? :)
    then (
          $path,
          for $m in $group/h5:participant[@xlink:type="locator"]
          let $newPath :=  concat($path, concat('/', $m/@xlink:title))
          let $x := $domain/h5:linkbase/h5:group[@id = $m/@xlink:href]
```

```
          let $isGroupWithParts := not(empty($x)) and
                                   not(empty($x/h5:participant[@xlink:type = "locator"]))
          return
            if ($isGroupWithParts)
            then h5xq:pathnames($domain,
                   $domain/h5:linkbase/h5:group[@id = $m/@xlink:href], $newPath, $depth)
            else ($newPath)
        )
    else ($path)
};
```

The function is then invoked on the root group of `sample.xml` with initial path `'.'`.

```
declare variable $doc := validate { doc("sample.xml") };

let $domain      := $doc/h5:domain
let $rootGroup   := $domain/h5:linkbase/h5:group[@id = $domain/h5:root/@xlink:href]
let $maxRecDepth := 8

let $names := h5xq:pathnames($domain, $rootGroup, '.', $maxRecDepth)
for $n in $names
order by $n
return $n
```

The output reads as follows:

```
. ./dset1 ./dset2 ./dset3 ./group1 ./group1/dset3 ./group2 ./group2/dset3 ./slink1
./type1
```

A similar utility functions `h5xq:whois` returns the value of the `id` XML attribute, if an HDF5 path name can be resolved to an element through the linkbase.

```
xquery version "1.0" encoding "UTF-8";

declare namespace h5xq = "http://www.hdfgroup.org/HDF5/XML/xquery";
declare namespace xlink = "http://www.w3.org/1999/xlink";

import schema namespace h5 =
  "http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11"
  at http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11";

declare function h5xq:whois(
  $domain  as element(h5:domain,h5:domainT),
  $group   as element(h5:group,h5:groupT),
  $relpath as xs:string
  ) as xs:string*
{
    let $names := tokenize($relpath, "/")
    return
      if (count($names) > 1)
      then
        let $newRelPath := string-join(subsequence($names, 2, count($names)), "/")
        let $id := $group/h5:participant[@xlink:title=$names[1]]/@xlink:href
        let $newGroup := $domain/h5:linkbase/h5:group[@id=$id]
        return if ($newGroup)
               then h5xq:whois($domain, $newGroup, $newRelPath)
               else ()
    else
      $group/h5:participant[@xlink:title=$names[1]]/@xlink:href
};
```

The function is then invoked on the root group of `sample.xml` with a sequence of path names.

```
declare variable $doc  := validate { doc("../sample.xml") };

let $domain := $doc/h5:domain
let $root   := $domain/h5:linkbase/h5:group[@id=$domain/h5:root/@xlink:href]
```

```
for $name in ("group1", "group2", "dset3", "dset4", "group1/dset3")
return h5xq:whois($domain, $root, $name)
```

The output reads:

```
be8dcb22-b411-4439-85e9-ea384a685ae0 be8dcb22-b411-4439-85e9-ea384a685ae0 4b43748e-817f-
44c6-a9f1-16e242fd374b 42f5e3a2-5e70-4faf-9893-fd216257a0d9
```

(There are 5 path names but only 4 UUIDs returned since the path `dset4` cannot be resolved.)

4 Comments

Most HDF5/XML use cases probably involve (1) going from HDF5 to XML or (2) going from XML to HDF5, or (3) going both directions. Anyone who intends to use both representations faces a fundamental coherence problem unless precautions are taken against independent modification. Maintaining some form of checksum or fingerprint might be sufficient to mitigate most of the risk.

4.1 From HDF5 to XML

The `h5dump` tool already supports creating old-style XML representations **[16]** and will support HDF5/XML at some point in the future. Initially, we'll provide an XSLT stylesheet that can be used to transform the old-style XML output from `h5dump` into HDF5/XML. Of course, users are free to create HDF5/XML instances that are only partial representations (e.g., drop dataset values) of the underlying HDF5 file. This might be sufficient, for example, for certain structural validation tasks, further XML processing, or application configuration. Through mechanisms like XLink and XPointer, HDF5/XML can also be used to link HDF5 to external, non-HDF5 resources including ontologies.

4.2 From XML to HDF5

Under certain circumstances it might be desirable to create HDF5 files from HDF5/XML instances or blueprints. Loading an HDF5/XML file into HDFView **[17]** should largely look and feel the same as loading and manipulating an actual HDF5 file. Determined users are free to load HDF5/XML into their favorite XML editor and manipulate it directly. At some point in the future, the magic "instantiate" button or a command line tool like `h5gen` will create an HDF5 file according to spec.

In most practical applications, there will probably be an intermediate step in the form of a domain XML to HDF5/XML transformation. HDF5/XML is good at representing HDF5 accurately, but it is pretty oblivious about, and hence unsuited for, modeling domain specific concepts. A domain expert should create an XML representation that is convenient for her users. She should also create an XML transformation (XSLT or XQuery) that converts domain XML into HDF5/XML. (If necessary, she must also provide the inverse transformation.)

As an example, consider the MXADataModel **[18]**,**[20]**. In Appendix C, an MXA domain XML sample is shown. It should give a domain expert a fair understanding of the nature of the underlying experimental data, but, taken at face value, there's nothing about the actual MXA/HDF5 layout in this representation (and there shouldn't be!). The heavy lifting is done by HDF5 reader and writer objects that hardcode the HDF5 details. HDF5/XML is intended to reduce, if not eliminate, this kind of hardcoding. XML transformations (XSLT, XQuery) are much easier to maintain and less brittle than the equivalent Python, C/C++, or JAVA code for the HDF5 readers and writers.

A. References

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B. An HDF5/XML Sample

```
<?xml version="1.0" encoding="UTF-8"?>
<domain id="e203fee7-89b4-4216-894d-7aef0e3a199d" created="1985-04-12T23:20:50.52"
    last-modified="1996-12-19T16:39:57" xmlns:xlink="http://www.w3.org/1999/xlink"
    xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11
                        http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">

    <root xlink:href="903d1d75-e617-4767-a3bf-0cb3ee509027"/>

    <linkbase>
        <group id="be8dcb22-b411-4439-85e9-ea384a685ae0" xlink:type="extended">
            <participant xlink:title="dset3" xlink:type="locator"
                         xlink:href="42f5e3a2-5e70-4faf-9893-fd216257a0d9" />
        </group>
        <group id="903d1d75-e617-4767-a3bf-0cb3ee509027" xlink:type="extended">
            <attribute name="attr1">
                <type xlink:href="74f1d847-27cb-414c-ac5f-ed72a88fd1c9"/>
                <shape>
                    <scalar/>
                </shape>
                <value>
                    string attribute
                </value>
            </attribute>
            <participant xlink:title="dset1" xlink:type="locator"
                         xlink:href="30292613-8d2a-4dc4-a277-b9d59d5b0d20" />
            <participant xlink:title="group1" xlink:type="locator"
                         xlink:href="be8dcb22-b411-4439-85e9-ea384a685ae0" />
            <participant xlink:title="group2" xlink:type="locator"
                         xlink:href="be8dcb22-b411-4439-85e9-ea384a685ae0" />
            <participant xlink:title="dset2" xlink:type="locator"
                         xlink:href="0a68caca-629a-44aa-9f37-311e7ffb8417" />
            <participant xlink:title="dset3" xlink:type="locator"
                         xlink:href="4b43748e-817f-44c6-a9f1-16e242fd374b"/>
            <participant xlink:title="slink1" xlink:type="locator"
                         xlink:href="somevalue"/>
            <participant xlink:title="type1" xlink:type="locator"
```

```
                        xlink:href="a93ff089-d466-44e7-b3f0-09db34ec2ef5"/>
    </group>
</linkbase>

<database>
    <dataset id="30292613-8d2a-4dc4-a277-b9d59d5b0d20">
        <type xlink:href="774a0564-a47e-4e69-aa86-051682aef065"/>
        <shape>
            <simple cur="10 10" max="10 10"/>
        </shape>
        <value media-type="application/json"
               serializer="http://www.hdfgroup.org/HDF5/serialization/JSON">
          [ 0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9,
            0, 1, 2, 3, 4, 5, 6, 7, 8, 9 ]
        </value>
        <layout>
            <contiguous/>
        </layout>
    </dataset>
    <dataset id="0a68caca-629a-44aa-9f37-311e7ffb8417">
        <type xlink:href="1b7f6991-17a4-478e-9e05-9c38f68a0288"/>
        <shape>
            <simple cur="5" max="5"/>
        </shape>
        <value media-type="application/json"
               serializer="http://www.hdfgroup.org/HDF5/serialization/JSON">
            [[1,0.1,0.01], [2,0.2,0.02], [3,0.3,0.03], [4,0.4,0.04], [5,0.5,0.05]]
        </value>
        <layout>
            <contiguous/>
        </layout>
    </dataset>
    <dataset id="4b43748e-817f-44c6-a9f1-16e242fd374b">
        <type xlink:href="709f3060-fa3a-4e38-846b-b6bd5f85bc87"/>
        <shape>
            <simple cur="4" max="4"/>
        </shape>
        <value media-type="application/json"
               serializer="http://www.hdfgroup.org/HDF5/serialization/JSON">
            [[0], [10, 11], [20, 21, 22], [30, 31, 32, 33]]
        </value>
        <layout>
            <contiguous/>
        </layout>
    </dataset>
    <dataset id="42f5e3a2-5e70-4faf-9893-fd216257a0d9">
        <type xlink:title="/type1"
              xlink:href="a93ff089-d466-44e7-b3f0-09db34ec2ef5"/>
        <shape>
            <simple cur="5" max="5"/>
        </shape>
        <value media-type="application/json"
               serializer="http://www.hdfgroup.org/HDF5/serialization/JSON">
            [
              [
                [ 0, 1, 2, 3 ],
                [ 0.1, 0.1, 0.1, 0.1, 0.1, 0.1,
                  0.2, 0.2, 0.2, 0.2, 0.2, 0.2,
                  0.3, 0.3, 0.3, 0.3, 0.3, 0.3,
                  0.4, 0.4, 0.4, 0.4, 0.4, 0.4,
                  0.5, 0.5, 0.5, 0.5, 0.5, 0.5 ]
              ],
              [
```

```
                    [ 0, 1, 2, 3 ],
                    [ 0.1, 0.1, 0.1, 0.1, 0.1, 0.1,
                      0.2, 0.2, 0.2, 0.2, 0.2, 0.2,
                      0.3, 0.3, 0.3, 0.3, 0.3, 0.3,
                      0.4, 0.4, 0.4, 0.4, 0.4, 0.4,
                      0.5, 0.5, 0.5, 0.5, 0.5, 0.5 ]
                  ],
                  [
                    [ 0, 1, 2, 3 ],
                    [ 0.1, 0.1, 0.1, 0.1, 0.1, 0.1,
                      0.2, 0.2, 0.2, 0.2, 0.2, 0.2,
                      0.3, 0.3, 0.3, 0.3, 0.3, 0.3,
                      0.4, 0.4, 0.4, 0.4, 0.4, 0.4,
                      0.5, 0.5, 0.5, 0.5, 0.5, 0.5 ]
                  ],
                  [
                    [ 0, 1, 2, 3 ],
                    [ 0.1, 0.1, 0.1, 0.1, 0.1, 0.1,
                      0.2, 0.2, 0.2, 0.2, 0.2, 0.2,
                      0.3, 0.3, 0.3, 0.3, 0.3, 0.3,
                      0.4, 0.4, 0.4, 0.4, 0.4, 0.4,
                      0.5, 0.5, 0.5, 0.5, 0.5, 0.5 ]
                  ],
                  [
                    [ 0, 1, 2, 3 ],
                    [ 0.1, 0.1, 0.1, 0.1, 0.1, 0.1,
                      0.2, 0.2, 0.2, 0.2, 0.2, 0.2,
                      0.3, 0.3, 0.3, 0.3, 0.3, 0.3,
                      0.4, 0.4, 0.4, 0.4, 0.4, 0.4,
                      0.5, 0.5, 0.5, 0.5, 0.5, 0.5 ]
                  ]
                ]
            </value>
            <layout>
                <contiguous/>
            </layout>
        </dataset>
    </database>

    <encodingbase>
        <datatype id="a93ff089-d466-44e7-b3f0-09db34ec2ef5">
            <compound>
                <member name="a">
                    <array dims="4">
                        <predefined>H5T_STD_I32BE</predefined>
                    </array>
                </member>
                <member name="b">
                    <array dims="5 6">
                        <predefined>H5T_IEEE_F32BE</predefined>
                    </array>
                </member>
            </compound>
        </datatype>
        <datatype id="774a0564-a47e-4e69-aa86-051682aef065">
            <predefined>H5T_STD_I32BE</predefined>
        </datatype>
        <datatype id="74f1d847-27cb-414c-ac5f-ed72a88fd1c9">
            <stringN length="17" strpad="H5T_STR_NULLTERM" cset="H5T_CSET_ASCII"/>
        </datatype>
        <datatype id="1b7f6991-17a4-478e-9e05-9c38f68a0288">
            <compound>
                <member name="a">
                    <predefined>H5T_STD_I32BE</predefined>
                </member>
                <member name="b">
                    <predefined>H5T_IEEE_F32BE</predefined>
                </member>
                <member name="c">
                    <predefined>H5T_IEEE_F64BE</predefined>
                </member>
```

```
            </compound>
        </datatype>
        <datatype id="709f3060-fa3a-4e38-846b-b6bd5f85bc87">
            <vlen>
                <predefined>H5T_STD_I32LE</predefined>
            </vlen>
        </datatype>
    </encodingbase>

</domain>
```

C. An MXA Sample File

The XML sample below is can be found at http://mxa.web.cmu.edu/XML_Usage.html.

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE File_Root SYSTEM "http://mxa.web.cmu.edu/mxa_0.4.dtd">
<File Root>
    <Data_Model Model_Type="MXA" Model_Version="0.4">
        <Data Root Name="DataModelTest/Data/Root/Is/Here/" />
        <Data_Dimensions>
            <Dimension Alt_Name="Vol Frac"
                Count="15" End_Value="50" Increment="2" Index="0"
                Name="Volume Fraction" Start_Value="20" Uniform="1" />
            <Dimension Alt Name="Rnd Seed" Count="10"
                End_Value="5000" Increment="500" Index="1"
                Name="Random Seed" Start_Value="1000" Uniform="1" />
            <Dimension Alt_Name="TS" Count="100" End_Value="99"
                Increment="1" Index="2"
                Name="Timestep" Start_Value="0" Uniform="1" />
            <Dimension Alt Name="slice" Count="256" End Value="255"
                Increment="1" Index="3"
                Name="Slice" Start_Value="0" Uniform="1" />
        </Data_Dimensions>
        <Data_Records>
            <Signal Alt_Name="AltComp" Name="Composition" />
            <Signal Group Alt Name="OP" Name="Order Parameters">
                <Signal Alt_Name="Alt Eta1" Name="Eta1" />
                <Signal Alt_Name="Alt Eta2" Name="Eta2" />
                <Signal Alt_Name="Alt Eta3" Name="Eta3" />
            </Signal_Group>
            <Signal_Group Alt_Name="OP 2" Name="Order Parameters 2">
                <Signal Alt Name="Alt Eta1" Name="Eta1" />
                <Signal Alt_Name="Alt Eta2" Name="Eta2" />
                <Signal Alt Name="Alt Eta3" Name="Eta3" />
            </Signal_Group>
        </Data_Records>
    </Data Model>
    <Meta_Data>
        <Required MD Creator="Mike Jackson"
            Date="2006:12:24 15:34.51"
            Description="Just a test case showing how to organize data"
            Distribution_Rights="Unlimited"
            Name="Testing Example Data Model"
            Original_Source_File="Original Data Files"
            Pedigree="Original"
            Release_Number="AFRL/WS07-0476" />
        <UserDefined_MD>
            <UserMetaData key="Vector Int8" dims="5 2" type="H5T_NATIVE_INT8">
                0 1 3 4 6
                7 9 10 12 13
            </UserMetaData>
        </UserDefined_MD>
    </Meta_Data>
</File_Root>
```

There's not much about HDF5 in MXA/XML (and there shouldn't be!). Contrast that with an HDF5/XML representation (outline) of the underlying HDF5 file.

```
<?xml version="1.0" encoding="UTF-8"?>
<domain id="63aa9ba0-ae7a-464f-a9e0-494644de5e34" created="2006-12-24T15:34:51"
    last-modified="2006-12-24T15:34:51" xmlns:xlink="http://www.w3.org/1999/xlink"
    xmlns="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11
                        http://www.hdfgroup.org/HDF5/XML/schema/2011/11/11">

    <root xlink:href="ae6c5a7d-d595-47d7-ad24-f40fe9f716d3"/>

    <linkbase>
        <group id="ae6c5a7d-d595-47d7-ad24-f40fe9f716d3" xlink:type="extended">
            <!-- HDF5 root group participants -->
            <participant xlink:title="DataModel" xlink:type="locator"
                xlink:href="953dcb90-5b7b-4b97-a261-8913293a32c7"/>
            <participant xlink:title="Meta Data" xlink:type="locator"
                xlink:href="f262ba12-ab59-4fcc-8d9c-8e78b82b4dcc"/>
            <participant xlink:title="RoboMet Data" xlink:type="locator"
                xlink:href="ae5f8dd2-cb8a-4550-a9f7-2a6b95054b95"/>
            <participant xlink:title="SupportFiles" xlink:type="locator"
                xlink:href="162d687d-0fd2-43f4-af68-10560262a852"/>
        </group>
        <group id="953dcb90-5b7b-4b97-a261-8913293a32c7" xlink:type="extended">
            <!-- Data Model attributes  and participants -->
            <attribute name="Model Type">
                <type xlink:href="ed5c780c-0150-4648-86c3-6a93865a9edd"/>
                <shape>
                    <scalar/>
                </shape>
                <value>MXA</value>
            </attribute>
            <attribute name="Model Version">
                <type xlink:href="50e3046c-df0a-4e54-9184-cbe3dcb31401"/>
                <shape><scalar/></shape>
                <value>0.4</value>
            </attribute>
            <participant xlink:title="Data Dimensions" xlink:type="locator"
                xlink:href="12f5325a-17bf-426f-9c9c-d435f68a52dd"/>
            <participant xlink:title="Data Records" xlink:type="locator"
                xlink:href="cfa1ac99-342f-49ed-a5a1-ebac1a796c4f"/>
            <participant xlink:title="Data Root" xlink:type="locator"
                xlink:href="509eae8d-fd08-4047-9959-e957526a1f6a"/>
        </group>
        <group id="f262ba12-ab59-4fcc-8d9c-8e78b82b4dcc" xlink:type="extended">
            <!-- Meta Data participants -->
            <participant xlink:title="Required" xlink:type="locator"
                xlink:href="a28c0255-ae6d-4588-abea-cf4dca95e151"/>
            <participant xlink:title="User Defined" xlink:type="locator"
                xlink:href="5c6eb012-1f32-480f-b1d8-f7b57e63ae66"/>
        </group>
        <group id="ae5f8dd2-cb8a-4550-a9f7-2a6b95054b95" xlink:type="extended">
            <!-- RoboMet Data participants omitted -->
        </group>
        <group id="162d687d-0fd2-43f4-af68-10560262a852" xlink:type="extended">
            <!-- SupportFile participants -->
            <participant xlink:title="0" xlink:type="locator"
                xlink:href="db7f3af3-5039-40df-ba89-0c430bf57888"/>
        </group>
        <group id="12f5325a-17bf-426f-9c9c-d435f68a52dd" xlink:type="extended">
            <!-- Data Dimensions participants -->
            <participant xlink:title="0" xlink:type="locator"
                xlink:href="59f21d1a-bd9b-4513-ac45-e435d21881a7"/>
            <participant xlink:title="1" xlink:type="locator"
                xlink:href="1a6db2d8-7c77-4590-81ea-5c6786a85f58"/>
        </group>
        <group id="cfa1ac99-342f-49ed-a5a1-ebac1a796c4f" xlink:type="extended">
```

```
            <!-- Data Records participants -->
            <participant xlink:title="0" xlink:type="locator"
                xlink:href="2120637c-34ce-4668-a2bb-46f86bfad397"/>
        </group>
    </linkbase>

    <database>
        <dataset id="509eae8d-fd08-4047-9959-e957526a1f6a">
            <type xlink:href="6fb36117-f97f-4b0f-87bc-83dac598ec9e"/>
            <shape>
                <simple cur="1" max="1"/>
            </shape>
            <value>RoboMet Data/</value>
            <layout>
                <contiguous/>
            </layout>
            <allocation-time>H5D_ALLOC_TIME_LATE</allocation-time>
        </dataset>
        <dataset id="a28c0255-ae6d-4588-abea-cf4dca95e151">
            <attribute name="Creator">
                <type xlink:href="c483a4c8-fb53-4795-8ff1-86cc6376ea0a"/>
                <shape><scalar/></shape>
                <value>RoboMet Operator</value>
            </attribute>
            <attribute name="Date">
                <type xlink:href="dc7f0ee9-f8a5-4d7e-9614-7d59c9d163fd"/>
                <shape><scalar/></shape>
                <value>2006:12:24 15:34.51</value>
            </attribute>
            <attribute name="Description">
                <type xlink:href="cd59397c-107d-43cf-af6c-d0d38095b820"/>
                <shape><scalar/></shape>
                <value>A beta-processed titanium alloy, courtesy of Dr. H. Fraser at
                    The Ohio State University. 100 Sections collected total.
                    Every 5th section, starting with section 0.
                    (0,5,10,15....95)</value>
            </attribute>
            <attribute name="Distribution Rights">
                <type xlink:href="e4163515-0f4c-440b-91a9-ab17b477c661"/>
                <shape><scalar/></shape>
                <value>Limited</value>
            </attribute>
            <attribute name="Name">
                <type xlink:href="2c4c01c3-2165-41cf-82a2-5ae43fc3539c"/>
                <shape><scalar/></shape>
                <value>mosaic test3 0816_10</value>
            </attribute>
            <attribute name="Original Source File">
                <type xlink:href="dc7f0ee9-f8a5-4d7e-9614-7d59c9d163fd"/>
                <shape><scalar/></shape>
                <value>Original Data Files</value>
            </attribute>
            <attribute name="Pedigree">
                <type xlink:href="dd913c15-6bbb-4369-8232-1bd5441ad985"/>
                <shape><scalar/></shape>
                <value>Original</value>
            </attribute>
            <attribute name="Release_Number">
                <type xlink:href="068d1607-36c0-4cc4-b421-f3a167162679"/>
                <shape><scalar/></shape>
                <value>Not Applicable</value>
            </attribute>
            <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
            <shape>
                <simple cur="1" max="1"/>
            </shape>
            <value>[0]</value>
            <layout>
                <contiguous/>
            </layout>
        </dataset>
```

```
        <dataset id="5c6eb012-1f32-480f-b1d8-f7b57e63ae66">
            <attribute name="Mosaic Style">
                <type xlink:href="e4163515-0f4c-440b-91a9-ab17b477c661"/>
                <shape><scalar/></shape>
                <value>Meander</value>
            </attribute>
            <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
            <shape>
                <simple cur="1" max="1"/>
            </shape>
            <value>[0]</value>
            <layout>
                <contiguous/>
            </layout>
        </dataset>
        <dataset id="db7f3af3-5039-40df-ba89-0c430bf57888">
            <attribute name="FileSystem_Path">
                <type xlink:href="cc644faa-9214-4ff1-9194-ee053b40b252"/>
                <shape><scalar/></shape>
                <value>Robomet_100.pdf</value>
            </attribute>
            <attribute name="File_Type">
                <type xlink:href="39708e3c-5aeb-4bfd-95de-85cc42e69147"/>
                <shape><scalar/></shape>
                <value>Binary</value>
            </attribute>
            <attribute name="Filename">
                <type xlink:href="cc644faa-9214-4ff1-9194-ee053b40b252"/>
                <shape><scalar/></shape>
                <value>Robomet_100.pdf</value>
            </attribute>
            <type xlink:href="0f377d84-b85d-4717-b859-b173919af3c6"/>
            <shape>
                <simple cur="1028528" max="1028528"/>
            </shape>
            <!-- value omitted -->
            <layout>
                <contiguous/>
            </layout>
        </dataset>
        <dataset id="59f21d1a-bd9b-4513-ac45-e435d21881a7">
            <attribute name="Alt Name">
                <type xlink:href="e11d7185-9b72-4c1a-811c-d65a65013a7c"/>
                <shape><scalar/></shape>
                <value>Slice</value>
            </attribute>
            <attribute name="Count">
                <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
                <shape><scalar/></shape>
                <value>20</value>
            </attribute>
            <attribute name="End_Value">
                <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
                <shape><scalar/></shape>
                <value>95</value>
            </attribute>
            <attribute name="Increment">
                <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
                <shape><scalar/></shape>
                <value>95</value>
            </attribute>
            <attribute name="Name">
                <type xlink:href="e11d7185-9b72-4c1a-811c-d65a65013a7c"/>
                <shape><scalar/></shape>
                <value>Slice</value>
            </attribute>
            <attribute name="Start Value">
                <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
                <shape><scalar/></shape>
                <value>0</value>
            </attribute>
```

```
            <attribute name="Uniform">
                <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
                <shape><scalar/></shape>
                <value>1</value>
            </attribute>
            <type xlink:href="038e6825-47f3-451a-a7c7-64d5d23d3b0e"/>
            <shape>
                <simple cur="1" max="1"/>
            </shape>
            <value>[0]</value>
            <layout>
                <contiguous/>
            </layout>
        </dataset>
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                <value>Tile Index</value>
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                <shape><scalar/></shape>
                <value>Zeiss Optical Image</value>
            </attribute>
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