S-100 – Part 10c

HDF5 Data Model and File Format

Contents

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10c-1 Scope

The Hierachical Data Format 5 (HDF5) HDF has been developed by the HDFgroup as a file format for the transfer of data that is used for imagery and gridded data. This Part is a profile of HDF5 and specifies an interchange format to facilitate the moving of files containing data records between computer systems. It defines a specific structure which can be used to transmit files containing data types and data structures conforming to the S-100 General Feature Model.

This Part specifies constraints and conventions that collectively specify the rules for S-100 HDF5 data formats. HDF5 features not required by S-100 HDF5 data are excluded. The scope of this Part is limited to the data format and does not include the application schema, nor does it include guidelines for how to develop product specifications or naming rules for features and attributes.

10c-2 Introduction

HDF5 uses an open source format. It allows users such as the IHO to collaborate with The HDF Group regarding functionality requirements and permits users' experience and knowledge to be incorporated into the HDF product when appropriate.

HDF5 is particularly good at dealing with data where complexity and scalability are important. Data of virtually any type or size can be stored in HDF5, including complex data structures and data types. HDF5 is portable, running on most operating systems and machines. HDF5 is scalable - it works well in high end computing environments, and can accommodate data objects of almost any size or multiplicity. It also can store large amounts of data efficiently - it has built-in compression. HDF5 is widely used in government, academia, and industry.

10c-3 Conformance

The S-100 HDF5 data format conforms to release 1.8.8 of HDF5.

10c-4 References

10c-4.1 Normative references

The HDF Group, November 2011*, HDF5 User's Guide Release 1.8.8*

The HDF Group, November 2011, *HDF5 Reference Manual 1.8.8*

ISO 8601:2004, *Data elements and interchange formats – Information interchange – Representation of dates and times*

ISO 19123, *Geographic information — Schema for coverage geometry and functions*

10c-4.2 Informative references

Gilbert, W., *A Cube-filling Hilbert Curve,* Mathematical Intelligencer 6(3), p.78, 1984

Goodchild, M. F. and Grandfield, A. W., *Optimizing Raster Storage: An Examination of Four Alternatives,* Proceedings Auto-Carto 6(1), pp. 400-407), Ottawa, 1983

Kidner, D.B., Higher-order interpolation of regular grid digital elevation models, International Journal of Remote Sensing, 24(14), July 2003, pp. 2981-2987. DOI: 10.1080/0143116031000086835

Kidner, D., Mark Dorey, M., & Smith, D., *What's the point? Interpolation and extrapolation with a regular grid DEM*, Proceedings of the 4th International Conference on GeoComputation, Fredericksburg, Virginia. URL: http://www.geocomputation.org/1999/082/gc_082.htm (retrieved 26 April 2018)

Laurini, R. and Thompson, D., *Fundamentals of Spatial Information Systems*, Academic Press, 1992

10c-5 HDF5 Specification

HDF5 implements a model for managing and storing data. The model includes an abstract data model and an abstract storage model (the data format), and libraries to implement the abstract model and to map the storage model to different storage mechanisms. The HDF5 library provides a programming interface to a concrete implementation of the abstract models. The library also implements a model of data transfer, i.e., efficient movement of data from one stored representation to another stored representation. The figure below illustrates the relationships between the models and implementations.

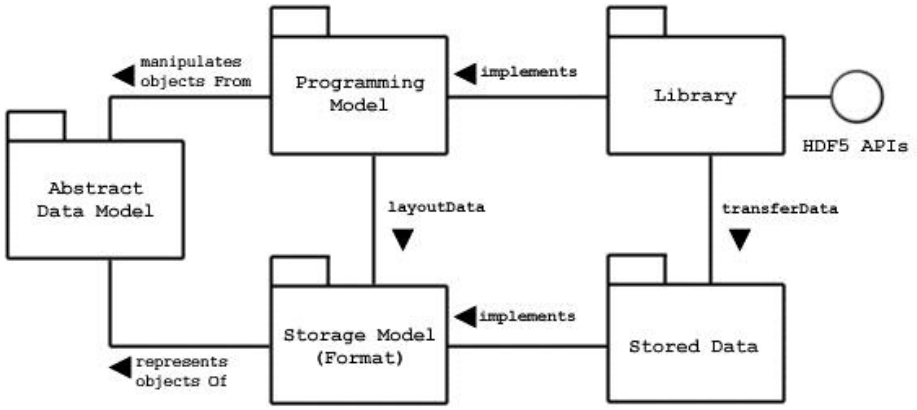

Figure 10c-1 - Abstract Data Model

The *Abstract Data Model* is a conceptual model of data, data types, and data organization. The abstract data model is independent of storage medium or programming environment. The *Storage Model* is a standard representation for the objects of the abstract data model. The *HDF5 File Format Specification* defines the storage model.

The *Programming Model* is a model of the computing environment and includes platforms from small single systems to large multiprocessors and clusters. The programming model manipulates (instantiates, populates, and retrieves) objects from the abstract data model.

The *Library* is the concrete implementation of the programming model. The Library exports the HDF5 APIs as its interface. In addition to implementing the objects of the abstract data model, the Library manages data transfers from one stored form to another. Data transfer examples include reading from disk to memory and writing from memory to disk.

Stored Data is the concrete implementation of the storage model. The storage model is mapped to several storage mechanisms including single disk files, multiple files (family of files), and memory representations.

The HDF5 Library is a C module that implements the programming model and abstract data model. The HDF5 Library calls the operating system or other storage management software (e.g., the MPI/IO Library) to store and retrieve persistent data. The HDF5 Library may also link to other software such as filters for compression. The HDF5 Library is linked to an application program which may be written in C, C++, Fortran, or Java. The application program implements problem specific algorithms and data structures and calls the HDF5 Library to store and retrieve data.

The HDF5 Library implements the objects of the HDF5 abstract data model. Some of these objects include groups, datasets, and attributes. An S-100 product specification maps the S-100 data structures to a hierarchy of HDF5 objects. Each S-100~~m~~ product specification will create a mapping best suited to its purposes.

The objects of the HDF5 abstract data model are mapped to the objects of the HDF5 storage model, and stored in a storage medium. The stored objects include header blocks, free lists, data blocks, B-trees, and other objects. Each group or dataset is stored as one or more header and data blocks.

10c-5.1 Abstract Data Model

The abstract data model (ADM) defines concepts for defining and describing complex data stored in files. The ADM is a very general model which is designed to conceptually cover many specific models. Many different kinds of data can be mapped to objects of the ADM, and therefore stored and retrieved using HDF5. The ADM is not, however, a model of any particular problem or application domain. Users need to map their data to the concepts of the ADM.

The key concepts include:

- *File* - a contiguous string of bytes in a computer store (memory, disk, etc), and the bytes represent zero or more objects of the model;
- *Group* - a collection of objects (including groups);
- *Dataset* - a multidimensional array of data elements with attributes and other metadata;
- *Dataspace* - a description of the dimensions of a multidimensional array;
- *Datatype* - a description of a specific class of data element including its storage layout as a pattern of bits;
- *Attribute* - a named data value associated with a group, dataset, or named datatype;
- *Property List* - a collection of parameters (some permanent and some transient) controlling options in the library;
- *Link* - the way objects are connected.

These key concepts are described in more detail below.

10c-5.1.1 File

Abstractly, an HDF5 file is a container for an organized collection of objects. The objects are groups, datasets, and other objects as defined below. The objects are organized as a rooted, directed graph. Every HDF5 file has at least one object, the root group. See the figure below. All objects are members of the root group or descendents of the root group.

HDF5 objects have a unique identity *within a single HDF5 file* and can be accessed only by its names within the hierarchy of the file. HDF5 objects in different files do not necessarily have unique identities, and it is not possible to access a permanent HDF5 object except through a file.

When the file is created, the *file creation properties* specify settings for the file. The file creation properties include version information and parameters of global data structures. When the file is opened, the *file access properties* specify settings for the current access to the file. File access properties include parameters for storage drivers and parameters for caching and garbage collection. The file creation properties are set permanently for the life of the file, and the file access properties can be changed by closing and reopening the file.

An HDF5 file can be “mounted” as part of another HDF5 file. This is analogous to Unix file system mounts. The root of the mounted file is attached to a group in the mounting file, and all the contents can be accessed as if the mounted file were part of the mounting file.

10c-5.1.2 Group

An HDF5 group is analogous to a file system directory. Abstractly, a group contains zero or more objects, and every object must be a member of at least one group. The root group is a special case; it may not be a member of any group.

Group membership is actually implemented via link objects. See the figure below. A link object is owned by a group and points to a named object. Each link has a name, and each link points to exactly one object. Each named object has at least one and possibly many links to it.

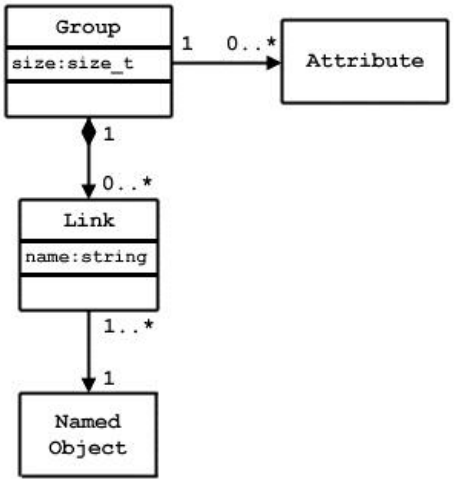

Figure 10c-2 - Group membership via link objects

There are three classes of named objects: group, dataset, and named datatype. See the figure below. Each of these objects is the member of at least one group, and this means there is at least one link to it.

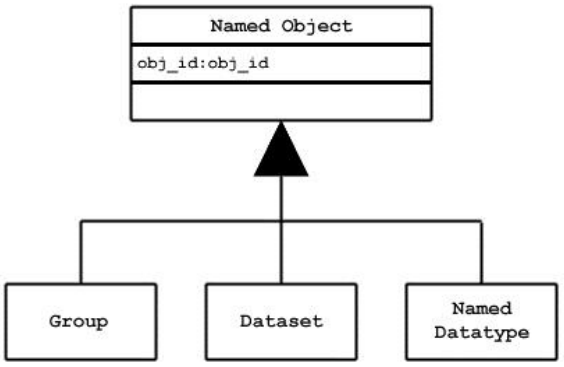

Figure 10c-3 - Classes of named objects

10c-5.1.3 Dataset

An HDF5 dataset is a multidimensional array of data elements. See the figure below. The shape of the array (number of dimensions, size of each dimension) is described by the dataspace object.

A data element is a single unit of data which may be a number, a character, an array of numbers or characters, or a record of heterogeneous data elements. A data element is a set of bits. The layout of the bits is described by the datatype.

The dataspace and datatype are set when the dataset is created, and they cannot be changed for the life of the dataset. The dataset creation properties are set when the dataset is created. The dataset creation properties include the fill value and storage properties such as chunking and compression. These properties cannot be changed after the dataset is created.

The dataset object manages the storage and access to the data. While the data is conceptually a contiguous rectangular array, it is physically stored and transferred in different ways depending on the

storage properties and the storage mechanism used. The actual storage may be a set of compressed chunks, and the access may be through different storage mechanisms and caches. The dataset maps between the conceptual array of elements and the actual stored data.

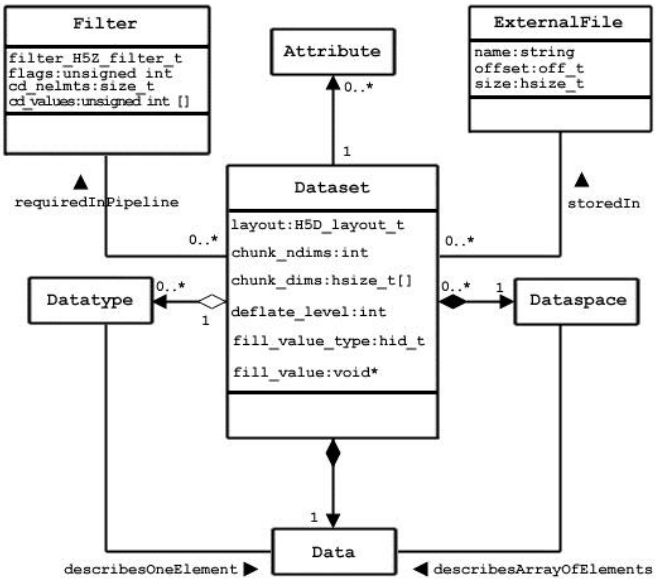

Figure 10c-4 - The dataset

The HDF5 concept of 'dataset' means an array, while the S-100 concept is defined as "an identifiable collection of data" (S-100 Annex A – Terms and Definitions) which is generally interpreted to mean a collection of instances of feature and/or information type.

This Part frequently uses the terms "data file" to mean a dataset in the S-100 sense and "HDF5 dataset" to mean a dataset in the HDF sense. Where these terms are not used, the sense should be apparent from the context.

10c-5.1.4 Dataspace

The HDF5 dataspace describes the layout of the elements of a multidimensional array. Conceptually, the array is a hyper-rectangle with one to 32 dimensions. HDF5 dataspaces can be extendable. Therefore, each dimension has a current size and a maximum size, and the maximum may be unlimited. The dataspace describes this hyper-rectangle: it is a list of dimensions with the current and maximum (or unlimited) sizes.

10c-5.1.5 DataType

The HDF5 datatype object describes the layout of a single data element. A data element is a single element of the array; it may be a single number, a character, an array of numbers or carriers, or other data. The datatype object describes the storage layout of this data.

Data types are categorized into 11 classes of datatype. Each class is interpreted according to a set of rules and has a specific set of properties to describe its storage. For instance, floating point numbers have exponent position and sizes which are interpreted according to appropriate standards for number representation. Thus, the datatype class tells what the element means, and the datatype describes how it is stored.

The figure below shows the classification of datatypes. Atomic datatypes are indivisible. Each may be a single object; a number, a string, or some other objects. Composite datatypes are composed of multiple

elements of atomic datatypes. In addition to the standard types, users can define additional datatypes such as a 24-bit integer or a 16-bit float.

A dataset or attribute has a single datatype object associated with it. See the Dataset Figure above. The datatype object may be used in the definition of several objects, but by default, a copy of the datatype object will be private to the dataset.

Optionally, a datatype object can be stored in the HDF5 file. The datatype is linked into a group, and therefore given a name. A *named datatype* can be opened and used in any way that a datatype object can be used.

Not all the HDF5 datatypes have exact equivalents in the S-100 basic and derived datatypes defined in Part 1 clause 1-4.5.2 (Table 1-2). The correspondences between HDF5 and S-100 datatypes are given in Table 10c-2 later in this Part.

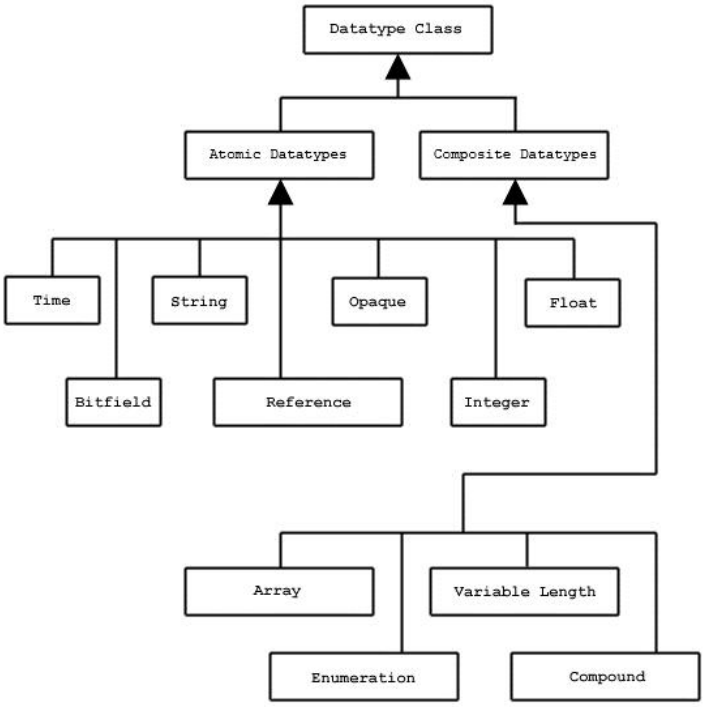

Figure 10c-5 - Datatype classifications

10c-5.1.6 Attribute

Any HDF5 named data object (group, dataset, or named datatype) may have zero or more user defined attributes. Attributes are used to document the object. The attributes of an object are stored with the object.

An HDF5 attribute has a name and data. The data portion is similar in structure to a dataset: a dataspace defines the layout of an array of data elements, and a datatype defines the storage layout and interpretation of the elements. See the figure below.

Attributes of data objects are in principle equivalent to thematic attributes but this edition of the HDF5 profile does not provide for vector feature or information type data in HDF5 files and therefore does not make use of vector object attributes. HDF5 attributes of groups, datasets, or named datatypes play the role of metadata.

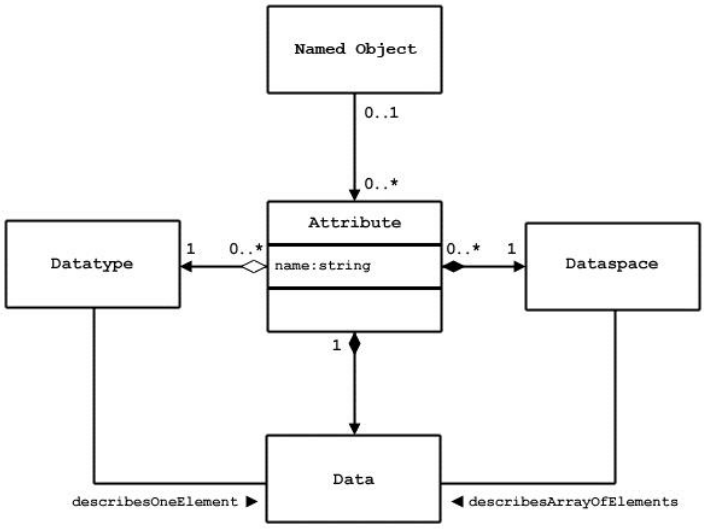

Figure 10c-6 - Attribute data elements

In fact, an attribute is very similar to a dataset with the following limitations:

- An attribute can only be accessed via the object;
- Attribute names are significant only within the object;
- An attribute should be a small object;
- The data of an attribute must be read or written in a single access (partial reading or writing is not allowed);
- Attributes do not have attributes.

Note that the value of an attribute can be an *object reference*. A shared attribute or an attribute that is a large array can be implemented as a reference to a dataset.

The name, dataspace, and datatype of an attribute are specified when it is created and cannot be changed over the life of the attribute. An attribute can be opened by name, by index, or by iterating through all the attributes of the object.

10c-5.1.7 Property List

HDF5 has a generic property list object. Each list is a collection of *name-value* pairs. Each class of property list has a specific set of properties. Each property has an implicit name, a datatype, and a value. A property list object is created and used in ways similar to the other objects of the HDF5 library.

Property Lists are attached to the object in the library, they can be used by any part of the library. Some properties are permanent (e.g., the chunking strategy for a dataset), others are transient (for example buffer sizes for data transfer). A common use of a Property List is to pass parameters from the calling program to a VFL driver or a module of the pipeline.

Property lists are conceptually similar to attributes. Property lists are information relevant to the behavior of the library while attributes are relevant to the user's data and application. Since the Property List couples the data specification to an implementation use of HDF5 property lists in S-100 Product Specifications is discouraged.

10c-5.2 HDF5 Library and Programming Model

The HDF5 Library implements the HDF5 abstract data model and storage model. Two major objectives of the HDF5 products are to provide tools that can be used on as many computational platforms as possible (portability), and to provide a reasonably object-oriented data model and programming interface.

Refer to the HDF5 User's Guide Release 1.8.8 and the HDF5 Reference Manual 1.8.8 for more details on the HDF5 model implementation. S-100 Product Specifications must specify the HDF5 groups, datasets and attributes in context of the S-100 General Feature Model.

10c-5.3 Prohibited HDF5 constructs

Constructs which cannot be processed using the standard libraries of the HDF5 release specified in this Part must not be used. This means specifically that HDF5 constructs which require the use of a library for a later release than that specified in this Part must not be used.

10c-6 S-100 profile of HDF5

The S-100 profile of HDF5 restricts the HDF5 datatypes and constructs which can be used in S-100 HDF5 datasets; describes correspondences between S-100 and HDF5 datatypes and other constructs; and defines rules for how S-100 HDF5 datasets must be structured.

The S-100 HDF5 profile must apply to the kinds of information listed below – noting that the types are not all mutually exclusive, though most individual product specifications will use only a subset of possible combinations:

- data for one or more individual, fixed stations;
- regularly-gridded data;
- irregularly-gridded data;
- grids with variable cell sizes;
- ungeorectified gridded data (Part 8 clause 8-8.1.2);
- TIN data;
- moving platform (for example surface drifter) data;
- either static data or time series data (for any of the other kinds), with fixed or variable intervals;
- tiled and untiled coverages;
- multiple feature classes in the same datafile;
- multiple types of coverages in the same datafile.

The restrictions, correspondences, and rules are described in the following sections;

10c-7 Data types

Predefined HDF5 data types include Integer, Float, String, and Enumeration, but there are no HDF5 equivalents to the S-100 data types Boolean, S100_Codelist or S100_TruncatedDate. The latter types are mapped to the HDF5 constructs specified in the Table below. The S-100 data types Date, DateTime, and Time are mapped to HDF5 strings due to potential problems with portability across different processor architectures of HDF5 Time formats. In S-100 HDF5 data products, S-100 data types defined in Part 3 are mapped to equivalent HDF5 data types. These equivalences are summarized in Table 10c-1 below. HDF5 datatype classes not mentioned in this Table shall not be used.

Table 10c-1 – Equivalences between S-100 and HDF5 datatypes

S-100 Attribute Value Types	HDF5 Datatype Class	Constraint on HDF5 datatype
real	Float	32 or 64-bit floating point
integer	Integer	1, 2, or 4-byte signed and unsigned integers
text (CharacterString in S-100 metadata)	String	variable-length string
enumeration	Enumeration	Numeric codes must be 1 or 2-byte unsigned integers, range [1, 2^8 – 1] or [1, 2^{16} - 1]
date	(Character) String, length=8	Date format according to Table 1-2 (Part 1); that is, complete representation, basic format, as specified by ISO 8601

time	(Character) Variable-length string	Time format according to Table 1-2 (Part 1); that is, complete representation, basic format as specified by ISO 8601. UTC indicated by "Z" suffix; local time by absence of suffix. The zone offset format is also permitted); for example, 123000+0100
dateTime	(Character) (variable length string)	Date-time format as specified by ISO 8601. EXAMPLES: 19850412T101530Z 19850412T101530-0500
boolean	(Integer)	1-byte unsigned, Values: 1 (TRUE); 0 (FALSE)
S100_Codelist	Compound (Enumeration, variable-length string)	Exactly one of the components is allowed; the other must be the numeric value 0 or the empty (0-length) string according to its data type
URI, URL, URN	String (variable-length)	Format specified in RFC 3986 (URI, URL) or RFC 2141 (URN)
S100_TruncatedDate	String, length=8	Format as in Part 1 Table 1-2
value record (Part 8)	Compound	Datatypes of components must be according to value attribute types in the application schema. The "value record" corresponds to the value(s) record in Part 8 Figs. 8-21, 8-22, 8-23, 8-28, 8-29
external object reference	String	Format: extObjRef:<fileName>:<recordIdentifier> where <fileName> is the base name of the ISO 8211 or GML file, and <recordIdentifier> is the record identifier of the vector object record within that file. The extension part of the file name is not used. The record identifier is the gml:id for GML datasets, or the record identification number (RCID) for ISO 8211 datasets. The file must be present in the same exchange set.

10c-8 Naming conventions

Names of HDF5 elements (datasets, objects, etc) that encode data elements in the Application Schema (i.e., feature classes, attributes, roles, enumerations, codelists, etc) must conform to the names in the Application Schema (since there is 1/1 mapping from the Application Schema to the Feature Catalogue, this also amounts to requiring the same conformance to the Feature Catalogue). 'Names' used must be the camel case names. Other sections in this Part indicate where the names from the Application Schema (or equivalently, the Feature Catalogue) are used.

Elements in embedded ("carrier") metadata and positioning information which correspond to attributes in Parts 4a-4c must also conform to the corresponding camel case names in Parts 4a-4c & 8.

Elements which do not have a direct correspondence may have names that are unique to the HDF5 format (the differences being intended to simplify the abstractions in ISO 19123 and S-100 Parts 4, 4b, and 8, and shorten fields which are deeply nested within the XML schemas).

The names 'latitude' and 'longitude' must be used for geographic coordinate axes when they are appropriate, in preference to 'X' and 'Y', which should be used only when latitude/longitude are inappropriate.

The correpondences between the carrier metadata elements in this profile and Parts 4-4c and Part 8 are specified later in this document.

Names in non-embedded metadata and catalogue files in exchange sets are treated as for vector product product specifications – that is, they must conform to the standard S-100 metadata and exchange catalogue schemas.

An HDF5 group which corresponds to a schema element already named in S-100 or in the product specification must be given the same name as that element, using the camel-case code if specified. For example, if a time series product specifies names for data collections at time points, those names should

be used as the group names if the collection is encoded as a group. (Product specification developers must take care to specify collection names which conform to the allowed HDF5 syntax.)

Numeric suffixes preceded by the underscore character (that is, the suffix 'NNN') may be added to distinguish groups which would otherwise have the same names (for example, data groups at different time points).

The following group names are reserved for the uses specified:

Table 10c-2 – Reserved group names

Positioning	Discrete positioning information of all kinds and dimensions. The type of positioning data is indicated by a group attribute or attributes. Includes compressed or compact encodings. Does not include positioning which can be completely specified by grid or coverage parameters alone (such parameters are encoded in attributes attached to the root group). Specifications which require non-uniform positioning (for example, second-order algebraic formulae) must be treated as ungeorectified grids.
Group_F	Feature specification information. For example, feature and attribute names, codes, types, multiplicities, roles, etc. Also includes format metadata specific to the HDF5 format, like chunk sizes.
Group_IDX	Indexes, if encoded in an HDF5 group. Includes indexes to sparse arrays.
Group_TL	Tiling information, if encoded in a group.
Group_nnn	Data for one member of a series; for example, at a time point in a time series, or for different stations. "n" means any digit from 0 to 9. Numbering must use 3 digits, 001-999.

10c-9 Structure of data product

10c-9.1 General structure

An S-100 HDF5 file is structured to consist of Groups, each of which may contain other Groups, Attributes and (HDF) Datasets. Groups are containers for different types of information (meaning data values, position information, metadata, or ancillary information). HDF datasets are designed to hold large amounts of numerical data and may be used to hold the coverage data values. Attributes are designed to hold single-valued information which apply to Groups or Datasets and may be used to hold certain types of metadata.

The following groups are contained within the root group. (The nesting levels in the list below correspond to the nesting levels in the HDF5 file.)

1) Feature information group.
2) Feature container groups – each acts as a container for individual instances of a feature class. Its attributes encode any feature-class-level metadata.
    a) Feature instance groups – each acts as a container for the positioning ~~positioning~~, tile, indexes, and data groups pertaining to a single feature instance. Its attribute encode any instance-level metadata
        i) Tiling information group (conditional, only if values are stored as tiles).
        ii) Indexes group (conditional, only if indexes to data are required).
        iii) Positioning group (conditional, only if positions are not computable from metadata).
        iv) Data values group(s). Only time series data will have more than one value group.

Note that the order in which groups and datasets are stored within the datafile may not be the same as the order in which they are created.

The basic structure of an S-100 HDF5 file is depicted in the figure below. 'F' is the number of feature classes defined in the product specification. It is not a requirement that every data file contain instances of all feature classes. There is one values group for each time point in the time series[1] (datasets which are not time series will have only a single values group in each feature instance group).

[1] Except for moving station data and fixed station (stationwise) data. The use of value groups for each coverage type is described later in this Part.

The FeatureContainer and Positioning groups are abstract classes because their attributes and content depend on the type of coverage.

A more detailed diagram is included later in this Part.

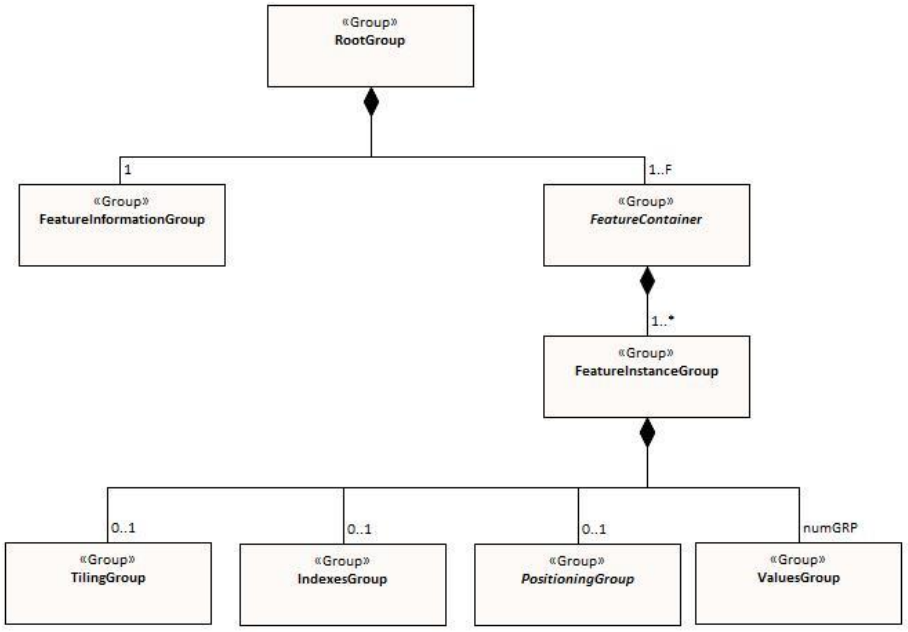

Figure 10c-7 - Basic structure of S-100 HDF5 file

10c-9.2 Metadata

Metadata is defined at different levels in the logical structure, so that metadata at the root group applies to all the features in the file, metadata at the feature container level applies to all instances of that feature class, and metadata at the instance level applies only to that particular feature instance.

10c-9.2.1 Discovery metadata

Full discovery metadata is encoded in an external discovery metadata file, as specified in Parts 4a (Metadata) and 4b (Metadata for Imagery and Gridded Data). See clause 10c-12 for naming conventions.

10c-9.2.2 Carrier (embedded) metadata

Carrier metadata is metadata that is encoded within the HDF5 file. It is divided into general, type, and instance metadata, depending on whether it pertains to the HDF5 file as a whole, describes the structure and attributes of data object classes, or provides parameters needed to read instances of data object classes. Metadata is encoded in the following places:

- General metadata, defined as general parameters that apply to the file as a whole. General metadata consists of parameters that apply to all information in the data file, such as dates of issue, datum information, and overall spatial extent (bounding box). This includes the essential general elements for processing and cell location (the rest of the essential information is encoded with the feature instance). This metadata is encoded as attributes of the root group;
- Type, or feature, metadata, defined as specific characteristics which describes data object classes in the file (for example, pertains to specific features and attributes) and which will therefore be different for each feature class. This metadata is used for feature and attribute specification information (corresponding to entries in the feature catalogue). This type information is analogous to the feature catalogue described in Part 5, but may contain only extracts from the Feature

Catalogue as well as add format-specific parameters relevant only to HDF5 encodings. The Type Metadata is encoded as content (HDF5 datasets) in the feature information group and as attributes of each feature container group. The feature information group (Group_F) is also the future intended container for information from the exchange set catalogue or about support files, if it is necessary to include that within the HDF5 file and it is not applicable to the file as a whole;

- Instance metadata, defined as parameters for each feature class in the application schema. This includes parameters that are needed to read the information in the data product even if external metadata files are unavailable, including coverage-specific spatial parameters (extent, grid parameters). This metadata may include parameters that have significance only in the context of the specific coverage spatial type(s) permitted for the feature class in the application schema. This metadata is encoded as attributes of the instances within each feature container group.

Additional information describing the data is contained in the values group, as attributes that apply to the values dataset in each values group. The data may be a time point, or station information such as station name and the time series characteristics such as time interval, number of values, and start and end times.

10c-9.2.3 Extended metadata

Extended metadata elements defined in the product specification are encoded as either or both of:

- Additional attributes of the root of feature container group, depending on whether they are considered necessary for processing and pertain to the datafile as a whole or to feature instances. An example is provided later in this Part (Table 10c-7). (Note that any extended metadata that is essential for processing implies product-specific modules in implementations.);
- Extended metadata in the external XML files encoding the discovery metadata or exchange catalogue, if they are considered discovery metadata.

Data products may also define vector feature metadata; for example, quality meta-features with vector geometry. Vector features are not encoded within the HDF5 file but in a separate file conforming to Part 10a or Part 10b. If vector meta-features are present, a reference to the separate file must be included in carrier metadata by naming the file in the *metaFeatures* attribute (see clause 10c-9.4).

10c-9.3 Generalized dimensions and storage of coordinates and data

This section provides an overview of the general approach to representing positioning information and storing data in S-100 HDF5 datasets. The basic approach is to minimize the variety of data structures used for storing data records. This profile stores data in one of two ways:

1) A multi-dimensional data array, of rank and dimensions corresponding exactly to the shape of the grid. This is used only for regular grids. In order to reduce space requirements, the coordinates of grid points are not explicitly stored because they can be computed from grid parameters;
2) One-dimensional arrays of data and grid coordinates, accompanied by meta-information describing the shape of the grid. This is also used for multipoint data (where there is no actual grid).

The key idea at the core of the structure is this: the organization of the data is logically the same for each of the various types of data, but the information itself will be interpreted differently depending on the type of spatial representation (which is indicated by an attribute).

For regularly-gridded data, the positioning information is not stored in the form of explicit coordinates because the grid metadata (extent and grid cell spacing information) suffices to specify the coordinates of each grid point. For example, for 2-D grids the value arrays are two dimensional, with dimensions specified by the attributes numPointsLongitudinal and numPointsLatitudinal. By knowing the grid origin and the grid spacings, the position of every point in the grid can be computed by simple formulae.

For non-regularly gridded data only, there is additional positioning information. The nature of the positioning information depends on the data type:

- For fixed stations and moving platform data, the positioning information is stored as explicit coordinates, in one-dimensional arrays of size numPOS of compound elements. The components of the compound element correspond to the coordinate axes; for example, latitude, longitude, z-coordinate, time, etc. The sequence of points corresponds either to the positions of fixed stations or sequential positions of moving platforms, as appropriate.

- For ungeorectified grids, the positioning information is also stored as explicit coordinates in one-dimensional arrays of size numPOS of compound elements that contain the coordinates (as defined above).
- For irregular grids, the positioning information is stored as one-dimensional arrays of size numPOS of compound elements containing information about the location of populated cells. Coordinate values for each grid point are not explicitly stored. In addition, the tiling group may be populated with tiles whose spatial union exactly covers the grid. The sequence of cell location arrays must conform to the sequencingRule metadata attribute in the feature container group (clause 10c-9.6). An optional tile index component (index into the tiles array – see clause 10c-9.7) may be added to by a Product Specification for faster retrieval. If used, the tile index component must be named 'tileIndex' and be of 'integer' datatype. This format is intended for grids of irregular shapes based on uniform rectangular cells.
- For grids with variable cell sizes, the positioning information is stored as two one-dimensional arrays of size numPOS of compound elements, one array containing information about cell location (as for irregular grids) and the other about cell sizes. Coordinate values for each grid point are not explicitly stored. The actual cell size is described in terms of aggregations of a unit cell size. The format assumes that the varying cells are aligned with the grid and that cell sizes are multiples of unit cell size in each dimension.
- For TIN data, the positioning information is stored as one-dimensional arrays of size numPOS encoding the vertex locations (using the same type of compound elements as for ungeorectified grids above) plus a Triangles array encoding references to the vertices of the triangle and references to adjacent triangles.

For irregular grids and variable cell size, the auxiliary arrays describing cell locations and sizes are stored in the 'values' group rather than the positioning group (this allows for different aggregations of cells at different time points in the variable cell size format). The storage of data and coordinate values is summarized in the Table below. ('D' is the number of dimensions of the coverage.)

The HDF datasets storing coordinates and values are designed so as to use uniform data storage structures across different coverage types as well as reduce the total data volume. These criteria resulted in storing the additional information needed by some coverage types separately (e.g., cell location and size information for irregular and variable cell size grids).

Table 10c-3 – Summary of storage strategies for coordinates and data values

Coverage type	Coordinate values	Data values
Regular grid	Not explicitly stored Computable from metadata	D-dimensional array of value tuples
Irregular grid	Not explicitly stored Computable from metadata	1-d array of value tuples + information about location of cells
Variable cell size grid	Not explicitly stored Computable from metadata	1-d array of value tuples + information about cell size and location
Fixed stations, ungeorectified grid, moving platform	1-d array of coordinate tuples	1-d array of value tuples
TIN	1-d array of coordinate tuples + triangle information	1-d array of value tuples

Data Groups are separate groups containing the data values, which are stored in arrays corresponding to the positioning information. For coverage types where positioning information is not explicitly stored (N-dimensional regular grids), data is stored in N-dimensional arrays of rank corresponding to the grid dimensions (for example, for 2-D data, 2-D arrays of size numROWS by numCOLS).

For time series data, multiple data groups are present. The total number of data Groups is numGRP. The meaning of numGRP for each type of spatial representation is specified in Table 10c-4. The format allows for time series data for all representations.

Positions in coordinate systems with more than 2 coordinate axes are encoded using correspondingly more dimensions. For example, for 3-dimensional data, the vertical dimension is used as a third dimension.

For processing efficiency, this profile recommends limiting the number of dimensions to no more than four (space and time), but higher dimensionality may be used if required for the data product.

The variables that determine the array sizes (numROWS, numCOLS, numPOS, and numGRP) are different, depending upon which coding format is used. They are given in Table 10c-4.

Table 10c-4 – Array dimensions for different types of coverages

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Coding Format	Data Type	Positioning	Data Values ~~Times~~			
		numPOS	**numCOLS**	**numROWS**	**numZ (3-d only)**	**numGRP**
1	Fixed Stations	numberOfStations	1	numberOfStations	1	numberOfTimes
2	Regular Grid	(not used)	numPointsLongitudinal	numPointsLatitudinal	numPointsVertical	numberOfTimes
3	Ungeorectified Grid	numberOfNodes	1	numberOfNodes	1	numberOfTimes
4	Moving Platform	numberOfTimes	1	numberOfTimes	1	1
5	Irregular Grid	numberOfNodes	1	numberOfNodes	1	numberOfTimes
6	Variable cell size	numberOfNodes	1	numberOfNodes	1	numberOfTimes
7	TIN	numberOfNodes	1	numberOfNodes	1	numberOfTimes
8	Fixed Stations (Stationwise)	numberOfStations	1	numberOfTimes	1	numberOfStations

Note that numROWS, numCOLS, numZ, and numPOS are not explicitly encoded in the HDF5 file. This specification uses them only to indicate array dimensions for implementation purposes. It is the number of stations, nodes, points, etc. that are encoded as attributes of feature instances (clause 10c-9.7).

The name of each data Group begins with the characters 'Group_nnn', where n is numbered from 1 to numGRP. A maximum of 999 data groups are allowed. The length of the data group name is 9.

For all data types, the logical product structure in HDF5 consists of (a) a metadata block, which is followed by (b) the feature information group, then (c) one or more data container groups, each of which contains one or more feature instance groups, which in turn contain tiling, indexing, positioning and data groups as described in clause 10c-9.1. The tiling, indexing, and positioning groups are conditionally required depending on the type of data, indicated by an HDF5 attribute that specifies the coding format.

The physical layout of the file may not be the same as its logical data structure, however the HDF5 API allows implementers to access information using the logical data structure.

The following sections describe the content and attributes of each group.

10c-9.4 Root group

The root group acts as a container for the other groups. The carrier metadata (Table 10c-6) is contained as attributes in the root group. The carrier metadata consists of the data and parameters (a) needed to read and interpret the information in the product even if external metadata files are unavailable, and, mostly, (b) are not included elsewhere in the metadata.

Table 10c-5 – Root group

Group	HDF5 Category	Name			Data Type	Data Space / Remarks
/ *(root)*	Attributes	(Carrier metadata attributes)			Integer, Float, Enumeration, or String	(none) Described in Table 10c-6
	Group	Group_F				Feature information group (see Section 10c-9.6)
	Group(s)	(featureCode)				Feature container group – one group for each ~~f~~feature type in the data product. The name is the feature code, which is given in Group_F. See clause 10c-9.6 for structure and attributes
		HDF5 Category	**Name**			
		Group(s)	(featureCode).N			Feature instance group(s) – one for each instance of the feature. See Section 10c-9.7 for structure and attributes
			HDF5 Category	**Name**		
			Group (optional)	Group_TL		Tiling information, only if product uses tiles. See Section 10c-9.8
			Group (optional)	Group_IDX		Spatial index information, only if product uses spatial indexes See Section 10c-9.9
			Group	Positioning		Positioning information – 2D or 3D. Not required for data~~C~~CEnc~~o~~odingFormat = 2 (Regular grid). See Section 10c-9.10
			Group(s)	Group_NNN		Static data – only 1 values group Time series data – 000 to 999 groups See Section 10c-9.11

The common (core) metadata elements are specified as attributes of the root group, as listed in Table 10c-6. The root group contains only a subset of the elements of minimum metadata specified in Parts 4a and 4b. The external XML metadata file is required to contain all the mandatory metadata elements.

Table 10c-6 – Embedded metadata (carrier metadata) in root group

No	Name	Camel Case	Mult	Data Type	Remarks and/or Units
1	Product specification number and version	productSpecification	1	String	For example[2], 'INT.IHO.S-NNN.X.X', with Xs representing the version number. "NNN" and "X" do not imply length restrictions Corresponds to combination of S100_ProductSpecification name and number fields
2	Time of data product issue	issueTime	0..1	String (Time format)	Must be consistent with issueTime in discovery metadata
3	Issue date	issueDate	1	String (Date format)	Must be consistent with issueDate in discovery metadata
4	Horizontal datum	horizontalDatumReference	1	String	For example, EPSG
5	Horizontal datum number	horizontalDatumValue	1	Integer	For example, 4326 (for WGS84)
6	Epoch of realization	epoch	0..1	String	Code denoting the epoch of the geodetic datum used by the CRS. For example, G1762 for the 2013-10-16 realization of the geodetic datum for WGS84
7a	Bounding box	westBoundLongitude	1	Float	Ref. dataCoverage.boundingBox > EX_GeographicBoundingBox Each of the components of the bounding box is encoded as a separate attribute
7b		eastboundLongitude	1	Float	
7c		southBoundLatitude	1	Float	
7d		northBoundLatitude	1	Float	
8	Geographic location of the resource (by description)	geographicIdentifier	0..1	String	EX_Extent > EX_GeographicDescription.geographicIdentifier > MD_Identifier.code
9	Metadata	metadata	1	String	MD_Metadata.fileIdentifier Name of XML metadata file (section 10c-12). Ref. Part 8
10	Vertical datum reference	verticalDatum	0..1	Enumeration	See S100_VerticalAndSoundingDatum Conditional, if and only if depthTypeIndex=3
11	Meta features	metaFeatures	0..1	String	Name of 8211 or GML file containing meta-features GML files must have extension .GML or .gml; ISO 8211 files must have extension .NNN where N is any digit

NOTES:

1) The bounding box is the cell bounding box; the coverage data feature instances may or may not cover the entire bounding box. If there is only a single coverage feature, its extent may or may not be the same as the cell.

[2] To be replaced by a common format used in all S-100 based products, after that is finalized.

2) The core attributes correspond to metadata attributes in S100_DatasetDiscoveryMetadata (Part 4a) or the imagery/gridded/coverage data attributes in Part 8. The correspondences are given in the Remarks column.

3) Vertical datum is optional since it is not applicable to some types of depth referencing as used in some data products; for example, Surface Currents.

Product specifications which need additional metadata attributes may include them as additional attributes, defined in the Product Specification. The additional attributes must be defined in the same way as Table 10c-6 – specifically, they must have a camel-case name beginning with a lower-case letter, multiplicity either 0..1 (optional) or 1 (mandatory) and be one of the allowed types listed in Table 10c-1. In addition, restrictions or additional conditions can be added for core carrier metadata attributes. The data types of common carrier metadata attributes cannot be changed, but the range of allowed values may be restricted or optional attributes made mandatory or conditionally mandatory.

EXAMPLE: The Table below shows how a Product Specification might define an additional attribute (Vertical reference), introduce a conditional test for a core metadata attribute (Vertical datum reference), and make an optional metadata attribute mandatory (Time of data product issue).

Table 10c-7 – Example of extended metadata attribute and additional conditions on core metadata attributes

No	Name	Camel Case	Mult	Data Type	Remarks and/or Units
Additional carrier metadata					
11	Vertical reference	depthTypeIndex	1	Enumeration	1: Layer average 2: Sea surface 3: Vertical datum (see verticalDatum) 4: Sea bottom
Additional restrictions or conditions on core carrier metadata					
2	Time of data product issue	issueTime	1	String (Time format)	Mandatory in S-111
9	Vertical datum reference	verticalDatum	0..1	Enumeration	Required if and only if depthTypeIndex=3

How the Product Specification describes core and extended metadata attributes is left to the specification writers, but specifications should distinguish core attributes from extended attributes as well as clearly indicating any additional restrictions or conditions on core attributes. The ISO format for specifying metadata extensions (Part 4a clause 4a-5.6.5) may be used.

10c-9.5 Feature information group

The feature information group contains the specifications of feature classes and their attributes. The components of the feature information group are described in the Table below.

Table 10c-8 – Components of feature information group

Group	HDF5 Category	Name	Data Type or HDF Category	Data Space
/Group_F	Dataset	featureCode	String (variable length)	Array (1-d): i=0, F-1 Values = codes of feature classes (F is the number of feature classes in the application schema.)
	Dataset(s) (feature information datasets - one for each feature in the featureCode array)	<featureCode> For example: SurfaceCurrent, WaterLevel	Attribute	Attribute name: chunking Type = string value = chunk dimensions (HDF5 chunk dimensions for data values of this feature, in string representation. See section 10c-5.1.3 and HDF5 documentation.)
			Array of Compound (String X 8)	Array (1-d): i=0, *NA_F-1 (NA_F = number of attributes of feature named by <featureCode>).* Components of the compound type: code: camel case code of attribute as in feature catalogue name: long name as in feature catalogue uom.name: units (uom>name from S-100 feature catalogue) fillValue: fill value (integer or float value, string representation) datatype: HDF5 data type, as returned by H5Tget_class() function lower: lower bound on value of attribute upper: upper bound on attribute value closure: type of closure The “code” and “datatype” components encode the rangeType attribute of the coverage features in Part 8 “lower”, “upper”, and “closure” encode any constraints on attribute values as encoded in the feature catalogue (see “S100_FC_SimpleAttribute>constraints” in Part 5 and S100_NumericRange in Part 1)

Notes:

1) Land mask or unknown values are represented by the attribute’s *fillValue*.

All the numeric values in the feature description dataset are string representations of numeric values; for example, “-9999.0” not the float value -9999.0. Applications are expected to parse the strings to obtain the numeric value. Inapplicable entries are represented by null values or the empty (0-length) string.

An entry in Group_F is required for every feature type that is used in the HDF5 data file. This means that:

- The **featureCode** array must include each feature type for which there is a feature instance somewhere in the current physical file.
- There must be a feature description dataset for each feature type named in the **featureCode** array.
- Each feature description dataset must list all the attributes of the feature type (both direct and inherited) as specified in the Feature Catalogue.

Note that the above requirements do not mandate entries in Group_F for feature types which are defined in the XML feature catalogue but for which there are no instances in the current data file.

The number of attributes for each feature type (NA_F in Table 10c-8) is not explicitly specified but can be determined using HDF5 API to determine the number of rows in each feature description dataset.

The Figure below depicts Group_F for a hypothetical product with two feature types, *SurfaceCurrent* and *WaterLevel*. The two features are named (using the camel case codes from the feature catalogue) in the dataset **featureCode**. The feature description datasets **SurfaceCurrent** and **WaterLevel** describe the attributes of each feature type. The feature description datasets are given the same names as the values in the **featureCode** dataset, which are the camel case codes of the features from the XML feature catalogue. Each feature description dataset is an array of compound type elements, whose components are the 8 components specified in Table 10c-8. The chunk dimensions for the data itself are provideds in the *chunking* attribute of each feature description dataset (shown in the two panels at the top right in the Figure).

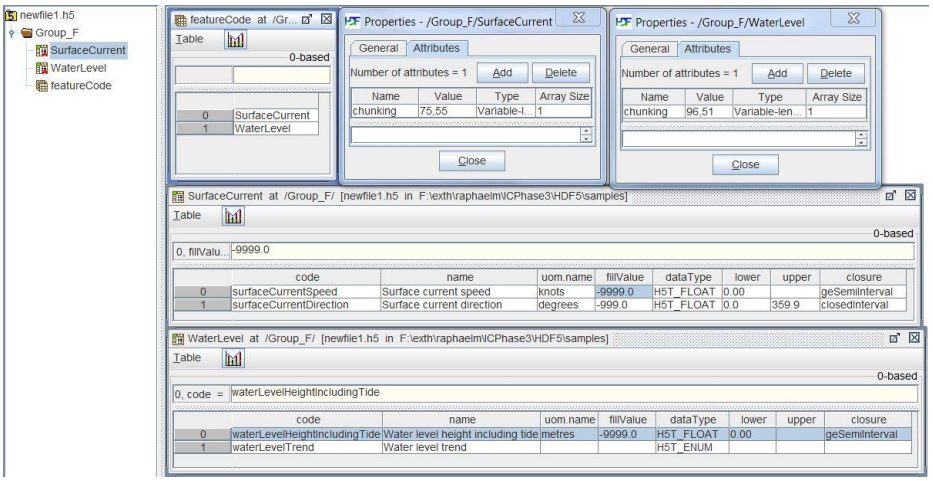

Figure 10c-8 – Example of Group_F

10c-9.6 Feature container group

The feature container groups contain the coordinates and values for all instances of a single feature class. Each feature instance is allocated its own group within the feature container group. This organization allows class-wide attributes to be attached to the class as a whole and instance-specific attributes to be attached to the appropriate feature instance.

NOTE: The decision to make a distinct group for each feature instance is based on the fact that there will be multiple datasets for a single instance in some circumstances (for example, index, TIN, etc), and placing all the datasets directly under the container group is likely to add confusion to the data organization from

the human perspective at least (though suffixes might suffice to distinguish different instances for programming purposes).

The structure of the Feature Container group is shown in Table 10c-9 below. This Table also shows the feature instance group(s). The axis names are given in a dataset at the feature container level.

Metadata that is common to all instances of the feature class (such as dimensionality) is encoded at the feature container level and these metadata elements are listed in Table 10c-10. Metadata that is specific to feature instances (such as grid parameters) is encoded at the instance level and these elements are listed in Table 10c-12.

Product specifications may add product-specific metadata attributes. The guidelines for additional metadata elements are the same as additional metadata elements in the root group (clause 10c-9.4).

Table 10c-9 – Structure of feature container groups

Group	HDF5 Category	Name	Data Type	Remarks / Data space
/(feature code)	attribute	See Table 10c-10	(see Table)	Single-valued attributes as described in Table 10c-10
	Dataset	axisNames	String	Array (1-D): 0..D-1 where D is the value of the *dimension* attribute Axes should be in major-minor order; that is, if storage is to be in row-major order the X/longitude axis should be first.
	Dataset (optional)	coordinateSize	Integer	Array (1-D): 0..D-1 where D is the value of the *dimension* attribute The size of the coordinate encoding in bytes. Allowed values are 1, 2, 4, or 8. If this dataset is not present the coordinates must be encoded using 64 bits (8 bytes) for Float coordinates and 32 bits (4 bytes) for Integer coordinates
	Dataset (optional)	interpolationParameters	Float	Array (1-D) of interpolation parameters Required if and only if the value of attribute *interpolationType* is 'biquadratic' or 'bicubic'
	Group	/(feature code).N		Container for each instance of a feature type. Numbered sequentially from 1 to *numInstances* (Table 10c-10). Zero-padding with leading zeros must be used so that the 'N' suffixes are all the same length. To accommodate expansion, an extra zero is recommended

NOTES:

1) "uncertainty" is the uncertainty in data values, position uncertainty (both horizontal and vertical) is encoded separately.
2) The length of the interpolationParameters dataset and sequence of parameters should be provided in the Product Specification.

Table 10c-10 – Attributes of feature container groups

No	Name	Camel Case	Mult	Data Type	Remarks and/or Units
	Data organization index	dataCodingFormat	1	Enumeration	Indication of the type of coverage in instances of this feature. Used to read the data (see Table 10c-4) 1: Time series at fixed stations 2: Regularly-gridded arrays 3: Ungeorectified gridded arrays 4: Moving platform 5; Irregular grid 6; Variable cell size 7; TIN 8: Time series at fixed stations (stationwise)
	Dimension	dimension	1	Integer	The dimension of the feature instances This is the number of coordinate axes, not the rank of the HDF5 arrays storing coordinates or values. For example, a fixed stations dataset with positions in latitude and longitude will have dimension=2
	Common point rule	commonPointRule	1	Enumeration	The procedure used for evaluating the coverage at a position that falls on the boundary or in an area of overlap between geometric objects Values from CV_CommonPointRule (Table 10c-2019)
	Horizontal position uncertainty	horizontalPositionUncertainty	1	Float	The uncertainty in horizontal coordinates. For example, -1.0 (unknown/inapplicable) or positive value (m)
	Vertical position uncertainty	verticalUncertainty	1	Float	The uncertainty in vertical coordinate(s). For example, -1.0 (unknown/inapplicable) or positive value (m)
	Time uncertainty	timeUncertainty	0..1	Float	Uncertainty in time values. For example, -1.0 (unknown/inapplicable) or positive value (s) Only for time series data
	Number of feature instances	numInstances	1	Integer	Number of instances of the feature (Records in the same time series or moving platform sequence are counted as a single instance, not as separate instances)
	(additional common attributes)				(As specified in Product Specification)
dataCodingFormat = 1					
	(none)				
dataCodingFormat = 2					
	Sequencing rule	sequencingRule.type	1	Enumeration	

		sequencingRule.scanDirection	1	String	Method to be used to assign values from the sequence of values to the grid coordinates Type and scan direction are encoded as separate attributes type: Enumeration CV_SequenceType (Table 10c-2~~1~~0) scanDirection: String <axisNames entry> (comma-separated). For example, “latitude, longitude”. Reverse scan direction along an axis is indicated by prefixing a ‘-‘ sign to the axis name
	Interpolation type	interpolationType	1	Enumeration	Interpolation method recommended for evaluation of the S100_GridCoverage Values: S100_CV_InterpolationMethod (Table 10c-2~~1~~1)
dataCodingFormat = 3					
	Interpolation type	interpolationType	1	Enumeration	Interpolation method recommended for evaluation of the S100_GridCoverage Values: S100_CV_InterpolationMethod (Table 10c-2~~1~~2)
dataCodingFormat = 4					
	(none)				
dataCodingFormat = 5					
	Sequencing rule	sequencingRule.type	1	Enumeration	Method to be used to assign values from the sequence of values to the grid coordinates Type and scan direction are encoded as separate attributes type: Enumeration CV_SequenceType (Table 10c-2~~1~~0) scanDirection: String <axisNames entry> (comma-separated). For example, “latitude, longitude”. Reverse scan direction along an axis is indicated by prefixing a ‘-‘ sign to the axis name
		sequencingRule.scanDirection	1	String	
	Interpolation type	interpolationType	1	Enumeration	Interpolation method recommended for evaluation of the S100_GridCoverage Values: S100_CV_InterpolationMethod (Table 10c-2~~1~~1)
dataCodingFormat = 6					
	Sequencing rule	sequencingRule.type	1	Enumeration	Method to be used to assign values from the sequence of values to the grid coordinates Type and scan direction are encoded as separate attributes type: Enumeration CV_SequenceType (Table 10c-2~~1~~0) scanDirection: String <axisNames entry> (comma-separated). For example, “latitude, longitude”. Reverse scan direction along an axis is indicated by prefixing a ‘-‘ sign to the axis name
		sequencingRule.scanDirection	1	String	
	Interpolation type	interpolationType	1	Enumeration	Interpolation method recommended for evaluation of the S100_GridCoverage Values: S100_CV_InterpolationMethod (Table 10c-2~~1~~1)
dataCodingFormat = 7					

	Interpolation type	interpolationType	1	Enumeration	Interpolation method recommended for evaluation of the S100_GridCoverage Values: S100_CV_InterpolationMethod (Table 10c-2~~1~~2)
dataCodingFormat = 8					
	(none)				
(any dataCodingFormat value)					
	(additional attributes)				(As specified in Product Specification)

10c-9.7 Feature instance group

The feature instance groups are contained within the feature container groups. The structure of a feature instance group is defined in Table 10c-11. The attributes that are specific to each feature instance are defined in the Table following (Table 10c-12) and consist of information that may vary for different instances in the same dataset, such as extent, location, time, and grid size.

Table 10c-11 – Structure of feature instance groups

Group	HDF5 Category	Name	Data Type	Remarks / Data space
/(feature code).N For example: SurfaceCurrent.01	attributes	See Table 10c-12	(see Table)	Single-valued attributes as described in Table 10c-12
	Dataset (optional)	domainExtent.polygon	Compound (Float, Float)	Spatial extent of the domain of the coverage Array (1-d): i=0, P Components: <longitude, latitude> or <X, Y> (coordinates of bounding polygon vertices as a closed ring; that is, the first and last elements will contain the same values) Either this or the bounding box attribute must be populated. For irregular arrays, this dataset must specify the polygon indicating the area for which data are provided
	Dataset (optional)	domainExtent.verticalElement	Compound (Integer X 2, Float X 2)	Array (1-d) of compound elements each providing a grid location and maximum, minimum vertical extents at the location The components of the compound type are: gridX, gridY: Integer (grid point numbers along X/longitude and Y/latitude axes) minimumValue, maximumValue (Float): minimum and maximum Z values at the grid point specified by gridX and gridY Applicable only to 3-D grids. Either this dataset or the verticalExtent attribute (Table 10c-12) must be populated for 3-D grids
	Dataset (optional)	extent	Compound (Integer X D)	1-D array, of compound elements, 2 rows. Row 0 gives the “low” values, row 1 the “high” values The area of the grid for which data are provided. (Part 8 Fig. 8-23) Components of compound type are named according to the axis names in the axisNames dataset
	Dataset (optional)	uncertainty	Compound (String, Float)	Array (1-d): i = 0, (up to) NA_F Code and uncertainty of data values For example, (“surfaceCurrentSpeed”, 0.1) The number of attributes for this feature class (NA_F) may be determined from Group_F

	Dataset (optional)	cellGeometry	Compound (String, Float X 2, Integer X 1)	Cell geometry. Array (1-d) of length the same as the *axisNames* array defined above (this means that if present, this dataset encodes all the axes including latitude, longitude, etc) Conditional, required only for regular grids (data_C~~Enc~~odingFormat=2) using coordinate reference systems with axes other than (latitude, longitude, vertical), or with more than 3 dimensions This array serves to extend the information encoded in the grid parameter attributes (origin, spacing, number of points) defined in Table 10c-12 (Attributes of feature instance group) for data products which use higher-dimensional grids or non-standard coordinate axes Components: axisName: string (an entry in the *axisNames* array defined above) gridOrigin: Float (the origin of the axis named in the axisName component) gridSpacing: Float (Cell spacing for the named axis) numPoints: Integer (the number of grid lines along the named axis)
	Group (optional)	/Group_TL		Tile information. Conditional, required if the product specification specifies tiling.
	Group (optional)	/Group_IDX		Spatial indexing method. Conditional, required if the product specification specifies spatial indexing.
	Group (optional)	/Positioning		Positioning information. Coordinates of data values. Conditional, required if dataCodingFormat is not 2 (Regular grid)
	Group	/Group_nnn		Data Values group(s).

Table 10c-12 – Attributes of feature instance groups

No	Name	Camel Case	Mult	Data Type	Remarks and/or Units
	Bounding box	westBoundLongitude	0..1	Float	The geographic extent of the grid, as a bounding box Ref. domainExtent: EX_GeographicExtent > EX_GeographicBoundingBox Either this or the domainExtent dataset must be populated The bounds must either all be populated or all omitted
		eastboundLongitude	0..1	Float	
		southBoundLatitude	0..1	Float	
		northBoundLatitude	0..1	Float	
	Number of time records	numberOfTimes	0..1	Integer	The total number of time records Time series data only. For dataCodingFormat = 8, this variable migrates to the values group attributes (Table 10c-19).
	Time interval	timeRecordInterval	0..1	Integer	The interval between time records. Units: Seconds Time series data only. For dataCodingFormat = 8, this variable migrates to the values group attributes (Table 10c-19).
	Valid Time of Earliest Value	dateTimeOfFirstRecord	0..1	Character	The validity time of the earliest time record. Units: DateTime Time series data only
	Valid Time of Latest Value	dateTimeOfLastRecord	0..1	Character	The validity time of the latest time record. Units: DateTime Time series data only
	Vertical extent	verticalExtent.minimumZ	0..1	Float	Vertical extent of 3-D grids minimumZ, maximumZ: Minimum and maximum values of the grid's spatial extent along the vertical direction. They are encoded as separate attributes
		verticalExtent.maximumZ	0..1	Float	
	Number of groups	numGRP	1	Integer	The number of data values groups contained in this instance group.
	Instance chunking	instanceChunking	0..1	String	Chunk size for values dataset. If present, this attribute overrides the setting in Group_F for this feature instance The format is a comma-separated string of (string representations of) positive integers (except that there is only one number for a 1-dimensional values dataset). The number of integers in the string must correspond to the dimension of the values dataset. For example, "50" for a 1-dimensional array; "150,200" for a 2-dimensional array Note: (1) The quotes are not part of the representation. (2) The dimension of the values dataset is its array rank, not the number of spatial dimensions for the coverage feature
	(additional attributes specific to data product)	(as defined in product specification)			
dataCodingFormat = 1					
	Number of fixed stations	numberOfStations	1	Integer	The number of fixed stations
dataCodingFormat = 2					
	Longitude of grid origin	gridOriginLongitude	1	Float	The longitude of the grid origin. Unit: Arc Degrees
	Latitude of grid origin	gridOriginLatitude	1	Float	The longitude of the grid origin. Arc Degrees
	Vertical grid origin	gridOriginVertical	0..1	Float	The grid origin in the vertical dimension. Only for 3-D grids. Units specified by product specifications
	Grid spacing, long.	gridSpacingLongitudinal	1	Float	Cell size in the X/longitude dimension. This is the X/longitudinal component of the offset vector (8-7.1.4). Units: Arc Degrees
	Grid spacing, lat.	gridSpacingLatitudinal	1	Float	Cell size in the Y/latitude dimension. This is the Y/latitudinal component of the offset vector (8-7.1.4). Units: Arc Degrees
	Grid spacing, Z	gridSpacingVertical	0..1	Float	Cell size in the vertical dimension. Only for 3-D grids. Units specified by product specifications.

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	Number of points, long.	numPointsLongitudinal	1	Integer	Number of grid points in the X/longitude dimension. (iMax)
	Number of points, lat.	numPointsLatitudinal	1	Integer	Number of grid points in the Y/latitude dimension. (jMax)
	Number of points, vertical	numPointsVertical	0..1	Integer	Number of grid points in the vertical dimension. (kMax)
	Start sequence	startSequence	1	String	Grid coordinates of the grid point to which the first in the sequence of values is to be assigned. The choice of a valid point for the start sequence is determined by the sequencing rule. Format: n, n… (comma-separated list of grid points, one per dimension – For example, 0,0)
dataCodingFormat = 3					
	Nodes in grid	numberOfNodes	1	Integer	The total number of grid points
dataCodingFormat = 4					
	Number of stations	numberOfStations	1	Integer	Value is always 1
dataCodingFormat = 5 or 6					
	Longitude of grid origin	gridOriginLongitude	1	Float	The longitude of the grid origin. Unit: Arc Degrees
	Latitude of grid origin	gridOriginLatitude	1	Float	The longitude of the grid origin. Arc Degrees
	Vertical grid origin	gridOriginVertical	0..1	Float	The grid origin in the vertical dimension. Only for 3-D grids. Units specified by product specifications
	Grid spacing, long.	gridSpacingLongitudinal	1	Float	Cell size in the X/longitude dimension. This is the X/longitudinal component of the offset vector (8-7.1.4). Units: Arc Degrees For variable cell size grids this is the unit cell size (the size of the smallest cell in this dimension)
	Grid spacing, lat.	gridSpacingLatitudinal	1	Float	Cell size in the Y/latitude dimension. This is the Y/latitudinal component of the offset vector (8-7.1.4). Units: Arc Degrees For variable cell size grids this is the unit cell size
	Grid spacing, Z	gridSpacingVertical	0..1	Float	Cell size in the vertical dimension. Only for 3-D grids. Units specified by product specifications. For variable cell size grids this is the unit cell size
	Nodes in grid	numberOfNodes	1	Integer	The total number of grid points
	Start sequence	startSequence	1	String	Grid coordinates of the grid point to which the first in the sequence of values is to be assigned. The choice of a valid point for the start sequence is determined by the sequencing rule. Format: n, n… (comma-separated list of grid points, one per dimension – for example, 0,0)
dataCodingFormat = 7					
	Nodes in grid	numberOfNodes	1	Integer	The total number of grid points
	Triangles in grid	numberOfTriangles	1	Integer	The total number of triangles in the TIN
dataCodingFormat = 8					
	Number of fixed stations	numberOfStations	1	Integer	The number of fixed stations
(any dataCodingFormat value)					

	(additional attributes)				(as specified in product specification)

NOTES:

1) The type-specific attributes for regular and variable cell size grids are the same except that the parameters giving the number of points in each dimension are replaced by the total number of nodes in the grid.
2) Attributes “Valid time of earliest value” and “Valid time of latest value” provide the *temporalElement* component of the domainExtent attribute in the grid model (Figures 8-21, 8-22, 8-28, 8-29).

10c-9.7.1 Overriding attributes

A feature instance group may also carry any of the following attributes defined in higher-level groups. The attribute value assigned in the feature instance group overrides the value in the higher group.

- The "Vertical datum reference" (verticalDatum) attribute from the Root group;
- Any attribute from the Feature Container group, **except** "Number of feature instances" (numInstances).

Product specifications may prohibit attribute overriding if not required for their products.

NOTES:

1) Attribute overriding is intended to allow certain products to encode variations of feature types in the same data file, for example, if an application schema defines a feature which can have either regular grid or fixed station information, and therefore may need different metadata attributes. Product Specification authors should note however that this issue can be resolved in application schemas by defining appropriate specializations of the feature class, which would be distinct feature types, and therefore encoded in different feature containers.
2) Attribute overriding also allows production-time differences, such as different vertical datums for different instances. While this is possible, its practice should be avoided in order to reduce the possibility of human error in application development as well as by the end-user.

10c-9.7.2 Example of container and instance structure

The figure below depicts the structure of a hypothetical data file containing 3 instances of the **SurfaceCurrent** feature type.

- The vertical panel on the left shows the overall structure. The data product consists of 2 features (**SurfaceCurrent** and **WaterLevel**). Each is represented by a group just under the root group. The Feature Information group described earlier (clause 10c-9.5) is also shown.
- The Feature Container group named **SurfaceCurrent** contains 3 instances of the **SurfaceCurrent** feature type (hypothetically, data for 3 separate places, each with a local coverage grid). Each instance contains subgroups (Group_001, etc) for time series data.
- Locations are encoded in the **geometryValues** dataset in the **Positioning** group (panel at top right). The **axisNames** panel to its left names the components of the **geometryValues** (that is., the coordinate axes).
- The **SurfaceCurrent** panel in the the middle shows the metadata attributes common to all instances, which are attached to the **SurfaceCurrent** feature container group.
- The two panels at the bottom show the instance-specific metadata for the feature instances **SurfaceCurrent.01** and **SurfaceCurrent.02**.

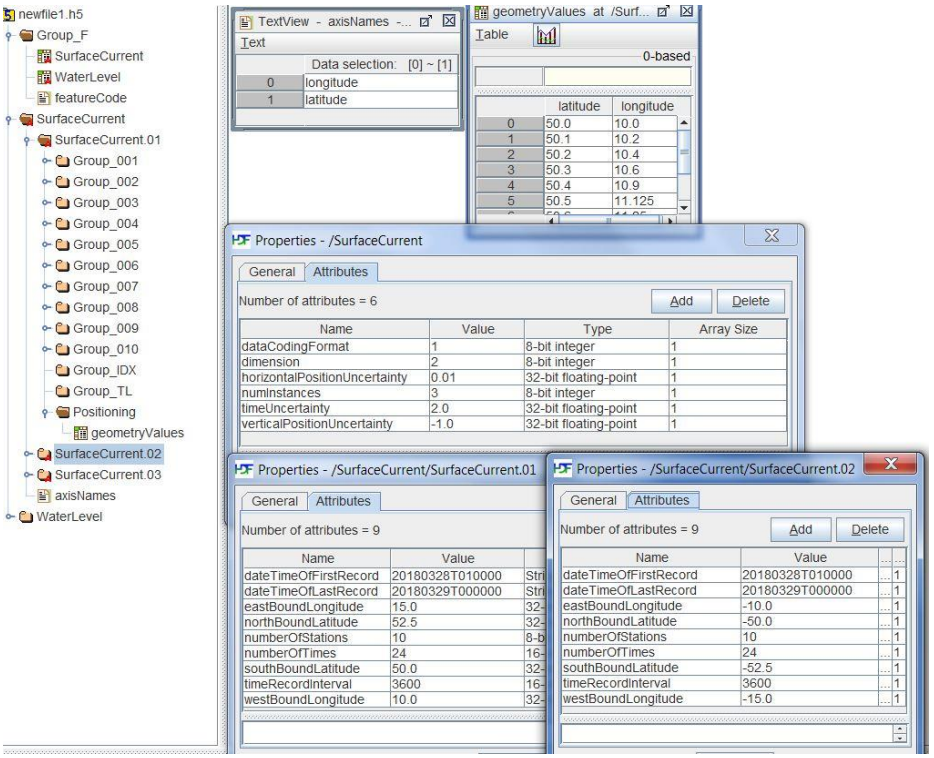


Figure 10c-9 – Illustrative example of dataset structure.

10c-9.8 Tiling information group

This group encodes information about the tiling scheme used in the (S-100) dataset. It is present if and only if the data is encoded in more than a single tile. Some tiling schemes are described in Part 8 (clause 8-7). This edition of the HDF5 profile supports only two tilings: simple grid and variable density simple grid. In both cases, the extents of the tiles are specified in terms of their bounding boxes (Table 10c-12).

The spatial union of tile surfaces must cover all the features in the (S-100) dataset, but the converse is not a requirement. (Informally, this means that there may be parts of tiles that are not covered by the geometry of any feature in the dataset, but not vice versa – there cannot be parts of feature geometry that are not covered by at least one tile.)

Note that tiling is not quite the same concept as “chunking”, as the latter is defined in HDF5 and NetCDF – tiles are coordinate-based geographical partitions, while chunking defines slices of HDF5 datasets for storage and retrieval performance optimization.

Table 10c-13 – Tiling information group

Group	HDF5 Category	Name	Data Type or HDF Category	Remarks / Data space
/Group_TL	Attribute	numTiles	Integer	Number of tiles value > 0
	Attribute	tilingScheme	Enumeration	1: Simple grid 2: Variable-density simple grid (Product Specification must pick one)

	Dataset	tiles	Array Compound (Float X 4, Integer)	Bounding boxes of tiles. Components: westBoundLongitude: Float eastboundLongitude: Float southBoundLatitude: Float northBoundLatitude: Float tileID: Integer (tile identifier)

The details of tiling methods are left to product specifications in this edition of S-100. This profile does not specify an ordering for the tiles, nor does it control the use or non-use of hierarchical tiling schemes. Part 8 (clause 8-7.1) requires that any tiling scheme used must be completely described as part of the Product Specification for a particular data product. This includes the dimensions, location and data density of tiles as well as a tile identification mechanism (tileID).

10c-9.9 Indexes group

The indexes group encodes spatial indexing information, if used by the Product Specification. This group is encoded if and only if the Product Specification prescribes a spatial indexing method and requires explicit encoding of the spatial index.

Table 10c-14 – Indexes group

Group	HDF5 Category	Name	Data Type or HDF Category	Remarks / Data space
/Group_IDX	Attribute	indexingMethod	Enumeration	Spatial indexing method. (Described in product specifications)
	Dataset(s)	spatialIndex	(Depends on indexing method)	Data encoding the spatial index. (Described in product specifications)

The details of indexing methods and the structure of index datasets are left to product specifications in this edition of S-100.

10c-9.10 Positioning group

Depending of the data coding format, there can be a positioning group, Positioning. This group contains no attributes, it contains a coordinates dataset, which is an array of compound type with components named the same as the *axisNames* dataset in the Feature Container group. This group is used for values of *dataCodingFormat* of 1, 3, 4, 7, and 8 (clause 10c-9.3). It is not used for *dataCodingFormat* = 2 (regular grids), 5 (irregular grid), or 6 (variable cell size grid).

The traversal order for grids of different types is specified by the carrier metadata attribute *sequencingRule* in the feature container group. Traversal order is not used for fixed station, moving platform, ~~or~~ TIN, or fixed station (stationwise) data (*dataCodingFormat* = 1, 4, ~~or~~ 7, or 8).

The dimensionality D of the data is given by the *dimension* metadata attribute in the feature container group.

10c-9.10.1 Spatial representation strategy

For regularly gridded data (dataCodingFormat = 2), the number of grid points in each dimension, grid spacing, and grid origin are encoded in metadata attributes. (For example, for 2-D grids, the metadata attributes *numPointsLongitudinal* and *numPointsLatitudinal* encode the points along the longitude and latitude axes.) Given these parameters and the indexes of a point in the grid, the position of the point can be computed by simple formulae.

For fixed station time series data, ungeorectified gridded data, moving platform data, ~~and~~ triangulated irregular networks, and fixed station (stationwise) time series data (that is, when dataCodingFormat is 1, 3, 4, ~~or~~ 7, or 8), the location of each point must be specified individually. This is accomplished in an HDF5

dataset in the “Positioning” group, which gives the individual location coordinates (for example, longitude and latitude) for each location. For fixed station time series and fixed station (stationwise) time series data, the longitude and latitude values are the positions of the stations; the number of stations is *numberOfStations*. For ungeorectified gridded data, the values are the positions of each point in the grid; the number of grid points is *numberOfNodes*. For moving platform data, values are the positions of the platform at each time; the number of platforms is *numberOfStations*.

For irregular grid and variable cell size coverages (dataCodingFormat 5 and 6), the storage format uses the same metadata as for regular grids plus HDF5 datasets indicating which cells are populated or aggregated respectively. The latter datasets encode the locations of cells in terms of grid point or cell address in grid coordinates – that is, the indexes in the grid, or the Morton code – not the geographic (latitude/longitude) coordinates. The sequencing and axis order needed for interpretation of the grid coordinates as geographic coordinates are given by the *sequencingRule* and *scanDirection* attributes respectively. By combining this information with the grid parameters provided in metadata, the position of populated cells/points can be computed with slightly more complex formulae than for regularly gridded data.

The Table below summarizes the strategies for storage of coordinate information.

Table 10c-15 – Positioning dataset types and dimensions for different coverage types

Type of coverage	dataCoding Format	Structure of coordinates dataset
Fixed Stations	1	1-dimensional Array, length = numberOfStations
Regular Grid	2	not used
Ungeorectified Grid	3	1-dimensional Array, length = numberOfNodes
Moving Platform	4	1-dimensional Array, length = numberOfTimes
Irregular Grid	5	not used
Variable cell size	6	not used
TIN	7	1-dimensional Array, length = numberOfNodes
Fixed Stations (Stationwise)	8	1-dimensional Array, length = numberOfStations

NOTE: Multiple moving platforms can be encoded as different feature instances.

10c-9.10.2 Data structures for storing position information for grid points

The number of positions is computed as specified in Table 10c-4 in clause 10c-9.3.

Table 10c-16 – Positioning group

Group	HDF5 Category	Name	Data Type	Data Space
/Positioning	Dataset	geometryValues	Compound (Float X D)	Array (1-dimensional) of size dependent on dataCEncodingFormat, see Table 10c-15 Components of compound type are named according to the axis names (for example, ‘latitude’, ‘longitude’, ‘Z’, etc) The dimension D and the component names are specified in the feature container group *dimension* attribute and *axisNames* dataset respectively (Tables 10c-10 and 10c-9)
	Dataset	triangles (optional)	Array (Integer)	Array (2-d): dimensions numberOfTriangles X 3 Each row encodes a triangle as the indexes of 3 coordinates in the *geometryValues* dataset Required only for dataCEncodingFormat = 7 (TIN)

	Dataset	adjacency (optional)	Array (Integer)	Array (2-d): dimensions numberOfTriangles X 3 Each row encodes the triangles adjacent to any given triangle by specifying their indexes in the triangles dataset adjacency[i][0] = triangle adjacent to the edge specified by triangles[i][0] & triangles[i][1] adjacency[i][1] = triangle adjacent to edge triangles[i][1] & triangles[i][2] adjacency[i][2] = triangle adjacent to edge triangles[i][2] & triangles[i][0] Elements for edges without adjacent triangles are filled with the value -1 Applicable only for data~~C~~EncodingFormat = 7 (TIN), but optional even for TIN.

10c-9.11 Data values groups

The structure of data values content is analogous to that of positioning content, except that regular grid data values (dataCEncodingFormat = 2) are stored as a D-dimensional array corresponding to the axis order in the *axisNames* dataset in the Feature Container group (major index precedes minor index). The dimensionality D is encoded in the *dimension* attribute of the Feature Container group.

EXAMPLE: For two-dimensional regularly gridded data, the value arrays are two dimensional, with dimensions numPointsLongitudinal and numPointsLatitudinal.

For fixed station time series data, ungeorectified gridded data, moving platform data, and triangulated irregular networks, and fixed station (stationwise) time series data (that is, when dataCodingFormat is 1, 3, 4, or 7, or 8), the data values are stored as 1-dimensional datasets of length given by the numberOfTimes, numberOfNodes, or numberOfStations metadata attribute of the feature instance group (Table 10c-12) depending on the dataCEncodingFormat.

For irregular grid coverages (dataCodingFormat=5), the storage of data values is the same as for ungeorectified grids etc (that is, a 1-dimensional array of value records, length = numberOfNodes) but the value group includes a dataset that specifies the grid point or cell address associated to each entry in the values array. This second dataset uses grid coordinates – that is, the indexes in the grid, or the Morton code – not the geographic (latitude/longitude) coordinates. The sequencing and axis order needed for interpretation of the grid coordinates as geographic coordinates are given by the *sequencingRule* and *scanDirection* attributes respectively.

For variable cell size coverages (dataCodingFormat=6) the storage of data values is the same as for irregular grid coverages but the values groups contains the grid index dataset used by irregular grids as well as a dataset indicating which cells are aggregated into larger cells.

The various datasets and their components are described in the following Table.

Table 10c-17 – Values dataset type and size for different data encoding formats

Type of coverage	dataCoding Format	Structure of values and auxiliary HDF5 datasets	HDF5 Dataset components
Fixed Stations	1	values: 1-dimensional Array, length = numberOfStations	Compound, one component for each attribute specified in the corresponding feature information dataset in the Feature Information group (Table 10c-8) Component name: attribute code as specified in the feature information dataset Component type: Any appropriate HDF5 datatype consistent with the attribute datatype specified in the Feature Information dataset
Regular Grid	2	values: D-dimensional array, dimensions specified by: 2-D: numPointsLatitudinal X numPointsLongitudinal 3-D: numPointsLatitudinal X numPointsLongitudinal X numPointsVertical If *cellGeometry* is present in feature instance group: product of all cellGeometry[i].numPoints values.	As for fixed stations
Ungeorectified Grid	3	values: 1-dimensional Array, length = numberOfNodes	As for fixed stations
Moving Platform	4	values: 1-dimensional Array, length = numberOfTimes	As for fixed stations
Irregular Grid	5	values: 1-dimensional Array, length = numberOfNodes	As for fixed stations. Ordered according to the sequence rule specified by the *sequencingRule* and *scanDirection* attributes of the Feature Container group (Table 10c-10)
		gridIndex: 1-dimensional Array, length = numberOfNodes (dataset attribute codeSize: Integer - gives the length of the bitfield)	Element type: bitfield (length determined by grid dimensions) Order of element corresponds to the values array Each element contains the code of the cell (grid point) according to the sequence rule specified by the *sequencingRule* and *scanDirection* attributes. For example, the Morton code of the cell
Variable cell size	6	values: 1-dimensional Array, length = numberOfNodes	As for fixed stations
		gridIndex: 1-dimensional Array, length = numberOfNodes (dataset attribute codeSize: Integer - gives the length of the bitfield)	(As for the *gridIndex* Array for irregular grids) For cells that aggregate multiple unit cells, use the first cell (grid point) encountered in the sequencing order. For example, the Morton code of the cell
		cellScale: 1-dimensional Array, length = numberOfNodes	Element type: Compound

			Order of elements corresponds to the values array Components of the compound type are named according to the axis names in the axisNames dataset in the Feature Container group Each component is of type Integer and gives the number of cells aggregated along the named axis
TIN	7	values: 1-dimensional Array, length = numberOfNodes	~~(~~As for fixed stations~~)~~
Fixed Stations (Stationwise)	8	values: 1-dimensional Array, length = numberOfTimes	As for fixed stations

NOTES:

2) 64-bit unsigned integers for gridIndex arrays allow 4-D grids with a maximum of 2^{16} - 1 (65,535) points/cells in each dimension.

3) The *gridIndex* datasets have an integer attribute named *codeSize* that gives the length (in bits) of the bitfield that contains the index. This depends on the type of code and the number of dimensions. For example, a 2-D grid with 8 points in each dimension needs 6-bit Morton codes.

4) The size of the bitfield is calculated by multiplying the number of bits needed to accommodate the largest dimension by the number of dimensions (D). To reduce complexity each dimension is allocated the same number of bits in the bitfield. For example, a 200 X 1000 array is given a 20-bit bitfield, calculated as:

$$\text{codesize } = 2 \times \max(\lceil \log_2 200 \rceil, \lceil \log_2 1000 \rceil).$$

The Figure that follows depicts *gridIndex* and *cellScale* arrays for an irregular grid (left) and variable cell size array (right). Both use Morton codes and 2-D grids of (nominally) 4×4 cells in each dimension. Note that in the Figure it is the cells rather than grid points that are assigned codes. The panels on the left describe an irregular grid with 11 populated cells. The panels on the right describe a variable cell size grid with two aggregate cells, each aggregating 2×2 unit cells.

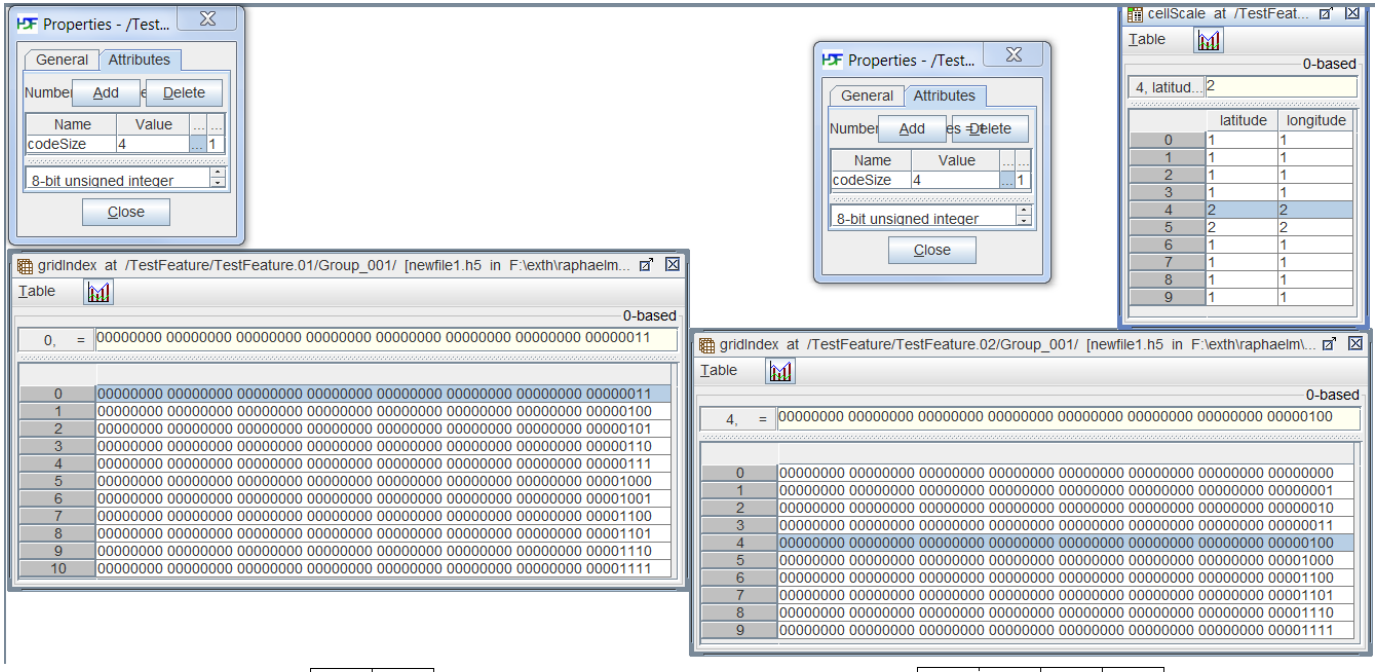
The grids themselves are depicted below the panels, with the Morton codes shown in the respective cells[3]. The example on the right also indicates the scaling of each cell in parentheses (it is assumed that the scaling is the same in all dimensions; that is, cells 0100 and 1000 each aggregate 2×2 regions of the grid).

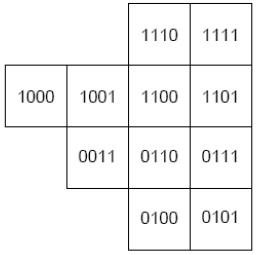
For the irregular grid example, the missing cells are not shown in the grid. For the variable cell size example, the greyed cells are aggregated with cells 0100 or 1000.

For variable cell size grids, this profile specifies the size of aggregated cells in terms of the number of unit cells they cover in each direction, instead of applying the same zoom factor in each dimension as depicted in the example at the bottom right of the Figure. This is for the better accommodation of rectangular and odd-shaped aggregations. Odd-shaped regions must be split into multiple rectangular aggregations. (Using rectangular aggregations has an associated extra storage cost.)

Further optimizations may be addressed in future editions of this profile.

[3] The two grid depictions at the bottom of the Figure are from “Elevation Surface Model Standardized Profile” (DGIWG 116-1) Ed. 1.0.1, Defence Geospatial Information Working Group (10 June 2014).





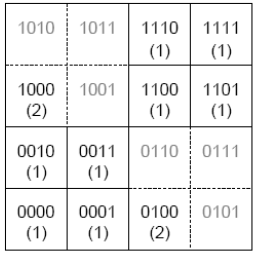


Figure 10c-10 – Illustrative examples of grid index array for irregular grids (left) and grid index and cell scale arrays for variable cell size grids (right).

The structure of the data values groups can now be described. Each group is structured as depicted in the Table below.

Table 10c-18 – Structure of values groups

Group	HDF5 Category	Name	Data Type	Data Space
/Group_NNN	Attribute	See Table 10c-19~~timePoint~~ ~~(optional)~~	(see Table)~~String (date-time format)~~	Single-valued attributes as described in Table 10c-19~~Time point for time series data~~ ~~For other types of data, it can be used to indicate the time for the whole grid~~
	Dataset	values	Compound	Array of Compound type, with array rank depending on dataCodingFormat and spatial dimension, as described in Table 10c-17
	Dataset	gridIndex	Bitfield	Required for dataC~~E~~odingFormat = 5 or 6 Described in Table 10c-17
	Dataset	cellScale	Compound	Required for dataC~~E~~odingFormat = 6 Described in Table 10c-17

Time series data for all except the moving platforms and fixed station (stationwise) format (dataC~~E~~odingFormat = 4, 8) are encoded in successive groups contained within the instance group.

The sub-Groups each contain a date-time value, and the value record arrays. For dataCodingFormat = 2, 3, 5, or 6, the date-time is for the entire grid. The data value arrays are two dimensional, with a number of columns (numCOLS) and rows (numROWS). For a time series, the data values will be for each time in the series. For a grid, the speed and direction values will be for each point in the grid.

The Groups are numbered 001, 002, etc, up to the maximum number of Groups, numGRP. For all coverage types except moving platforms and fixed station (stationwise) data, the number of Groups is the number of time records. For moving platform data, there is only one Group, corresponding to a single platform; additional platforms can be accommodated in additional feature instances. For fixed stations (stationwise) data, the number of Groups is the number of stations.

The number of individual Groups is given by the metadata variable, *numGRP*. The uniform time interval between individual times is given by the metadata variable *timeRecordInterval*.

Values which represent different times are stored sequentially, from oldest to newest. The initial date-time value is contained in a metadata attribute (Table 10c-12). By knowing the time interval between each record, the time applicable to each value can be computed.

Groups, if they represent different times, are numbered sequentially, from oldest to newest.

Attributes (Table 10c-19) may consist of a single value (timePoint) as for the gridded data, or an extended list of variables that describe several characteristics of ~~stationwise~~ fixed station (stationwise) time series data (dataCodingFormat=8~~1~~).

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Table 10c-19 – Attributes of values groups

No	Name	Camel Case	Mult.	Data Type	Remarks and/or Units
dataCodingFormat = 1, 2, 3, 5, 6 or 7					
1	Time stamp	timePoint	1	Character	DateTime
dataCodingFormat = 8					
1	Name of the station	stationName	0..1	Character	
2	Station identification number	stationNumber	0..1	Integer	
3	Number of time records	numberOfTimes	0..1	Integer	Only mandatory if *timeIntervalIndex* = 1. Use at Values Group level only for dataCodingFormat = 8.
4	Index for time interval	timeIntervalIndex	1	(Integer)	1 (TRUE) denotes uniform time interval; interval provided by *timeRecordInterval*. 0 (FALSE) denotes non-uniform time interval. This is a boolean implemented as described in Table 10c-1.
5	Time interval	timeRecordInterval	0..1	Integer	Only if *timeIntervalIndex* = 1 The uniform interval between time records. Units: Seconds. Use at Values Group level only for dataCodingFormat = 8.
6	Valid time of earliest value	startDateTime	0..1	Character	Only mandatory if *timeIntervalIndex* = 1. DateTime format
7	Valid time of latest value	endDateTime	0..1	Character	Only mandatory if *timeIntervalIndex* = 1. DateTime format
	(additional attributes)				(As specified in Product Specification)

10c-10 Common Enumerations

10c-10.1 CV_CommonPointRule

ISO 19123 states that "CV_CommonPointRule is a list of codes that identify methods for handling cases where the DirectPosition input to the evaluate operation falls within two or more of the geometric objects. The interpretation of these rules differs between discrete and continuous coverages. In the case of a discrete coverage, each CV_GeometryValuePair provides one value for each attribute. The rule is applied to the set of values associated with the set of CV_GeometryValuePairs that contain the DirectPosition. In the case of a continuous coverage, a value for each attribute shall be interpolated for each CV_ValueObject that contains the DirectPosition. The rule shall then be applied to the set of interpolated values for each attribute."

Table 10c-2019 – CV_CommonPointRule enumeration

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Item	Name	Description	Code	Remarks
Enumeration	CV_CommonPointRule	Codes that identify methods for evaluating the coverage at positions that fall on the boundary or in an area of overlap between geometric objects in the domain of the coverage		ISO 19123 CV_CommonPointRule
Literal	average	return the mean of the attribute values	1	
Literal	low	use the least of the attribute values	2	
Literal	high	use the greatest of the attribute values	3	
Literal	all	return all the attribute values that can be determined for the position	4	
~~Literal~~	~~start~~	~~use the *startValue* of the second CV_ValueSegment~~	~~5~~	~~only for segmented curve coverages~~
~~Literal~~	~~end~~	~~use the *endValue* of the first CV_ValueSegment~~	~~6~~	~~only for segmented curve coverages~~

NOTE: Use of 'start' and 'end' is prohibited for product specifications conforming to this edition of S-100, since segmented curves are not included among the coverages defined in Part 8 of this edition. They are included in the Table because the figures in Part 8 include them.

10c-10.2 CV_SequenceType

The scan methods are described in detail in ISO 19123. The order in which scanning takes place is the same as the order of axes in the attribute *scanDirection* (Table 10c-10). The starting location of the scan is given in the attribute *startSequence* (Table 10c-12).

Note: Product Specification authors and producers should take care that the start location is compatible with the sequence rule and scan direction; for example, linear sequencing would be incompatible with a start location at the upper bound of the grid bounding box and forward scan order in *scanDirection*.

Table 10c-2021 – CV_SequenceType enumeration

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Item	Name	Description	Code	Remarks
Enumeration	CV_SequenceType	Codes that identify the method of ordering grid points or value records		ISO 19123 CV_ SequenceType
Literal	linear	Sequencing is consecutive along grid lines, starting with the first grid axis listed in scanDirection	1	For example, for 2-D grids with scan direction=(x,y), scanning will be in row-major order
Literal	boustrophedonic	Variant of linear sequencing in which the direction of the scan is reversed on alternating grid lines. For grids of dimension > 2, it is also reversed on alternating planes	2	
Literal	CantorDiagonal	Sequencing in alternating directions along parallel diagonals of the grid. For dimension > 2, it is repeated in successive planes	3	
Literal	spiral	Sequencing in spiral order	4	

Literal	Morton	Sequencing along a Morton curve	5	
Literal	Hilbert	Sequencing along a Hilbert curve	6	

Morton curves are generated by converting the grid coordinates (axial indexes) of each grid point to binary numbers and interleaving the binary digits of the results to produce the Morton code of the grid point. The method is documented in computer science textbooks as well as ISO 19123 and other accessible articles[4]. Hilbert curves are more complex but descriptions are available in computer science and other reference texts (for example, the non-normative references in clause 10c-4.2).

10c-10.3 S100_CV_InterpolationMethod

S100_CV_InterpolationMethod extends the ISO 19123 codelist CV_InterpolationMethod with the 'discrete' literal. The ISO 19123 CodeList CV_InterpolationMethod includes nine interpolation methods. Each is used in the context of specified grid types, indicated in the Remarks column. The entire list from ISO 19123 is reproduced since the figures in Part 8 depict all the ISO values. S-100 adds a 'discrete' literal for use when there is no interpolation.

Table 10c-~~21~~ 22 – S100_CV_InterpolationMethod enumeration

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Item	Name	Description	Code	Remarks
Enumeration	S100_CV_InterpolationMethod	Codes for interpolation methods between known feature attribute values associated with geometric objects in the domain of the discrete coverage		Extension of ISO 19123 CV_ InterpolationMethod
Literal	nearestneighbor	Assign the feature attribute value associated with the nearest domain object in the domain of the coverage	1	Any type of coverage
~~Literal~~	~~linear~~	~~Assign the value computed by a linear function along a line segment connecting two point value pairs, or along a curve with positions are described by values of an arc-length parameter~~	~~2~~	~~Only segmented curves~~
~~Literal~~	~~quadratic~~	~~Assign the value computed by a quadratic function of distance along a value segment~~	~~3~~	~~Only segmented curves~~
~~Literal~~	~~cubic~~	~~Assign the value computed by a cubic function of distance along a value segment~~	~~4~~	~~Only segmented curves~~
Literal	bilinear	Assign a value computed by using a bilinear function of position within the grid cell	5	Only quadrilateral grids
Literal	biquadratic	Assign a value computed by using a biquadratic function of position within the grid cell	6	Only quadrilateral grids
Literal	bicubic	Assign a value computed by using a bicubic function of position within the grid cell	7	Only quadrilateral grids
Literal	lostarea	Assign a value computed by using the lost area method described in ISO 19123	8	Only Thiessen polygons
Literal	barycentric	Assign a value computed by using the barycentric method described in ISO 19123	9	Only TIN
Literal	discrete	No interpolation method applies to the coverage	10	

[4] At the time of writing there is even a Wikipedia article: <https://en.wikipedia.org/wiki/Z-order_curve> (retrieved 26 April 2018).

NOTES:

1) The literals *linear*, *quadratic*, and *cubic* are prohibited since this edition does not include segmented curve coverages.
2) Interpolation parameters, if needed, must be encoded in the *interpolationParameters* dataset (Table 10c-10).

10c-11 Support files

The HDF5 format does not encode support file information as feature attributes; that is, application schema thematic attributes cannot be references to support files. This means that references to pictures or text files, etc, are not permitted in coverage features.

Also, feature and information associations from coverage to vector features are not permitted.

The HDF5 "metadata" attribute of the root group is a reference to an external metadata file. The reference must be a string of the form:

fileRef:<fileName>

where <fileName> is the base name of the ISO 8211 or GML file. The extension part of the file name is not used.

Mixed vector-coverage data products may continue to use support files in connection with vector feature classes and define vector feature or information classes with attributes that are references to support files, as usual.

10c-12 Catalogue and metadata files

Exchange set catalogues and metadata files must conform to the standard XML schemas for catalogues and metadata defined for this edition of S-100 and the relevant ISO standards. The files must be named as follows:

CATALOG.XML (or .xml) Exchange catalogue XML file.

MD_<HDF5 data file base name>.XML (or .xml) ISO metadata

10c-13 Vector spatial objects, features, and information types

In some circumstances it may be necessary to use vector spatial objects, such as area of influence polygons. This edition of the profile does not encode vector spatial objects directly in the HDF5 data file. Instead, the spatial objects should be defined in an external file (either GML or ISO 8211 format) and a reference to the spatial object encoded. The reference must be a string of the form:

extObjRef:<fileName>:<recordIdentifier>

where <fileName> is the base name of the ISO 8211 or GML file, and <recordIdentifier> is the record identifier of the vector object record within that file. The extension part of the file name is not used. The record identifier is the gml:id for GML datasets, or the record identification number (RCID) for ISO 8211 datasets. The file must be present in the same exchange set.

This method can be used to reference polygons, etc, defined in external files in GML or 8211 format data files in the same exchange set. It can also be used to reference feature or information type instances in the GML or ISO 8211 file.

EXAMPLES:

USSFC00001:S093546 references the object with gml:id S093456 in the GML data file USSFC00001.GML (GML).

USSFC00001:93546 references the object with record identifier 93456 in the ISO 8211 data file USSFC0000.000 (ISO 8211).

10c-14 Constraints and validation

10c-14.1 Validation tests

Validation tests must be defined in the Product Specification, and include checks that:

- HDF5 file structure conforms to this profile;
- Mandatory attributes in the groups are present according to the encoded value of dataCodingFormat;
- Group, dataset, and attribute names conform to this profile;
- Lengths of positioning and value records arrays are consistent;
- Components of compound types are named as required by the specification.

10c-15 Updates

Updates to HDF5 datafiles are recommended to follow the same structure as the base HDF5 datafile. Updates may include only the HDF5 datasets which are being updated. The specific datasets being updated are included in their entirety in the update datafile.

This clause implies that S-100 datasets may be updated in part as well as replaced completely by updated data, but product specifications are not required to permit partial updates. They may define update creation and management processes which are more suitable for their particular domains and applications. However, if updates to parts of S-100 datasets are allowed, the rule in the previous paragraph must be followed.

10c-16 Summary of model

The basic structure of the HDF5 profile (Figure 10c-7~~Figure 10c-7~~) can now be presented as a more model using the group and dataset specifications in the previous sections. The conceptual model of HDF5 file contents is shown in the following Figure. This Fgure shows the group structure and the datasets which contain spatial representations and data values. (Metadata attributes and datasets containing metadata are not included for the sake of simplicity.) The *MatchingOrders* association indicates that the sequences of elements in the associated datasets are interdependent.

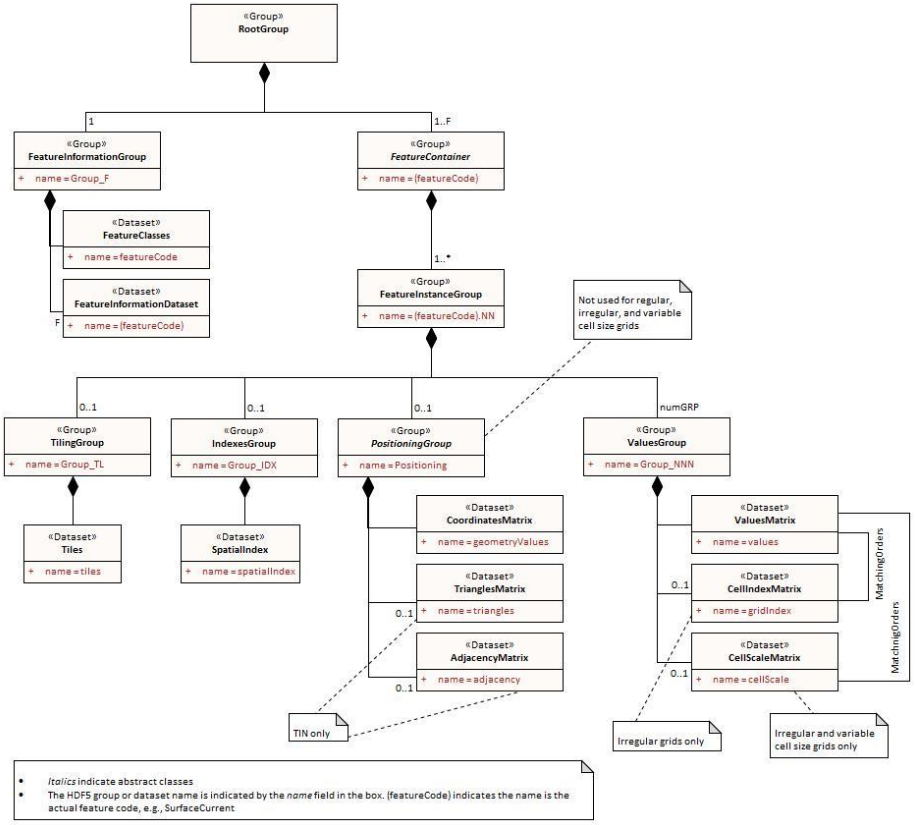

Figure 10c-11 - Conceptual model of content

10c-17 Rules for product specification developers

10c-17.1 Defining the format for a product specification from this profile

Most product specifications will need only a subset of this profile. However, all product specifications must include the mandatory elements of this profile.

The logical structure of the datafile must conform to the logical structure depicted in Figure 10c-11 and specified in the preceding sections.

The 'Data Format' section of the Product Specification must indicate what part of the profile is used (for example, which values *dataCodingFormat* can take, which groups and datasets are used, whether the spatial representation is 2-dimensional, 3-dimensional, etc).

UML diagrams derived from the conceptual structure depictions in this Part are recommended but not mandatory. Documentation tables specifying product-specific constraints or limitations on metadata and content must be provided unless the corresponding table in this profile applies without modification.

Specifications which require grids with non-uniform spacing must be treated as ungeorectified grids and have the coordinates of each position explicitly encoded.

This profile does not prevent a feature class from having different coverage types of coverage, but repeating spatial attributes for the same instance is not possible in this profile. This means that a feature instance cannot have two grids, whether or not they are the same coverage type. If product specifications

appear to need multiple coverages for the same instance, consider combining the two into a single coverage object or using two feature instances.

Feature and information associations are not fully implemented in this profile. However, it is possible to link coverage objects to vector feature or information objects in accompanying GML or ISO 8211 datasets using the object reference methods described in clause 10c-13. References to vector objects, such as influence polygons must be encoded using the same method.

Product specifications should specify the precision of the numeric metadata elements which are encoded in the HDF5 datafile, either individually or in blanket statements. For example, a product specification may require that all the metadata attributes of type Float be encoded using 64-bit floating point numbers.

If uncertainty in positions or data values varies over the spatial extent of a single feature, Product Specification developers should consider solutions as part of the product specification; for example, subdividing the grid into different feature instances, or addressing this at the application schema level by defining an overlay feature to encode uncertainties or adding an uncertainty attribute to the values record. This Part does not require any specific approach to this problem.

10c-17.2 Miscellaneous rules

The use of variable length strings as components of compound types is discouraged due to reported performance problems.

In theory, the use of tiles can interact with HDF5 chunking to affect performance. Product specifications for which performance is a significant consideration may need to consider possible interaction effects and investigate their magnitude and consequences.

10c-17.3 Extensions of this profile

Product specifications may extend the format in this profile by defining additional data structures or extending the data structures defined in this profile, but all extensions must retain the core specifications of this profile so that **implementations must be able to ingest and portray data without processing the additional data structures**. **The Product Specification must be written so that use of these extra data structures for processing or portrayal is optional.**

Such additions should be placed in the appropriate location in the HDF5 data file; for example, spatial indexes in the Group_IDX group.

Extensions must not reuse the names of items defined in this profile. Items defined in this profile must not be renamed in product specifications.

Some examples of permissible and impermissible extensions are given below.

- Permissible extensions:
  - Quadtree index, added as an HDF5 dataset in the indexes group.
  - Extension of the value record structure that retain the core format described in this profile (that is, the 1-d array structure and the specified components).
  - Linear scale arrays indicating the grid points on each axis where the cell size changes, as an adjunct to variable cell size arrays.
  - Product-specific metadata as attributes of any of the groups specified in this profile.
  - Product-specific metadata as additional HDF5 datasets in any of the groups specified in this profile.
  - Additional groups, provided these are not used as substitutes for one of the mandatory groups in this profile.
- Impermissible extensions:
  - Changes to the rank of an array dataset type; for example, using a 2-d array in place of a 1-d array.
  - Changes to the rules for naming of a component of a compound data type defined in this profile.

10c-17.4 Extensions that add metadata

While section 10c-17.3 permits adding metadata, defining product-specific metadata means that implementation must – if they are to do anything with the additional metadata other than merely display it – include product-specific coding in applications. Given that the S-100 ecosystem includes multiple data products which would ideally all be processable (including portrayal) by an S-100 application, this Part recommends against adding product-specific metadata that has any effects on processing or portrayal. If such additions are considered essential they should be proposed as an extension to the S-100 framework itself using the maintenance mechanism described in S-100 and related documents. Display-only metadata (that is, where the application is only expected to display the content of the added attribute) may be added but is discouraged.

10c-18 Implementation guidance

The HDF5 C API includes interfaces for determining the types of compound type components. This suggests that the size of a datatype can be checked to mitigate possible conversion issues.

The HDF5 C API also defines iterators for iterating over attributes or items in a group. These iterators can be used to discover profile datasets, groups, or attributes from datasets, groups, and attributes defined only in individual product specifications (the product-specific items will have names different from the profile items).

The order in which objects are retrieved may not be the same as the creation order. Implementers should allow for this or investigate the availability of order-preserving functions in the HDF5 API.

Linkage between the XML feature catalogue and objects in the HDF5 file is preserved by using the (camel case) codes for features, and attributes.

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