Resolution 909 addressed the restart for project 19123-1.

The text of the resolution states:

Resolution 909 Reinitiating the project for the revision of ISO 19123-1 Schema for coverage geometry and functions

ISO/TC 211 instructs the secretariat to send out a ballot to reinitiate the work on the revision of ISO 19123-1 as 36-month project. ISO/TC 211 appreciates the nomination of Dr. Liping Di from national member body of the USA to continue as project leader. ISO/TC 211 instructs the secretariat to send out a call for experts within 30 days.

In order to continue the work the current draft version of the working document has been put into the form of an initial Working Draft document WG6N522. This Working Draft addresses the initial comments received when the revision project was begun in 2016 and all of the input received in the several project team meetings since that time. However, there are still aspects of the document that need to be improved.

The German national body has provided a major contribution to the work on 19123-1 to assist in alignment with 19123-2 the Coverage Implementation Specification. This input is in WG6N523 DIN Spec 18144. Aspects of the DIN Spec have been incorporated into this document.
Geographic information — Schema for coverage geometry and functions -- Part 1: Fundamentals

Information géographique — Schéma de la géométrie et des fonctions de couverture – Partie 1 : Principes de base

Working Draft
for revision for project 19123-1
based on document WG6 N 522
November 2018 and the German DIN contribution WG6 N 522 - DIN SPEC 18144(E)
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 19123-1 was prepared by Technical Committee ISO/TC 211, Geographic information/Geomatics.
Introduction

Geographic phenomena fall into two broad categories — discrete and continuous. Discrete phenomena are recognizable objects that have relatively well-defined boundaries or spatial extent. Examples include buildings, streams and measurement stations. Continuous phenomena vary over space and have no specific extent. Examples include temperature, soil composition and elevation. A value or description of a continuous phenomenon is only meaningful at a particular position in space (and possibly time). Temperature, for example, takes on specific values only at defined locations, whether measured or interpolated from other locations.

These concepts are not mutually exclusive. In fact, many components of the landscape may be viewed alternatively as discrete or continuous. For example, a stream is a discrete entity, but its flow rate and water quality index vary from one position to another. Similarly, a highway can be thought of as a feature or as a collection of observations measuring accidents or traffic flow, and an agricultural field is both a spatial object and a set of measurements of crop yield through time.

Historically, geographic information has been treated in terms of two fundamental types called vector data and raster data.

"Vector data" deals with discrete phenomena, each of which is conceived of as a feature. The spatial characteristics of a discrete real-world phenomenon are represented by a set of one or more geometric primitives (points, curves, surfaces or solids). Other characteristics of the phenomenon are recorded as feature attributes. Usually, a single feature is associated with a single set of attribute values. ISO 19107:2019 provides a schema for describing features in terms of geometric and topological primitives.

"Raster data", on the other hand, deals with real-world phenomena that vary over space and time. It contains a set of values, each associated with one of the elements in an array of points or cells. It is usually associated with a method for interpolating values at spatial positions between the points or within the cells. Since this data structure is not the only one that can be used to represent phenomena that vary continuously over space, this document uses the term “coverage,” adopted from the Abstract Specification of the Open GIS Consortium[1], to refer to any data representation that assigns values directly to spatio-temporal position. A coverage is a function from a spatial, temporal or spatiotemporal domain to an attribute range. A coverage associates a position within its domain to a record of values of defined data types.

A coverage function has as its domain, an area or space defined by any combination of the three physical spatial dimensions plus the physical dimension time. Mathematics also uses the word dimension to represent an axis in a numeric space. The mathematical meanings of dimension and space are broader than those used in the physical world. The three physical spatial dimensions plus the physical dimension time may be mapped to mathematical dimensions. The range of a coverage function is a set of attribute values for each of the attribute types. These range values may also be represented as mathematical dimensions. That is, we have two complementary ways of viewing a coverage function, as a domain and range or as a mathematical space based on axes.

In this document, coverage is a subtype of feature. A coverage is a feature that has multiple values for each attribute type, where each direct position within the geometric representation of the feature has a single value for each attribute type.

A coverage consists of spatio-temporally extended objects where information content depends on (and varies with) the particular coordinate where it is probed. Standardization in this area is a cornerstone for other geographic information design, specification and standardization.

---

1 “Raster” is a widely used but imprecise colloquial term that encompasses imagery, gridded and other types of coverage data.
Such space-time varying objects are described as sets of geographic objects ("features"), called coverages. The feature objects collected in a coverage define the positions where values are available (called Direct Positions), and the individual values associated with each feature.

NOTE Direct Positions can be of different dimension. For example, in a raster image modelled as a coverage the Direct Positions will be the grid points; in a Multi-Solid Coverage a Direct Position is given by the interior of a 3D solid.

As the concept of feature collections is already provided in ISO 19107:2019, a coverage can be seen as a special type of feature. However, coverages are not just arbitrary feature collections but impose homogeneity – most importantly, all features contained are of the same type, their coordinates are expressed in the same CRS, and the values associated with the features all have the same data type.

In practice, coverages encompass regular and irregular grids, point clouds, and general meshes. Examples include raster data, triangulated irregular networks, point sets and polygon coverages. Coverages are multi-dimensional, including examples like 1D sensor timeseries, 2D satellite images, 3D x/y/t image timeseries and x/y/z geophysical voxel data, and 4D x/y/z/t climate and ocean data. Axes of such coverages can have spatial, temporal, or any other dimension, and they can be combined freely.

EXAMPLE The electromagnetic spectrum is an example for an axis with neither spatial nor temporal semantics. As such a spectral axis can be defined following the rules of ISO 19111-1, so it qualifies as a coverage axis.

A coverage which provides values only at the Direct Positions is called "a discrete coverage" (discrete in its domain); if interpolation information is added so that values can be obtained also beyond the coverage's Direct Positions such a coverage is called "a continuous coverage".

Just as the concepts of discrete and continuous phenomena are not mutually exclusive, their representations as discrete features or coverages are not mutually exclusive. The same phenomenon may be represented as either a discrete feature or a coverage. A city may be viewed as a discrete feature that returns a single value for each attribute, such as its name, area and total population. The city feature may also be represented as a coverage that returns values such as population density, land value or air quality index for each position in the city.

A coverage, moreover, can be derived from a collection of discrete features with common attributes, the values of the coverage at each position being the values of the attributes of the feature located at that position. Conversely, a collection of discrete features can be derived from a coverage; each discrete feature being composed of a set of positions associated with specified attribute values.

The previous version of this standard ISO 19123:2005 addressed coverage modelling on both conceptual and (to some extent) implementation level. For this edition of the document, coverage modelling has been split into two separate, but connected documents: ISO 19123-1 (this document) establishes an abstract, high-level coverage model while ISO 19123-2 establishes a implementation-level model ensuring interoperability, based on the concepts of ISO 19123-1.
Geographic information — Schema for coverage geometry and functions – Part 1: Fundamentals

1 Scope

This document defines a conceptual schema for coverages. A coverage is a mapping from a spatial, temporal or spatiotemporal domain to attribute values sharing the same type within the domain. A coverage domain consists of a collection of direct positions in a coordinate space that may be defined in terms of spatial and/or temporal dimensions. Examples of coverages include meshes/grids, triangulated irregular networks, point coverages and polygon coverages. Coverages are the prevailing data structures in a number of application areas, such as remote sensing, meteorology and mapping of bathymetry, elevation, soil and vegetation. This document defines the relationship between the domain of a coverage and an associated attribute range. The characteristics of the domain are defined whereas the characteristics of the attribute range are not part of this standard.

2 Conformance

2.1 Interoperability and Conformance Testing

This document being an abstract standard allows for multiple different implementations and does not define a standardized interoperable implementation. The abstract concepts described herein can be implemented in a variety of ways which may not be directly interoperable, that is: the same abstract coverage represented through two different implementation models will not necessarily be identical in their structure, and services following two different implementation models will not necessarily deliver equivalent results on equivalent queries or other operations. The purpose of the abstract description standardized in this document is to provide an underlying consistency at the data level that makes it possible to convert from one implementation structure to another.

Conformance testing is accomplished by manually validating a candidate concretization against all requirements by exercising the tests set out in Annex A.

In an implementation standard based on this abstract specification the semantics defined in this document will normally be cast into a concrete data model (describing data structures to be stored, transferred, ingested, or extracted) and a concrete service model (describing the functionality of a service operating on coverages); such derived models should be designed in an interoperable manner, i.e.: allow concise conformance testing.

This document has a companion standard, ISO 19123-2 Coverage Implementation Schema (CIS). Based on this ISO 19123-1 standard, ISO 19123-2 defines a concrete coverage model in the sense that interoperability can be guaranteed and interoperability tests (such as the OGC compliance tests on coverages [13]) can be established.

Annex E defines a Generic Coverage Data Structure. This structure represents one possible data structure that is compatible with the interface defined in this standard. This is the structure that was defined in the previous version of ISO 19123:2005. The purpose of Annex E is to retain backward compatibility because there exist other standards both in ISO and in external organizations that make direct reference to the generic data classes that were defined in the previous version of ISO 19123:2005 and which now may reference the same classes as defined in this Annex. The interface approach is more flexible, but the classes defined in Annex E are one valid structure that may be supported through the interface.
The Conformance Tests in Annex A shows the implementation requirements necessary to conform to this document.

2.2 Organization

The coverage schema is organized into the packages shown in Figure 1 and Table 1. Each package establishes one requirements class. Grouping into these requirements classes has been done with a practical perspective in mind: Realizations of this document may be, focused on particular structures, such as grid coverages or point clouds, while ignoring all the other options.

Figure 1 — Packages of the coverage schema

Table 1 — Conformance classes

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3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.
4 Terms, definitions, abbreviated terms and notation

4.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1.1 analytical coverage

a type of continuous coverage which is a spatially bounded, but transfinite set of direct positions, and a mathematical function that relates direct position to feature attribute value.

4.1.2 Axis

〈coordinate geometry〉

linear feature from which a 1D coordinate system is constructed

NOTE This definition is established in accordance with ISO 19111-1:2019 clause 10.4

4.1.3 continuous coverage

coverage that returns different values for the same feature attribute at different direct positions within a single spatial object, temporal object or spatiotemporal object in its domain

NOTE Although the domain of a continuous coverage is ordinarily bounded in terms of its spatial and/or temporal extent, it can be subdivided into an infinite number of direct positions.

4.1.5 coordinate

one of a sequence of \( n \) numbers designating the position of a point

[ISO 19111-1:2019]

Note: A direct position is described by an ordered sequence of coordinates. The number of elements in a direct position is established by the number of axes of the coverage.
4.1.6 \textbf{coordinate dimension}
number of measurements separate decisions needed to describe a position in a coordinate system

[ISO 19107:2019]

Note: The number of separate decisions corresponds to the number of axes.

4.1.7 \textbf{coordinate system}
set of mathematical rules for specifying how coordinates are to be assigned to points

[ISO 19111-1:2019]

4.1.8 \textbf{coordinate reference system}
coordinate system that is related to an object by a datum

[ISO 19111-1:2019]

4.1.9 \textbf{coverage}
feature that acts as a \textit{function} to return values from its \textit{range} for any \textit{direct position} within its \textit{domain}

4.1.10 \textbf{coverage dimension}
coordinate dimension

<coordinate geometry>
number of separate decisions needed to describe a position in a coordinate system

[19107:2019]

NOTE: This is equivalent to "the number of axes in the coordinate reference system of the coverage domain set"

4.1.11 \textbf{coverage geometry}
configuration of the \textit{domain} of a \textit{coverage} described in terms of \textit{coordinates}

4.1.12 \textbf{Delaunay triangulation}
network of triangles such that the circle passing through the vertices of any triangle does not contain, in its interior, the vertex of any other triangle

4.1.13 \textbf{direct position}

<geographic information>
position described by a single set of coordinates within a coordinate reference system

[ISO 19107]

NOTE: Cells in a grid coverage are identified by their direct position in the domain set of this coverage.

4.1.14 \textbf{(grid) cell}
(grid coverage) cell
neighbourhood around a direct position in a coverage grid
4.1.15
discrete coverage
coverage that returns the same feature attribute values for every direct position within any object in its domain

NOTE: The domain of a discrete coverage consists of a finite set of spatial, temporal, or spatiotemporal objects.

NOTE: Discrete coverages have values only where they are defined, whereas continuous coverages can be interpolated thereby providing intermediate values.

4.1.16
domain
well-defined set

[ISO 19109:2015]

NOTE: All elements within a domain (set) are of a given type

4.1.17
external coordinate reference system
coordinate reference system whose datum is independent of the object that is located by it

[ISO 19130-1:2018]

4.1.18
evaluation
(coverage) determination of the values of a coverage at a direct position within the domain of the coverage

4.1.19
feature
abstraction of real world phenomena

[ISO 19101-1:2014]

4.1.20
feature attribute
characteristic of a feature

[ISO 19101-1:2014]

NOTE: Also known as “feature property” and may support potential attribute, quality, or characteristic of a feature.

4.1.21
function
<mathematics, programming> rule that associates each element from a domain (“source domain”, or “domain” of the function) to a unique element in another domain (“target domain”, “co-domain” or “range” of the function)

[ISO 19107:2019]

4.1.22
geometric dimension
(geometry, topology) largest number n such that each point in a set of points can be associated with a subset that has that point in its interior and is topologically isomorphic to En, Euclidean n-space
4.1.23 geometric object
spatial object representing a geometric set

NOTE: A geometric object consists of a geometric primitive, a collection of geometric primitive, or a geometric complex treated as a single entity. A geometric object may be the spatial representation of a feature object.

4.1.24 geometric set
<geometry>
set of direct positions

4.1.25 georectified
corrected for positional displacement with respect to the surface of the earth.

4.1.26 georeferenceable
associated with a geopositioning information that can be used to convert grid coordinate values to values of coordinates referenced to an external coordinate reference system related to the Earth by a datum.

4.1.27 georeferencing
geopositioning an object using a Correspondence Model derived from a set of points for which both ground and image coordinates are known.

4.1.28 grid
nonempty, ordered set of axes with a set of positions along each axis acting as reference point for connected compact smooth hypersurfaces at whose intersections direct positions are defined

NOTE: a grid consists of a network composed of one or more sets of curves in which the members of each set intersect the members of the other sets

4.1.29 grid coordinate reference system
coordinate reference system for the positions in a grid that uses a defined coordinate system congruent with the coordinate system described by the GridEnvelope and axisLabels of gml:GridType.

NOTE: A grid CRS uses a defined coordinate system with the same grid point positions and origin as the GridEnvelope, with the same axisLabels, but need not define any limits on the grid size. This coordinate system is sometimes called the internal grid coordinate system

4.1.30 grid coordinate system
coordinate system in which a position is specified relative to the intersection of curves
4.1.31  
grid coordinates  
sequence of two or more numbers specifying a position with respect to its location on a grid

[19115-2:2019]

4.1.32  
grid point  
point located at the intersection of two or more curves in a grid

4.1.33  
gridded data  
data whose attribute values are associated with positions on a grid coordinate system.  

NOTE: Gridded data are a subtype of coverage data, which represent attribute values of geographic features in terms of a spatial grid  

[19115-2:2019]

4.1.34  
image coordinate reference system  
ImageCRS  
coordinate reference system based on an image datum  

NOTE: Gridded data are a subtype of coverage data, which represent attribute values of geographic features in terms of a spatial grid.  

[19111:2007]

4.1.35  
image coordinates  
data whose attribute values are associated with positions on a grid coordinate system  

NOTE: Gridded data are a subtype of coverage data, which represent attribute values of geographic features in terms of a spatial grid.  

NOTE: The image coordinates can be in pixels or in a measure of length (linear measure)  

[19130-2:2014]

4.1.36  
image datum  
enGINEERING datum which defines the relationship of a coordinate system to an image  

[19111-1:2019]

4.1.37  
inverse evaluation  
<coverage>  
selection of a set of objects from the domain of a coverage based on the feature attribute values associated with the objects  

4.1.38  
mesh  
a Geometry with associated Topology of dimension greater than zero  

ICS  35.240.70  
Price based on 65 pages
NOTE: Geometry and Topology are defined in ISO 19107. Mesh examples include curves, TINs, and solids. Points (and point clouds) resemble geometries with dimension zero.

4.1.39
native CRS (of a coverage)
the common CRS in which all coordinates of a coverage are expressed

4.1.40
pixel
smallest element of a digital image to which attributes are assigned

NOTE: A pixel is the smallest unit of display for a visible image.

NOTE: This term originated as a contraction of "picture element"

[19101-2:2018]

4.1.41
point cloud
collection of data points in 3D space

[19130-2:2014]

NOTE: The distance between points is generally non-uniform and hence all three coordinates (Cartesian or spherical) for each point must be specifically encoded.

4.1.42
point coverage
coverage that has a domain composed of points

4.1.43
polygon coverage
coverage that has a domain composed of polygons

4.1.44
range
(coverage)
set of feature attribute values associated by a function, the coverage, with the elements of the domain of a coverage

NOTE: This is consistent with the more generic definition of range in 19107 and 19136.

4.1.45
raster
usually rectangular pattern of parallel scanning lines forming a grid

NOTE: Historically, the term derives from the display pattern on a cathode ray tube.

NOTE: Often raster data are processed to yield regular grids (such as orthorectified imagery), but sometimes irregular grids are of interest as well (such as raw satellite swath data and oblique imagery).

NOTE: The term is also used as an imprecise generic term for all imagery, gridded and coverage data.

4.1.46
rectified grid
grid for which there is an affine transformation between the grid coordinates and the coordinates of an external coordinate reference system

NOTE: If the coordinate reference system is related to the earth by a datum, the grid is a georectified grid.
4.1.47
referenceable grid
grid associated with a transformation that can be used to convert grid coordinate values to values of coordinates referenced to an external coordinate reference system

NOTE If the coordinate reference system is related to the earth by a datum, the grid is a georeferenceable grid.

4.1.48
solid
3-dimensional geometric primitive, representing the continuous image of a region of Euclidean 3-space

[ISO 19107:2019]

NOTE A solid is realizable locally as a three-parameter set of direct positions. The boundary of a solid is the set of oriented, closed surfaces that comprise the limits of the solid.

4.1.49
spatial object
<topology, geometry>
object used for representing a spatial characteristic of a feature

[ISO 19107:2019]

4.1.50
spatial reference system
system for identifying position in the real world

[ISO 19112]

4.1.51
spatiotemporal domain
<coverage>
domain composed of spatiotemporal objects

NOTE The spatiotemporal domain of a continuous coverage consists of a set of direct positions defined in relation to a collection of spatiotemporal objects.

4.1.52
spatiotemporal object
object representing a set of direct positions in space and time

4.1.53
Thiessen polygon
polygon that encloses one of a set of points on a plane so as to include all direct positions that are closer to that point than to any other point in the set

4.1.54
triangulated irregular network (TIN)
tessellation composed of triangles

4.1.55
vector
quantity having direction as well as magnitude
NOTE: A directed line segment represents a vector if the length and direction of the line segment are equal to the magnitude and direction of the vector. The term vector data refers to data that represents the spatial configuration of features as a set of directed line segments.

### 4.2 Abbreviated terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>TIN</td>
<td>Triangulated Irregular Network</td>
</tr>
<tr>
<td>UML</td>
<td>Unified Modelling Language</td>
</tr>
<tr>
<td>URI</td>
<td>Uniform Resource Identifier (IETF RFC 3986)</td>
</tr>
<tr>
<td>DGGS</td>
<td>Discrete Global Grid System</td>
</tr>
</tbody>
</table>

### 4.3 Notation

The conceptual schema specified in this document is described using the Unified Modelling Language (UML)\[^4\], following the guidance of ISO 19103.

Several model elements used in this schema are defined in other International Standards developed by ISO/TC 211. UML classes defined in this document have the two-letter prefix of CV. Table 2 lists the other standards and packages in which UML classes used in this document have been defined.

<table>
<thead>
<tr>
<th>Prefix</th>
<th>International Standard</th>
<th>Package</th>
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<tbody>
<tr>
<td>EX</td>
<td>ISO 19115-1</td>
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<td>GF</td>
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<td>General Feature Model</td>
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<td>GM</td>
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<td>SC</td>
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<td>TM</td>
<td>ISO 19108</td>
<td>Temporal Schema</td>
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</table>

### 5 Coverages

#### 5.1 Overview

This Document uses the term coverage, adopted from the Abstract Specification of the Open GIS Consortium [1], to refer to any data representation that assigns values directly to spatial and/or temporal positions. As such, a coverage conceptually can be viewed as a function which, for every value of its domain set, provides a particular value taken from its range set; actually, a coverage may provide a set of values for a particular position.

**EXAMPLE** Point clouds can be modelled as Multi-Point Coverages. Several observation values can be acquired for a particular location, and reading such a location will result in the set of all values observed.

Coverages are multi-dimensional by nature – such as 1-D sensor timeseries, 2-D x/y images, 3-D x/y/t image timeseries and x/y/z geophysical information, and 4-D x/y/z/t atmospheric and oceanographic information. The dimension axes spanning the coverage’s can be of spatial, temporal, or “abstract” nature (where abstract is understood in the sense of being neither spatial nor temporal), or any combination of these. As such, a coverage forms a digital representation of some space/time varying phenomenon.
EXAMPLE A satellite image timeseries has two spatial and one temporal axis. A geo-statistical datacube may have a temporal axis, spatial extents, and population density.

The set of locations (in a wide, spatio-temporal sense) where a coverage has objects sitting and, hence, has values to offer is called the coverage’s Domain Set, said locations are called Direct Positions. The set of all these values is the coverage’s Range Set, described by the Range Type.

Coordinates in a coverage are all expressed in one and the same Coordinate Reference System (CRS), its Native CRS. Such a CRS may either be defined directly (such as in the EPSG collection of CRSs [14]) or it may be composed from CRS and axis definitions through the mechanisms defined in ISO 19111.

EXAMPLE The CRS of a satellite image timeseries consists of two spatial and one temporal axis, in some given order. Coordinates along each axis are expressed accordingly—horizontal spatial coordinates may be expressed in degrees Lat and Long, laid down in the EPSG:4326 CRS, while time is expressed in seconds since epoch or some calendar, like Gregorian-Proleptic.

In terms of common data structures coverages encompass regular and irregular grids (requirements class Grid Coverage), point clouds (requirements class Multi-Point Coverage), and general meshes (requirements classes Multi-Curve Coverage, Multi-Surface Coverage, and Multi-Solid Coverage).

Different views on this coverage concept exist. Therefore, several practically relevant views are explicitly supported:

- In a mathematical view a coverage is defined as a function $C: D \rightarrow R$ with Domain Set $D$ and Range Set $R$ which delivers some value for each element from $D$. This view is realized as one variant of coverage modelling in subclass CV_CoverageByDomainAndRange (see Subclause 5.8.2).

- In standardization terms, a coverage can be described as a set (a 19107 Collection) of features (as per 19101). As each such feature has a location and attributes, the set of all these pairs defines the coverage’s mapping from location to values. “Geometry” here is understood in the widest possible sense, including all spatial and temporal dimensions. All features in such a collection forming a coverage must have locations expressed in the same CRS (the coverage’s Native CRS), and all attribute values must share the same data type (the coverage’s Range Type). See Subclause 5.8 for details.

5.2 Coverage Schema


Requirement 1: An instantiation of package CV_Coverage shall have all instances and properties specified for this package, its contents, and its dependencies, contained in the UML model for this package in this Document.

The UML interface modelling approach allows multiple different compatible data structures to be implemented which exhibit the same behaviour through the interface. Standardization targets are specifications concretizing the abstract concepts into implementation standards; one such example is 19123-2:2018 which in turn as standardization target has concrete implementations.

Standardization targets are specifications concretizing the abstract concepts into implementation standards; one such example is 19123-2:2018 which in turn as standardization target has concrete implementations.

Requirement 3: A Coverage is an instantiation of ISO 19107 interface Collection, with two changes: (i) the elements association is unordered (instead of ordered, as in ISO 19107) and (ii) the code list GeometryType for possible geometry types is extended with values provided by the Coverage package.

5.3 Probing Coverages: evaluate() Function

One way to define the semantics of a coverage is via a probing function which, for some Direct Position coordinate expressed in the coverage’s CRS, returns the set of values associated with it. This function can be defined, for a coverage $C$ with Domain Set $D$ and value set $V$ of that coverage, as

\[ \text{evaluate}_C: D \rightarrow V. \text{evaluate}_C(p) = \bigcup_{f \in C} f.\text{contains}(p) \]

based on the contains() probing predicate of ISO 19107.

NOTE: This probing function serves for definition purposes only, it is not required to be implemented. In practice, other retrieval functionality is desirable, such as bounding box subsetting in the OGC Web Coverage Service (WCS) Core [15].

While in general more than one value can be returned for a particular Direct Position, sometimes exactly one value will be delivered. This can occur in two cases:

— In case of a Grid Coverage, no two Direct Positions share the same coordinates by definition, and so there is always one value available via evaluate().

— If a Common Point Rule (see 5.2.4) is defined then this constitutes a selection mechanism ensuring that exactly one member of the set of values available for a given Direct Position is returned by evaluate().

EXAMPLE More than one values per Direct Position can occur in several cases, such as in point clouds with two points incidentally sharing the same coordinates, but bearing different values, or in MultiSolid Coverages that overlap.

5.4 Domain of a coverage

5.4.1 Concept

The coverage domain set describes for which positions in the coverage's multi-dimensional space values are available. Within this multi-dimensional space defined by the Domain’s Coordinate Reference System (CRS) the coverage Domain contains a set of geometric objects which determines the Direct Positions, i.e.: the locations in this space where the coverage offers a value. This description can be given through direct enumeration of the Direct Positions (example: point clouds) or through containment descriptions (example: areas and volumes), or some other mechanism (example: Ground Control Points in sensor models). The coverage’s Extent gives a bounding box – i.e.: lower and upper bounds along every coordinate axis – within which all its Direct Positions are located.

EXAMPLE The space spanned in coverages representing 1-D temperature measurement timeseries, 2-D x/y images of the Earth surface, 3-D x/y/t image timeseries and x/y/z subsurface voxel data, and 4-D x/y/z/t atmospheric and ocean data, all are described through some appropriate CRS with the respective dimension.

The geometric objects in a coverage domain are not strictly confined through 3-dimensional physical space. They can be $m$-dimensional objects where $m \leq n$ for an $n$-dimensional coverage. Coverage subtypes are defined in terms of their domain types in Clause 6 onwards.

EXAMPLE A 3-dimensional x/y/t image timeseries datacube may be composed of 0-dimensional points, its pixels. A domain of coordinate dimension 3 may be composed of points, curves, surfaces, or solids, while a domain of coordinate dimension 2 may be composed only of points, curves or surfaces.
5.4.2 Coordinates

ISO 19111-2 defines CRSs which contain ordered lists of axes used for addressing points in space. For an n-dimensional coverage, n>0, the corresponding CRS contains an ordered set of n axes whose syntax and semantics (such as unit of measure, discrete or continuous) is part of the CRS definition. Points in the coverage domain’s n-dimensional space are addressed through n-tuples of coordinates based on the n-dimensional coverage’s CRS.

ISO 19107:2019 defines geometric objects (subtypes of class GM_Object), ISO 19108:2002 defines temporal objects (class TM_GeometricPrimitives) that may be used to define domains of coverages.

The Domain Set of a coverage, as described by its Coordinate Reference System (CRS) consists of a number of axes which together define some n-dimensional space, with n>0.

Further, axes can represent alternate representations of coordinate measurements. Finally, other possible axes, without any spatial nor temporal semantics, might be called “abstract”.

EXAMPLE The following is a non-exhaustive list of possible axes in coverage Domain Sets:

- A CRS consisting of a single time axis can model a timeseries of measurements.
- Pressure altitudes, measured in hekto-Pascal (hPa), as well as Flight Levels, expressed in 100 ft steps like “FL150” for 15000 ft above some reference point, represent “proxies” for altitude used in aviation.
- Integer coordinates can be used to define a coverage axis of spectral frequencies.

5.4.3 Coordinate Reference Systems for Coverage Domains

The coverage’s CRS defines the theoretically available space for Direct Positions, bounded additionally by the coverages extent in that space. Generally, though, not for every position in this space a Direct Position may be defined. The type of feature bundled in a coverage determines where Direct Positions, expressed in coordinates based on the coverage’s Native CRS, are available. As feature types commonly are sorted along their topological dimensions – thereby defining points, lines, surfaces, and solids in natural space – this is an appropriate criterion for classifying coverage types. Additionally, there may hold further constraints, such as with grid coverages which are based points having topological dimension 0, but additionally require the Direct Positions to sit on some grid. In the following Clauses, coverage types sorted along their topological dimension as defined in ISO 19107.

ISO 19111-2 describes ways to compose CRSs for building higher-dimensional CRSs from lower-dimensional ones.

**Requirement:** The coverage CRS shall be described in accordance with ISO 19111-1:2019 describes the semantics of CRSs and their axes, as well as their composition into higher-dimensional CRSs.

**Requirement:** A coverage CRS shall be identified by an ISO 19107 DirectPosition::RSID.

**Requirement:** In a coverage CRS, coordinates with a spatial semantics shall be represented by an ISO 19107 DirectPosition.

**Requirement:** In a coverage CRS, coordinates with a temporal semantics shall be represented by an ISO 19108:2002 TM_Position.

Axes without any further semantics may make use of an IndexCRS, as defined by OGC, which is a family of CRSs where each axis is defined over unit-less integer numbers. IndexCRS1D defines a single-axis CRS,

---

Index2D a 2D CRS, and so on. By combining such IndexCRSs with spatial and temporal CRSs a wide range of multi-dimensional domain sets can be described.

The concept of an Image Coordinate Reference System (ImageCRS) has been introduced with the purpose of unifying the handling of referenced objects, being defined as a CRS specifically for non-referenced image data. With this ImageCRS there is always a CRS for coverages, even if they are not related to any position in space/time. Technically, an ImageCRS can be defined as subclass of ISO 19111-1:2020 Coordinate Reference System. It is characterized by being 2D and having integer coordinates on both axes. As such, an ImageCRS is identical to the OGC Index2D CRS.

**EXAMPLE**  
A 4D domain set may be described through axes Lat and Long (given by EPSG:4326) combined with a time axis as per ISO 8601 combined with an IndexCRS2D for spectral bands.

**EXAMPLE**  
The Direct Positions in a coverage’s Domain Set can be enumerated (example: point sets in a Multi-Point Coverage), they can be given implicitly (example: corner points indicating the set of all raster positions in a Rectified Grid Coverage).

The range of CRSs to be used is open-ended; CRSs not described nor mentioned in this standard might be used in a coverage. Recommendation, though, is to use CRSs from some standard repository, such as the OGC spatial and temporal CRS repository, or following some standardized syntax, such as OGC WKT, or some geo referenced grid system like DGGS which uses a compound tessellation by fitting a polyhedron such as a 20-sided icosahedron or 6-sided cube to a sphere or ellipsoid and then tessellating each facet.

## 5.4.4 Multi-Dimensional Coverages

A single axis, being component of a one- or higher-dimensional Native CRS, can be established in various ways. When composing axes, as per ISO 19111, both CRSs and single axes can be combined into some higher-dimensional CRS. Mechanisms to do so are out of scope of this document, they are defined in ISO 19111.

The Domain Set of a coverage, as described by its Coordinate Reference System (CRS) consists of a number of axes which together define some n-dimensional space, with \( n > 0 \). While this document does not define Domain Set semantics (this is done in ISO 19111) it can be stated that physical dimensions consist of two horizontal axes (such as x and y), a vertical axis, and a temporal axis. By combining one or more of these axes spatio-temporal objects can be built. Further, axes can represent alternate representations of coordinate measurements. Finally, other possible axes, without any spatial nor temporal semantics, might be called “abstract”.

**EXAMPLE**  
The following is a non-exhaustive list of possible axes in coverage Domain Sets:

- A CRS consisting of a single time axis represents a timeseries of values.
- Pressure altitudes, measured in hekto-Pascal (hPa), as well as Flight Levels, expressed in 100 ft steps like “FL150” for 15000 ft above Mean Sea Level, represent “proxies” for altitude used in aviation.
- Spectral frequencies can define a coverage axis.

The CRS defines the theoretically available space for Direct Positions. Generally, though, not for every position in this space a Direct Position may be defined. The type of feature bundled in a coverage determines where Direct Positions, expressed in coordinates based on the coverage’s Native CRS, are available. As feature types commonly are sorted along their topological dimensions – thereby defining points, lines, surfaces, and solids in natural space – this is an appropriate criterion for classifying coverage types. Additionally, there may hold further constraints, such as with grid coverages which are based points having

3 [http://secure.rasdaman.org/def/crs/OGC/0/Index2D](http://secure.rasdaman.org/def/crs/OGC/0/Index2D)
4 [http://www.opengis.net/def/crs/](http://www.opengis.net/def/crs/)
5 [https://www.ogc.org/standards/wkt-crs](https://www.ogc.org/standards/wkt-crs)
topological dimension 0, but additionally require the Direct Positions to sit on some grid. In the following Clauses, coverage types sorted along their topological dimension as defined in ISO 19107.

5.4.5 Mathematical vs Physical Coordinates

The Domain Set of a coverage, as described by its Coordinate Reference System (CRS) consists of a number of axes which together define some n-dimensional space, with n > 0. Geographic data typically have a subset of two horizontal axes, one height axis (expressing elevation or bathymetry), and time. Climate modeling adds a second time axis for differentiating model run time from time modelled. By combining one or more of these axes multi-dimensional spatio-temporal objects can be built. Further, axes can represent alternate representations of coordinate measurements. Additionally, “abstract” (in the sense of non-spatio-temporal) axes may occur as well, like in Online Analytical Processing (OLAP) where, e.g., time / product / subsidiary axes are common.

EXAMPLE Non-spatio-temporal axes occur in practice as well. For example, bands in hyperspectral imagery make sense as a numbered sequence once there are hundreds of such bands, such as the Hyperion instrument on board of EO-1 with its 220 bands\(^6\). With natural numbers addressing becomes less wieldy.

NOTE Originally spatial dimensions might become non-spatial at some level of generalization. For example, cities in Europe might be expressed through coordinates originally, but at some higher level get abstracted to be in Bavaria, in the Alps region, etc. which is at a symbolic level. This may lead to dimension hierarchies like in OLAP.

5.5 Range of a coverage

At every direct position a coverage holds a single value or a nonempty set of values. All these values of a coverage together make up the coverage’s range set.

EXAMPLE A coverage might assign to each direct position in a county the temperature, pressure, humidity, and wind velocity and direction vector, at a specific time, at that point. The coverage maps every direct position in the county to a record of these fields. In this case, the common type of the coverage range values is a record of components, each of its individual type.

The Range Type component describes the type of the set of values available for the Range Set. Structures such described can be atomic or composite.

Requirement 14: The Range Type component shall be of type Record Type as defined in ISO/TS 19103.

Requirement 15: The Range Type of a coverage at minimum shall provide the information necessary to decode the Range Set values and process them in a computer system, consisting of (i) data type information in some available typing system, (ii) null values, and (iii) unit of measure.

EXAMPLE RGB images, when modelled as a coverage, have as their range type a record consisting of three components red, green, and blue (in that order), each of them of type unsigned 8-bit integer. Accuracy could be stated in a superficial way as “3 valid digits”.

Recommendation: Range Type definitions should rely on some commonly agreed system of measurement.

NOTE One way of providing this information is via a HTTP-URI pointing to a location that provides this information in a standardized manner. Another way is to provide this information directly as part of the coverage.

5.6 Interpolation

5.6.1 Concept

Through interpolation, range values can be obtained for coordinates within the domain set of a coverage which are not Direct Positions. Basically, a coverage provides values only at its Direct Positions. Interpolation means applying some algorithm to obtain a range value for locations inside a coverage’s domain set which are not Direct Positions, usually by combining the values of several Direct Positions in the neighbourhood of the coordinate location under inspection.

Interpolation requires domain set coordinates to be in a CRS which allows for expressing “inbetween” values.

EXAMPLE Index coordinates, representing integer numbers, do not allow expressing any inbetween value as it would not be an integer any more. Latitude, Longitude, height, and time, conversely allow expressing values between any two given coordinates.

Depending on the interpolation method, i.e.: the algorithm applied, the range set may require to provide “in between” values, too. In general, for interpolation it may be necessary that the range type allows for arbitrary such values to be generated, requiring a continuous range type. Therefore, applicability of a particular interpolation method in general also depends on the range type.

EXAMPLE “Nearest neighbour” interpolation does not require values to be determined as the resulting value will be chosen from the available ones taken from the surrounding Direct Positions. “Linear interpolation”, on the other hand, usually will generate values different from the surrounding ones, based on the arithmetic means computation.

5.6.2 Discrete and Continuous Coverages

The domain set characteristics decide in the first place whether interpolation is applicable. The CRS, which defines the set of possible coordinate values, may or may not allow addressing of coordinate values beyond the Direct Positions. Hence, coverages are possible which allow interpolation along one axis, but not along another.

EXAMPLE A grid coverage with Lat, Long, and an index axis can be interpolated in Lat and Long, but not along the index axis.

An axis is called discrete if every possible interval with finite bounds describes a finite set of values, otherwise such an axis is called continuous.

A coverage is called discrete if its axis list contains only discrete axes. A coverage is called continuous if its axis list contains at least one continuous axis.

Coverages can be discrete (or continuous) in their range, in their domain, or in both.

EXAMPLE A map of postal code zones is a coverage which is discrete in its range. The postal code zones cover an entire country and at every location in the country one can evaluate the coverage function and get a value that represents the postal code for that location. Within a postal code zone the value is constant. One cannot interpolate such a discrete coverage.

EXAMPLE A coverage that maps a set of polygons to the soil type found within each polygon is a coverage which is discrete in its range. More examples of this type of coverage are given in ISO 19144-2 Classification Systems – Part 2 – Land Cover Meta Language (LCML).

EXAMPLE A point set representing a set of measurements that are only valid at the position of each point, and which cannot be interpolated, is a discrete coverage (discrete in domain).

EXAMPLE An image, sampled by a sensor, may be represented as a grid coverage consisting of a set of pixels corresponding to grid cells in the domain of the coverage. A value is associated with each grid cell. However, since the coverage is continuous an interpolation function – such as linear, quadratic, or cubic – may be applied so that a continuously variable value may be determined at any location within the domain extent of the image.
EXAMPLE  In a coverage that maps direct positions in San Diego County to their temperature at noon on a specific day, both domain and range may take an infinite number of different values. This continuous coverage would be associated with a discrete coverage that holds the temperature values observed at a set of weather stations (discrete in domain). That is, the measured values correspond to a point set coverage. This point set coverage is discrete because each point can only have one value. The associated continuous coverage uses the point values as driving values for the coverage function and allows interpolation between the points.

EXAMPLE  A set of bathymetric soundings is a discrete point set coverage with a single measured water depth value at each point location (discrete in domain). An associated continuous coverage allows one to interpolate between the measured depth soundings to determine the bottom surface of a body of water.

EXAMPLE  Evaluation of a triangulated irregular network involves interpolation of values within a triangle composed of three neighbouring point value pairs.

5.6.3 Interpolation Set

The Interpolation Set component contains a – possibly empty – set of interpolation methods which are applicable to the coverage on hand, thereby establishing ways to derive values for locations beyond the coverage’s direct position. If interpolation is allowed on a coverage then proper range values can be obtained between direct positions by applying one of the coverage’s interpolation methods.

An empty interpolation set indicates that no interpolation can be applied meaningfully. See Annex B for descriptions of specific interpolation methods. This list is open ended – additional interpolation methods, including interpolation methods for higher-dimensional coverages, may be defined in an Application Schema that makes use of this standard.

NOTE: As coverages are passive data structures this cannot be enforced. However, it is a valuable hint to any application as to what interpolation technique(s) can be applied meaningfully to the data set on hand.

ISO 19107:2019 defines a set of interpolation methods, individually for the particular geometry types, upon which this Document relies.

Requirement 16: Interpolation types allowed for the geometries contained in a coverage shall be given by the interpolation methods specified in ISO 19107:2019 for the respective geometry type.

Recommendation: An application may apply one interpolation method collectively along all axes of the coverage, or it may allow indicating individual interpolation methods applied to different axes of the coverage.

EXAMPLE  In an image timeseries having Latitude, Longitude, and time axes several ways of interpolation are relevant:

— Linear interpolation along latitude and longitude (“bilinear interpolation”), with temporal resolution unchanged (in plain words: all existing timeslices get extracted) and, hence, no interpolation occurring along time.

— Interpolate each pixel’s history (i.e., along time) using linear interpolation, without any spatial interpolation.

— Linear interpolation along latitude, longitude, and time simultaneously (“trilinear interpolation”).

NOTE: As this standard is a data model and not a processing nor service model use of a particular interpolation method on a given coverage cannot be enforced. Rather, a coverage may provide information on the set of interpolation methods that should be applied whenever, in the course of performing some general processing, interpolation needs to be performed (such as in rescaling a coverage along one or more axes).

NOTE: Interpolation methods may require additional control parameters; these are not considered in this Document.
5.7 Common Point Rule

The optional CV_Coverage attribute commonPointRule of type CV_CommonPointRule identifies the procedure to be used for evaluating the CV_Coverage at a position for which more than one range values exist. Its behaviour is defined in Annex E.

5.8 Realization Variants

In a coverage, the domain and range sets may be organised in different ways, driven by practical considerations. Possible organisations include:

— Separate representation of domain and range sets in some serialization; if both use the same serialization scheme then corresponding location/value pairs can be identified through their position in the sequence. This is useful, for example, in image processing when the domain is not needed for the image operation on hand.

— Having an implicit description (rather than an explicit representation) of the domain. This reduces a coverage’s size and, again, allows convenient range set processing while avoiding the sometimes unwanted overhead of addressing each value one by one through its direct position.

— A set of position/value pairs. This is a natural representation, for example, for point clouds.

— Partitioning a coverage into smaller units. This is commonly known as tiling. In fact, this concept can be extended to recursively nested coverages.

— Combinations of the above.

NOTE One interoperable concretization supporting various such organizations is given by ISO 19123-2 [17] which is identical to OGC CIS [16].

In the subclauses below some of the above coverage organizations are detailed further.

5.8.1 Geometry/Value Pair View

The collection of feature objects constituting a coverage can be seen as establishing a mapping from the features’ space to the set of values associated with the features. In case these features and their values get enumerated this naturally leads to a set representation where each set element is a (geometry, value) pair. This is the view supported by the ISO 19107 Collection paradigm, captured in CV_CoverageByPartitioning containing a Partition Set consisting of geometry/value pairs (Figure 3). The constraints relevant for this coverage variant have been established in 5.2.

However, other logical organisations of a coverage, with identical information content, can be constructed. Two of them are established below. Figure 3 gives a synoptic view of all variants discussed.

Requirement 7: A CV_Coverage shall be structured as described in Figure 5.
5.8.2 Domain/Range View

Another way of viewing a coverage is as a mapping from a set of direct positions (given by the geometry objects) to a set of values (given by the feature’s associated value payload). In this view, a coverage is defined as a function $C: D \rightarrow R$ with Domain Set $D$ and Range Set $R$ which delivers some value for each element from $D$. This variant is realized in subclass $CV_{CoverageByDomainAndRange}$ (Figure 3).

NOTE: Conceptually, the Domain Set of a coverage consists of all Direct Positions defined for this coverage. This set can be enumerated (Example: point sets in a MultiPointCoverage), they can be given implicitly (Example: corner points indicating the set of all raster positions in a RectifiedGridCoverage as per ISO 19123:2005). Hence, the domain/range view on a coverage is particularly relevant for grid coverages.

5.8.3 Partitioned View

The previously introduced modelling variants resemble two extreme ends of a modelling continuum: In the geometry/value pair representation, the finest possible granularity is adopted by having each single feature object with its value represented together. In the domain/range variant, conversely, the coarsest possible granularity is adopted by having one set of positions which get mapped to one set of values. In the partitioning approach, organizations in between these extremes are gathered. To this end, a coverage gets split into sub-coverages forming partitions of the original coverage. In the coverage model, this is captured by a PartitionSet containing Partitions.
For a coverage set to be aggregated into a larger coverage, some homogeneity constraints must hold:

**Requirement 8:** All sub-coverages in a partition shall share the same CRS and range type; their Domain Sets shall fulfil all constraints imposed on the particular coverage type of the super-coverage.

**Requirement 9:** A coverage shall not recursively contain itself in a partitioning hierarchy.

NOTE: Having only one partition realizes the domain/range variant. Having partitions which contain only one feature object each represents the geometry/value pair variant.

NOTE: Partitioned storage organization can massively increase performance of access and processing. In technology such partitioning is also known as tiling and chunking.

### 5.9 Envelope

For practical purposes it may be convenient for an application reading a coverage that it can quickly determine where approximately Direct Positions can be expected. Therefore, Coverage contains an optional component envelope of type Envelope of type Extent (as per ISO 19115-1) giving a simplified summary description of the coverage’s Domain Set. This envelope consists of an enclosing bounding shape which should be close to the actual coverage extent but does not have to be minimal. Further, the envelope can be expressed in any CRS which can be transformed to and from the coverage’s Native CRS.

**EXAMPLE** A satellite swath image may contain a bounding box expressed in WGS 84 (Figure 2).

![Figure 2 — Satellite image embedded in bounding box](image)

**Recommendation:** Coverages should contain an Envelope.

**Requirement 10:** The Envelope of a Coverage shall contain all or a subset of the axes of the corresponding Domain Set.

**EXAMPLE** In a 3D x/y/t image timeseries datacube the extent may only represent the approximated 2D footprint on the Earth surface, say, in WGS84, thus ignoring the time axis.

**Requirement 11:** The Envelope of a Coverage should approximate its Domain Set as closely as possible, for all axes of the Domain Set present in Extent.

**Requirement 12:** If a Coverage contains an Envelope then this Envelope shall contain the Domain Set of this Coverage.

**Requirement 13:** The CRS component of the Coverage shall reference a CRS definition conformant with ISO 19111-1:2019.

The association Coordinate Reference System shall link the Coverage to the coordinate reference system to which the direct positions in the domain set are referenced. Class SC_CRS is specified in ISO 19111-1:2019.
6 Multi-Point Coverages

A MultiPointCoverage is a coverage consisting of a collection of points. To maintain a unique value per Direct Position it is mandatory that the point coordinates be disjoint.

Requirement 17: A MultiPointCoverage shall contain only elements of the same type, which is ISO 19107 data type PointData or a subtype thereof, as described by Figure 3.

Requirement 18: Function evaluate( ) shall be defined, for some coverage c and position p, as

\[
\text{evaluate}(p) = \{ v \mid \exists \text{ point feature } f \in c: f.\text{contains}(p) \}
\]

where contains( ) is defined in ISO 19107.

NOTE An alternative (and different) realization of MultiPointCoverage is given by the ISO 19107 data type PointCloud. MultiPointCoverage is included here for achieving a complete, coherent framework across all topological and geometric dimensions.

Figure 3 — Class MultiPointCoverage

7 Grid Coverages

7.1 Overview

A Grid Coverage is a special case of a Multi-Point Coverage in that all direct positions must sit on a grid. The concept of a multi-dimensional grid is defined in Subclause 7.2.

Requirement 19: A Grid Coverage shall be a subtype of Multi-Point Coverage.

NOTE Although abstractly Grid Coverage is a subtype of Multi-Point Coverage, in practice implementation of both types will differ substantially, and likewise will functionality defined on each. The regularity of a grid generally allows determining Direct Positions easier than in a point cloud, and often – depending on the degree of regularity of the grid – it is not even required to materialize the coordinates. This entails particularly efficient storage and processing methods.
7.2 Grids

7.2.1 Grid Definition

In a Grid Coverage, a Grid serves to determine the locations of the Direct Positions of the Domain. The Direct Positions carrying range values are aligned to specific points given by the grid definition.

Grids generally can be constructed based on triangles, rectangles, or hexagons. In the context of coverages, rectangular grids are modelled through Grid Coverages, hexagonal grids can be mapped to Grid Coverages (see Subclause 7.6), and triangular grids are modelled through meshes, i.e., Multi-Surface (Clause 9) or Multi-Solid Coverages (Clause 10). Therefore, in this standard the term “grid” is always understood as a rectangular grid.

**NOTE** In 2-D, rectangular grids form tessellations based on quadrilaterals; in the n-D case these become n-gons.

In a rectangular grid, every direct position not sitting on the domain set boundary (“inner position”) has exactly two distinct neighbouring direct positions; those direct positions sitting on the domain set boundary (“boundary position”) have exactly one such neighbouring direct position. Rectangular grids in general do not have equidistant spacing between the Direct Positions. Figure 5 illustrates some cases of regular and irregular grids.

**NOTE** As opposed to a mesh (in Computational Fluid Dynamics also called unstructured grid) where a vertex (i.e.: cell) can be connected with any number of neighbouring vertices a Grid has a regular structure based on some given number of neighbourhood vertices; therefore such a Grid sometimes is referred to as a structured grid, for clarity.

Mathematically, an n-dimensional Grid is a tessellation of the Grid Coverage's Domain Set defining a set of Direct Positions through geometric rules as follows. For some $n\geq0$ let $A = (a_1, \ldots, a_n)$ be a finite ordered set of axes where each axis $a_i = \{v_{i,1}, \ldots, v_{i,m_i}\}$ is a totally ordered set of $m_i\geq0$ values. This induces a Grid $G = a_1 \times \cdots \times a_n$ as the cross product. $G$ can be interpreted as a set of coordinates yielding Direct Positions, $G = \{(x_1, \ldots, x_n) \mid x_i \in a_i \text{ for } 1 \leq i \leq n \}$. In a coverage context, $A$ is described by an n-dimensional CRS together with axis boundaries, typically given as lower and upper bounds per axis. The resulting regular and irregular grids are described in Subclause 7.2.2.2.

Obviously, when walking from one Direct Position to the next neighbour by incrementing or decrementing just one single axis coordinate $x_i$ to the next allowed value of this axis we obtain another Direct Position, except when starting from the lower or upper bound of the axis. We can therefore replace the actual axis coordinates by counts and establish a bijective mapping between an axis $a_i = \{v_{i,1}, \ldots, v_{i,m_i}\}$ and a Cartesian axis $c_i = \{0, \ldots, m_i\}$. The CRS corresponding to this Cartesian grid is an Index CRS.

**NOTE** Often rectangular grids get described through curve bundles, one per axis, whose intersections establish the Direct Positions; within each such bundle the curves pairwise must not touch nor intersect). In case of CV_IndexAxis, CV_RegularAxis and CV_IrregularAxis a curve bundle will be a set of straight lines. Obviously this construction method can only explain grids in 2-D or higher.

Cartesian grids, also known as square grids, can be represented efficiently as arrays in programming languages, which leads to a preferred storage technique for coverages where the range set is modelled as an array based on some implementation-dependent mapping (such as row-major or column-major arrangement) of the Native CRS to the array’s Cartesian CRS. This allows tools like image processing to ignore the real-world coordinates and operate on the (Cartesian) array.

This grid notion can be generalized so that Direct Positions do not sit at the coordinate positions induced by the grid, but with some offset in arbitrary directions (although not beyond the neighbouring positions). Further, n-D grids can be embedded in some (n+m)-D space for some $m>0$. These cases are addressed in Subclause 7.2.2.3.

In the most general case, coordinates of the Direct Positions are not stored explicitly, but obtained algorithmically from some implementation-dependent parameters. This case is covered by Subclause 7.2.2.4.

**Requirement 20:** In a Grid Coverage, the Direct Position shall be given by a rectangular Grid.
Requirement 21: In a Grid Coverage, Direct Position has exactly one value (taken from the coverage’s Range Type) associated, i.e.: \[ \text{evaluate}(p) \mid 1 \text{ for all Direct Positions } p. \]

7.2.2 Grid Axis Types

7.2.2.1 General

The axes of a CRS are defined in the CRS, as per ISO 19111-1:2019. Hence, every axis (set) definition contains a reference to the overall CRS it is embedded in. Additionally, axes describe the subset of coordinate values at which Direct Positions are given. The complete coordinate tuples (as per Native CRS) can be constructed as the cross product of these admissible axis values due to the lattice isomorphy of the grid (for example, such a grid does not contain “holes”). In Figure 4, type Axis – with its subtypes Index Axis, Regular Axis, and Irregular Axis – establishes how isolated, single axes can be described (see Subclause 7.2.2.2). Multiple axes making up a grid (or belonging to it, with further, independent axes existing) Grid axes are defined through Displacement Axis Nest (see Subclause 7.2.2.3). In the most general case, axis information is derived algorithmically, represented by Algorithmic Axis (see Subclause 7.2.2.4).

Figure 4 — Class Grid

7.2.2.2 Index, Regular, and Irregular Axes

An Index Axis is a 1D Cartesian axis: there is no georeference, and admissible coordinates are at discrete, integer positions and unit-less.

Requirement 22: An Index Axis shall be given by an axis identifier, a CRS, lower and upper bounds \( lo \) and \( hi \) with \( lo, hi \in \mathbb{C} \) and \( lo \leq hi \). Direct Positions shall be defined for every coordinate tuple where the coordinate value of the Index Axis on hand is from the closed interval \( S = \{ x \in \mathbb{Z} \mid lo \leq x \leq hi \} \).

NOTE: The unit of measure of an Index Axis is 1, i.e.: coordinate values are unitless.

NOTE: As distances are known (always 1) there is no need to store such values as they can be computed when accessing particular Direct Positions.
A Regular Axis has an equi-distant spacing like an Index Axis, but is continuous and not constrained to integer positions and distances. Such an axis can be georeferenced, i.e.: it can have a spatial or temporal semantics attached.

**Requirement 23:** A Regular Axis shall be given by an axis identifier, a 1D CRS, lower and upper bounds \( l_0 \) and \( h_1 \) with \( l_0, h_1 \in \mathbb{C} \) and \( l_0 \leq h_1 \), a resolution \( r \in \mathbb{C} \). Direct Positions shall be defined for every coordinate tuple where the coordinate value of the Regular Axis on hand is from the set \( S = \{ x \in \mathbb{C} \mid l_0 \leq x*r \leq h_1 \} \).

NOTE 1 Unit of measure, coordinate set, as well as datum are defined in the CRS.

NOTE 2 Storing Direct Positions along irregular axes requires materialization of the initial point (such as the minimum position on the axis) and the (constant) offset; any storage location of a Direct Position can be computed from this.

The next level of generalization is an Irregular Axis. It is continuous, possibly georeferenced, and its distances are irregular. Such an axis can be georeferenced, i.e.: it can have a spatial or temporal semantics attached.

**Requirement 24:** An Irregular Axis shall be given by an axis identifier, a 1D CRS, a set of positions \( P = \{ p_1, \ldots, p_n \} \subseteq \mathbb{C} \). Direct Positions shall be defined for every coordinate tuple where the coordinate value of the Irregular Axis on hand is from \( P \).

NOTE Storing Direct Positions along irregular axes requires materialization of the list of positions as they cannot be computed.

### 7.2.2.3 Displacement Axis Nest

A Displacement Axis Nest (or Warped Nest) is a set of continuous, possibly georeferenced axes, forming a subset of the Native CRS’s axes. Relative to a regular grid, each Direct Position is shifted by some individual offset within the CRS space spanned by the axes participating.

**Requirement 25:** A Displacement Axis Nest shall be given by a list of axis identifiers with \( d > 0 \) items, a \( d \)-D CRS. Direct Positions shall be defined for every coordinate tuple where the coordinate value of each axis participating in the Displacement Axis Nest on hand is given as a set of \( d \)-dimensional coordinates from the CRS.

NOTE: The parameter set is an application-specific data structure not defined in this document.

NOTE: Storing Direct Positions in this case requires materializing the coordinate values for each coordinate tuple of the CRS subspace spanned by the axes participating.

### 7.2.2.4 Algorithmic Axis

Algorithmic Axes are given by a set of continuous, possibly georeferenced axes, forming a subset of the Native CRS’s axes, where the Direct Positions have to be derived algorithmically from some otherwise abstract parameters (hence, the alternative name Transformation Model). Examples of such algorithmic axes include sensor models where, instead of the coordinate information, a set of sensor parameters (such as ground control parameters) is provided which needs to be fed into the model for deriving the actual Direct Positions.

**Requirement 26:** An Algorithmic Axis set shall be given by a list of axis identifiers with \( n > 0 \) items, an \( n \)-D CRS, a parameter set \( P \). Direct Positions shall be given through some algorithm parametrized with \( P \).

NOTE The structure and meaning of \( P \) is not specified further in this document.
7.2.2.5 Combinations

By combining all the above axis types freely, any type of grid can be modelled. The list of possible axis types is not conclusive, some standard or application may define their own additional axis types. Figure 5 shows some sample grid types combining different axis types defined in this document.

Figure 5 — Sample 2D and 3D grids, from left to right: regular, irregular, warped nest, combination of regular Lat/Long with irregular time, combination of warped Lat/Long nest with irregular time

7.2.3 Grid Offsets

In addition to the above construction principles for grids, ISO 19111-1:2019 CRS handling allows expressing the following situations:

— Skewed grids (Figure 7, second from left) can be expressed as an affine transformation applied to some base CRS. This can be formulated by concatenating the base CRS with a suitable Engineering CRS (implementing the affine transformation) as established in ISO 19111-1:2019.

— Pixel-in-centre vs pixel-in-corner: Sometimes tools interpret values as sitting at the Direct Positions indicated (referred to as pixel-in-centre semantics), sometimes tools assume a half-pixel offset from the Direct Position indicated (referred to as pixel-in-corner semantics). The former situation does not require any special handling, the latter situation — for regular grids — can be expressed again through an affine CRS transformation, specifically: a half-pixel shift of the Native CRS, applied through a CRS concatenation as established in ISO 19111-1:2019. Irregular grids require individual handling.

7.2.4 Sequence Rule

Each mathematical dimension corresponds to a particular axis. More than one axis may be taken together to form a compound index. This compound index may follow a sequence rule that assigns order to space. The rule may be as simple as Row then Column, or it may be more complex. Complex rules allow for Quadtrees, or more general structures in Riemann hyperspace, Hilbert space and other patterns. An example is a spiral search pattern that may be used in Search and Rescue. CV_SequenceRule is a data type that describes the mapping of grid coordinates to a position to attribute values along axis. CV_SequenceType is a code list that identifies methods for sequential enumeration of the grid points. Methods for sequential enumeration are described in Annex E. The sequence rule describes an index into data, not the organization of the data. More than one sequence rule may be applied to the same data in different indexes.

Figure 6 — Sequence Rule
7.3 Grid Cells

7.3.1 Grid cells

Common practice is to consider the information stored at a direct position (such as radiance energy) not concentrated in the zero-extent point, but distributed over some area around this direct position. For example, in Charge-Coupled Device (CCD) sensor arrays each individual sensor collects photons on some finite surface, hence the electrical charge delivered is representative not only for the direct position, but represents an aggregated value for the whole area seen by the CCD sensor.

This concept is captured by the notion of a grid cell, which, in its full generality, is given by a neighbourhood around a direct position. Cells are constrained in that they do not overlap, while “empty” space not covered by any cell may exist within a coverage’s domain extent.

In case of regular grids all of its cells share the same shape and size, otherwise the grid cells in general are not equal in size and shape.

7.3.2 Pixel-in-center, Pixel-in-corner

If cells are positioned in a way that the direct positions corresponding to a cell sit in its center then this is commonly referred to as “pixel in center”. If cells are positioned such that the corresponding direct positions sit in the “upper-left”, “lower-left”, etc. of the cell’s corners is called “pixel in corner”. Figure 7 shows both situations for a regular 2D grid.

In case of a regular grid, all cell positions can be obtained from a “pixel in center” case by applying a translation by half the grid distance along each axis. Technically, this can be achieved through an Engineering Coordinate System transformation with these offsets, concatenated with the grid’s CRS.

NOTE Obviously, pixel-in-center and pixel-in-corner resemble just two special cases of a general shift to be applied; for example, the corner to be chosen might be any of 2^n choices for an n-dimensional regular grid. In the most general case any coordinate position within the cell could act as such an “anchor point”.

![Figure 7 – Grid Cell with “pixel-in-center” (left) and “pixel-in-corner” sitting “upper-left (right) with direct position (x,y) and corresponding grid cell marked](image-url)
**Requirement 27**: The sub-coverage partitions contained in a given Grid Coverage shall, in their entirety, satisfy all requirements established in 7.2 and Figure 8.

**Requirement 28**: Function evaluate( ) shall be defined, for some coverage c and position p, as evaluate(p) = v for the corresponding point feature f ∈ c with f.contains(p), where contains( ) is defined in ISO 19107.

NOTE By construction, Direct Positions in a Grid are pairwise disjoint. Hence, there can be only one associated value for any given Direct Position.

![Figure 8 — Class GridCoverage](image)

**7.5 Rectified and Referenceable Grid Coverages**

A grid may be defined in terms of an external coordinate reference system. This requires additional information about the location of the grid’s origin within the external coordinate reference system, the orientation of the grid axes, and a measure of the spacing between the grid lines. If the spacing is uniform, then there is an affine relationship between the grid and external coordinate system, and the grid (Figure 14) is called a rectified grid. If, in addition, the external coordinate reference system is related to the earth by a datum, the grid is a georectified grid. The grid lines of a rectified grid need not meet at right angles; the spacing between the grid lines is constant along each axis but need not be the same on every axis. The essential point is that the transformation of grid coordinates to coordinates of the external coordinate reference system is an affine transformation.
NOTE: The word rectified implies a transformation from an image space to another coordinate reference system. However, grids of this form are often defined initially in an earth-based coordinate system and used as a basis for collecting data from sources other than imagery.

NOTE: The internal grid coordinate system is an instance of an engineering coordinate reference system as specified by ISO 19111:2019. Its datum is a set of one or more ground control points.

EXAMPLE Figure 9 shows a two-dimensional grid in the 3-space determined by the axes X, Y, and Z. The grid origin is at O. There are two offset vectors labelled $V_1$ and $V_2$ which specify the orientation of the grid axes and the spacing between the grid lines. The coordinates of the grid points are of the form: $O + aV_1 + bV_2$.

![Figure 9 — Geometry of a rectified grid](image)

Key

X, Y, Z axes to determine 3-space

$V_1$, $V_2$ offset vectors

O grid origin

When the relationship between a grid and an external coordinate reference system is not adequate to specify it in terms of an origin, an orientation and spacing in that coordinate reference system, it may still be possible to transform the grid coordinates into coordinates in the coordinate reference system. This transformation need not be in analytic form; it may be a table, relating the grid points to coordinates in the external coordinate reference system. Such a grid is classified as a referenceable grid. If the external coordinate reference system is related to the earth by a datum, the grid is a georeferenceable grid. A referenceable grid is associated with information that allows the location of all points in the grid to be determined in the coordinate reference system, but the location of the points is not directly available from the grid coordinates, as opposed to a rectified grid where the location of the points in the coordinate reference system is derivable from the properties of the grid itself. The transformation produced by the information associated with a referenceable grid will produce a grid as seen in the coordinate reference system, but the grid lines of that grid need not be straight or orthogonal, and the grid cells may be of different shapes and sizes.

The terms rectified grid coverage and georeferenceable grid coverage can be described as follows:

— A Rectified Grid Coverage is a Grid Coverage where every axis is either an Index Axis or a Regular Axis.

— A Referenceable Grid Coverage is a Grid Coverage where at least one axis is neither an Index Axis nor a Regular Axis.

7.6 Further Grid Coverages

Coverages are sometimes based on tessellations composed of regular hexagons. Such tessellations are usually called hexagonal grids.

One example is Hexagonal Grid Coverages which are given by tessellations composed of regular hexagons. Such tessellations are usually called hexagonal grids. The centers of a set of regular hexagons that form such a tessellation correspond to the grid points of a quadrilateral grid (Figure 9). That grid can be described as a rectified grid in which the two offset vectors are of equal length but differ in direction by 60°. The length of a side of the hexagon is $L = S \tan 30°$, where $S$ is the length of the offset vector. This means that the values in the coverage range can be stored in a computer as a multi-dimensional array. The hexagons are the Thiessen polygons that are generated around the grid points.

NOTE A set of Thiessen polygons generated from the grid points of any two-dimensional rectified grid described by two offset vectors that are equal in length but not orthogonal will be a set of congruent hexagons. The hexagons will be irregular – and, hence, out of scope – unless the offset vectors differ in direction by exactly 60°.
A Hexagonal Grid Coverage (Figure 10) evaluates a coverage at direct positions within a network of hexagons centred on a set of grid points. Evaluation is based on interpolation between the centres of the value hexagons surrounding the input position.

![Sample hexagonal grid](image)

**Figure 10 — Sample hexagonal grid**

8 Multi-Curve Coverages

A MultiCurveCoverage is a coverage consisting of a collection of curves.

**EXAMPLE** A coverage that assigns a route number, a name, a pavement width and a pavement material type to each segment of a road network can be represented as a MultiCurveCoverage.

**Requirement 29**: A MultiCurveCoverage shall contain only elements of the same type, which is ISO 19107 data type CurveData or a subtype thereof, as described by Figure 11.

**Requirement 30**: Function evaluate( ) shall be defined, for some coverage c and position p, as

\[
evaluate(p) = \{ v \mid \exists \text{ curve feature } f \in c : f.\text{contains}(p) \}\]

where contains( ) is defined in ISO 19107.
8.1 Segmented curve coverages

Segmented curve coverages are used to model phenomena that vary continuously or discontinuously along curves, which may be elements of a network. The domain of a segmented curve coverage is described by a set of curves and includes all the direct positions in all of the curves in the set.

9 Multi-Surface Coverages

9.1 General Multi-Surface Coverages

A MultiSurfaceCoverage is a coverage consisting of a collection of surfaces.

EXAMPLE A coverage that represents soil types typically has a spatial domain composed of surfaces with irregular boundaries.

Requirement 31: A MultiSurfaceCoverage shall contain only elements implementing ISO 19107 data type SurfaceData or a subtype thereof, as described by Figure 12.

Requirement 32: Function evaluate() shall be defined, for some coverage c and position p, as 

\[ \text{evaluate}(p) = \{ v \mid \exists \text{surface feature } f \in c: f.\text{contains}(p) \} \]

where contains( ) is defined in ISO 19107.

There are various practically relevant subtypes of multi-surface coverages, including polyhedral surfaces and their special case of Triangulated Irregular Networks (TINs). While in the previous version of 19123:2005 TIN coverages were modelled separately they now can be obtained through subtyping of ISO 19107 Surface.
9.2 Further Surface Coverages

9.2.1 General

So far surface coverages have been considered which represent a bundle of surfaces not constrained further. Some applications consider surfaces establishing tessellations.

9.2.2 Thiessen Polygon Coverages

A finite collection of points on a plane determines a partition of the plane into a collection of polygons equal in number to the collection of points. A Thiessen polygon is generated from one of a defining set of points by forming the set of direct positions that are closer to that point than to any other point in the defining set. The specific point is called the centre of the resulting polygon. The boundaries between neighbouring polygons are the perpendicular bisectors of the lines between their respective centres. Each polygon shares each of its edges with exactly one other polygon. Each polygon contains exactly one point from the defining set. Thiessen polygons are also known as Voronoi Diagrams or Proximal Sets.

A Thiessen polygon network (Figure 12) is a tessellation of a 2D space into surfaces bounded by Thiessen Polygons. A finite collection of points on a plane determines a partition of the plane into a collection of polygons equal in number to the collection of points. A Thiessen polygon is generated from one of a defining set of points by forming the set of direct positions that are closer to that point than to any other point in the defining set. The specific point is called the centre of the resulting polygon. The boundaries between neighbouring polygons are the perpendicular bisectors of the lines between their respective centres. Each polygon shares each of its edges with exactly one other polygon. Each polygon contains exactly one point from the defining set. Thiessen polygons are also known as Voronoi Diagrams or Proximal Sets.

EXAMPLE Figure 13 shows a collection of points with their (x, y) coordinates, the perpendicular of the lines that would be drawn between them, and the resultant polygons.
Evaluation of a Thiessen Polygon Coverage involves two steps. The first is to find the Thiessen polygon that contains the input Direct Position; the second is to interpolate the feature attribute values at the Direct Position from the geometry/value pairs at the centres of the surrounding Thiessen polygons.

9.2.3 Triangulated Irregular Networks (TINs)

The basic idea of a TIN is to partition of the points in the spatiotemporal domain of a discrete point coverage into a computationally unique set of non-overlapping triangles. Each triangle is formed by three of the points in the spatiotemporal domain of the discrete point coverage. The Delaunay triangulation method is commonly used to produce TIN tessellations with triangles that are optimally equiangular in shape, and are generated in such a manner that the circumscribing circle containing each triangle contains no point of the discrete point coverage other than those at the vertices of the triangle (Figure 14).

10 Multi-Solid Coverages

A MultiSolidCoverage is a coverage consisting of a collection of solids.

Requirement 33: A MultiSolidCoverage shall contain only elements of the same type, which is ISO 19107 data type SolidData or a subtype thereof, as described by Figure 14.

Requirement 34: Function evaluate( ) shall be defined, for some coverage c and position p, as

\[
evaluate(p) = \{ v \mid \exists \text{ solid feature } f \in c : f.contains(p) \}\]

where contains( ) is defined in ISO 19107:2019.
Figure 14 — Class MultiSolidCoverage
Annex A
(normative)

Conformance Tests

A.1 Conformance Class

This standard defines a single conformance class, CV_Coverage. Standardization targets are specifications containing provisions for coverages based on this standard. Test method is manual inspection of the specification documents to determine semantic coherence with the requirements of this standard. Below this is described for each requirement. Note that some requirements contain dependencies on other standards; such dependencies are mentioned with the requirements specification.

A.2 Requirements

A.2.1 Requirement 1

Test statement: An instantiation of package CV_Coverage shall have all instances and properties specified for this package, its contents, and its dependencies, contained in the UML model for this package in this Document; item naming may be chosen differently as long as there is no ambiguity or disambiguation is provided.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.2 Requirement 2


Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.3 Requirement 3

Test statement: A Coverage is an instantiation of ISO 19107 interface Collection, with two changes: (i) the elements association is unordered (instead of ordered, as in ISO 19107) and (ii) the code list GeometryType for possible geometry types is extended with values provided by the Coverage package.

The set of Direct Positions of a coverage is given by the union of all Direct Positions of its member features.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.4 Requirement 4

Test statement: For each Direct Position defined in the coverage there shall be exactly one Range Set value provided.
Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.5 Requirement 5

Test statement: For a given CV_Coverage,

- In case of no Common Point Rule provided and more than one range value existing for a Direct Position p, evaluate(p) shall return the set of all these values.

- In case of a a discrete coverage with a Common Point Rule provided, evaluate( ) shall provide one range value for each Direct Position, selected from the set of available range values in accordance with the Common Point Rule value.

- In case of a continuous coverage (i.e., when at least one interpolation method is indicated in the coverage, see 5.6) with a Common Point Rule provided, a value for each attribute shall be obtained by applying one of the interpolation methods provided for each geometric object in the coverage that contains the Direct Position, and a range value shall be selected in accordance with the Common Point Rule value.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.6 Requirement 6

Test statement: The semantics of a CV_CommonPointRule shall be given by Figure 4 and Table 3, but may be extended with further values whose interpretation is implementation-defined.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.7 Requirement 7

Test statement: A CV_Coverage shall be structured as described in Figure 5.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.8 Requirement 8

Test statement: All sub-coverages in a partition shall share the same CRS and range type; their Domain Sets shall fulfil all constraints imposed on the particular coverage type of the super-coverage.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.9 Requirement 9

Test statement: A coverage shall not recursively contain itself in a partitioning hierarchy.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.10 Requirement 10

Test statement: The Envelope of a Coverage shall contain all or a subset of the axes of the corresponding Domain Set.
Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.11 Requirement 11

Test statement: The Envelope of a Coverage should approximate its Domain Set as closely as possible, for all axes of the Domain Set present in Extent.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.12 Requirement 12

Test statement: If a Coverage contains an Envelope then this Envelope shall contain the Domain Set of this Coverage.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.13 Requirement 13

Test statement: The CRS component of the Coverage shall reference a CRS definition conformant with ISO 19111-1.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.14 Requirement 14

Test statement: The Range Type component shall be of type Record Type as defined in ISO 19103.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.15 Requirement 15

Test statement: The Range Type of a coverage at minimum shall provide the information necessary to decode the Range Set values and process them in a computer system, consisting of (i) data type information in some available typing system, (ii) null values, (iii) accuracy information, and (iv) unit of measure.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.16 Requirement 16

Test statement: Interpolation types allowed for the geometries contained in a coverage shall be given by the interpolation methods specified in ISO 19107 for the resp. geometry type.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.
A.2.17 Requirement 17

**Test statement:** A MultiPointCoverage shall contain only elements of the same type, which is ISO 19107 data type PointData or a subtype thereof, as described by Figure 7.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.18 Requirement 18

**Test statement:** Function evaluate( ) shall be defined, for some coverage c and position p, as evaluate(p) = { v | ∃ point feature f ∈ c: f.contains(p) } where contains( ) is defined in ISO 19107.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.19 Requirement 19

**Test statement:** A Grid Coverage shall be a subtype of Multi-Point Coverage.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.20 Requirement 20

**Test statement:** For each axis in a Grid, the hypersurfaces associated with any two coordinate values shall be disjoint.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.21 Requirement 21

**Test statement:** The Direct Positions of a Grid shall be given by those hypersurface intersection points where one hypersurface representative from every axis in G intersect.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.22 Requirement 22

**Test statement:** An Index Axis shall be given by an axis identifier, a CRS, lower and upper bounds lo and hi with lo, hi ∈ C and lo ≤ hi. Direct Positions shall be defined for every coordinate tuple where the coordinate value of the Index Axis on hand is from the closed interval S = { x ∈ Z | lo ≤ x ≤ hi }.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.23 Requirement 23

**Test statement:** A Regular Axis shall be given by an axis identifier, a 1D CRS, lower and upper bounds lo and hi with lo, hi ∈ C and lo ≤ hi, a resolution r ∈ C. Direct Positions shall be defined for every coordinate tuple where the coordinate value of the Regular Axis on hand is from the set S = { x ∈ C | lo ≤ x*r ≤ hi }.

**Test procedure:** Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.
A.2.24 Requirement 24

Test statement: For each Direct Position defined in the coverage there shall be exactly one Range Set value provided.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.25 Requirement 25

Test statement: A Displacement Axis Nest shall be given by a list of axis identifiers with \( d > 0 \) items, a \( d \times D \) CRS. Direct Positions shall be defined for every coordinate tuple where the coordinate value of each axis participating in the Displacement Axis Nest on hand is given as a set of \( d \)-dimensional coordinates from the CRS.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.26 Requirement 26

Test statement: An Algorithmic Axis set shall be given by a list of axis identifiers with \( n > 0 \) items, an \( n \times D \) CRS, a parameter set \( P \). Direct Positions shall be given through some algorithm parametrized with \( P \).

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.27 Requirement 27

Test statement: The sub-coverage partitions contained in a given Grid Coverage shall, in their entirety, satisfy all requirements established in 7.2 and Figure 10.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.28 Requirement 28

Test statement: Function \( \text{evaluate}( ) \) shall be defined, for some coverage \( c \) and position \( p \), as \( \text{evaluate}(p) = v \) for the corresponding point feature \( f \in c \) with \( f.\text{contains}(p) \), where \( \text{contains}( ) \) is defined in ISO 19107.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.29 Requirement 29

Test statement: A MultiCurveCoverage shall contain only elements of the same type, which is ISO 19107 data type CurveData or a subtype thereof, as described by Figure 12.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.
A.2.30 Requirement 30

Test statement: Function evaluate( ) shall be defined, for some coverage c and position p, as evaluate(p) = \{ v | \exists curve feature f \in c: f.contains(p) \} where contains( ) is defined in ISO 19107.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.31 Requirement 31

Test statement: A MultiSurfaceCoverage shall contain only elements implementing ISO 19107 data type SurfaceData or a subtype thereof, as described by Figure 13.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.32 Requirement 32

Test statement: Function evaluate( ) shall be defined, for some coverage c and position p, as evaluate(p) = \{ v | \exists surface feature f \in c: f.contains(p) \} where contains( ) is defined in ISO 19107.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.33 Requirement 33

Test statement: A MultiSolidCoverage shall contain only elements of the same type, which is ISO 19107 data type SolidData or a subtype thereof, as described by Figure 14.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.

A.2.34 Requirement 34

Test statement: Function evaluate( ) shall be defined, for some coverage c and position p, as evaluate(p) = \{ v | \exists solid feature f \in c: f.contains(p) \} where contains( ) is defined in ISO 19107.

Test procedure: Inspect the specification text as well as any associated (machine or human readable) files, such as schema definitions, for conformance.
Annex B
(informative)

Interpolation methods

B.1 General

Evaluation of a continuous coverage involves interpolation between known feature attribute values associated with geometric objects in the spatiotemporal domain of the discrete coverage that is provided as control for the continuous coverage. There are several interpolation methods. Each is used in the context of specified geometric configurations (Table C.1).

The enumerated data type CV_InterpolationMethod includes the following methods: nearest neighbour, linear, quadratic, cubic, bilinear, biquadratic, bicubic, lost area, and barycentric. These are described in B.2 through B.10.

A set of interpolation methods which also apply to coverages is given in ISO 19107. This document defines further interpolation techniques below; some of these are identical to interpolations defined in ISO 19107, but are still kept to introduce them under the name that has been established by earlier versions of this document. Generally, an application or standard may define additional ways of interpolation.

Since CV_InterpolationMethod is a CodeList, it may be extended in an application schema that specifies additional interpolation methods.

Table B.1 — Interpolation methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Coverage Type</th>
<th>Value Object Dimension</th>
<th>Subclause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearest Neighbour</td>
<td>Any</td>
<td>Any</td>
<td>B.2</td>
</tr>
<tr>
<td>Linear</td>
<td>Segmented Curve</td>
<td>1</td>
<td>B.3</td>
</tr>
<tr>
<td>Quadratic</td>
<td>Segmented Curve</td>
<td>1</td>
<td>B.4</td>
</tr>
<tr>
<td>Cubic</td>
<td>Segmented Curve</td>
<td>1</td>
<td>B.5</td>
</tr>
<tr>
<td>Bilinear</td>
<td>Quadrilateral Grid</td>
<td>2</td>
<td>B.6</td>
</tr>
<tr>
<td>Biquadratic</td>
<td>Quadrilateral Grid</td>
<td>2</td>
<td>B.7</td>
</tr>
<tr>
<td>Bicubic</td>
<td>Quadrilateral Grid</td>
<td>2</td>
<td>B.8</td>
</tr>
<tr>
<td>Lost Area</td>
<td>Thiessen Polygon, Hexagonal Grid</td>
<td>2</td>
<td>B.9</td>
</tr>
<tr>
<td>Barycentric</td>
<td>TIN</td>
<td>2</td>
<td>B.10</td>
</tr>
<tr>
<td>Other</td>
<td>Defined in an Application Schema</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B.2 Nearest neighbour interpolation

Nearest neighbour interpolation can be applied to any coverage. It generates a feature attribute value at a Direct Position by assigning it the feature attribute value associated with the nearest Direct Position in the

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Price based on 65 pages
spatiotemporal domain of the coverage. Nearest neighbour interpolation extends a discrete coverage to a step function defined on the convex hull of the domain objects in the domain of the coverage. Nearest neighbour interpolation is the only interpolation method described in this document that can be used to interpolate attributes that have nominal or ordinal values.

### B.3 Linear interpolation

Linear interpolation is commonly used to interpolate along curves. It is based on the assumption that feature attribute values at different positions along the curve differ in proportion to the distances between those positions:

Given two point value pairs \((p_s, v_s)\) and \((p_t, v_t)\), where \(p_s\) is the start point and \(p_t\) is the end point of a value segment, and \(v_s\) and \(v_t\) are the feature attribute values associated with those points, the feature attribute value \(v_i\) associated with the direct position \(p_i\) is:

\[
v_i = v_s + (v_t - v_s) \left( \frac{(p_i - p_s)}{(p_t - p_s)} \right)
\]

**NOTE** In the case of a discrete point coverage, the “steps” of the step function are the Thiessen polygons generated by the set of points in the domain of the coverage.

### B.4 Quadratic interpolation

Quadratic interpolation is also used to interpolate along curves. It is based on the quadratic polynomial:

\[
v = a + bx + cx^2
\]

where

- \(a\) is the value of a feature attribute at the start of a value segment and
- \(v\) is the value of a feature attribute at distance \(x\) along the curve from the start.

Three point value pairs are needed to provide control values for calculating the coefficients of the function.

### B.5 Cubic interpolation

Cubic interpolation is also used to interpolate along curves. It is based on the cubic polynomial:

\[
v = a + bx + cx^2 + dx^3
\]

where

- \(a\) is the value of a feature attribute at the start of a value segment and
- \(v\) is the value of a feature attribute at distance \(x\) along the curve from the start.

Four point value pairs are needed to provide control values for calculating the coefficients of the function.

### B.6 Bilinear interpolation

Bilinear interpolation is used to interpolate feature attribute values at direct positions in two dimensions.

Given a direct position, \(p\), contained in a grid cell whose vertices are \(V, V + V_1, V + V_2,\) and \(V + V_1 + V_2,\) and with feature attribute values at these vertices of \(w_1, w_2, w_3,\) and \(w_4,\) respectively, there are unique numbers \(i\) and \(j,\) with \(0 < i < 1,\) and \(0 < j < 1\) such that \(p = V + iV_1 + jV_2.\) The feature attribute value at \(p\) is:
\[ w = (1-i)(1-j) \, w_1 + i(1-j) \, w_2 + j(1-i) \, w_3 + ij \, w_4 \]

NOTE In an unrectified grid, \( V_1 \) and \( V_2 \) are the unit vectors \((0,1)\) and \((1,0)\).

B.7 Biquadratic interpolation

Biquadratic interpolation is also used to compute feature attribute values at Direct Positions in two dimensions. It is based on the biquadratic polynomial:

\[ v = a + bx + cy + dx^2 + ey^2 + hxy^2 + ixy^2 \]

B.8 Bicubic interpolation

Bicubic interpolation is also used to compute feature attribute values at direct positions in two dimensions. Bicubic interpolation uses the function:

\[ v = a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2 + a_6 x^2 y + a_7 x y^2 + a_8 x^3 + a_9 y^3 + a_{10} x y^3 + a_{11} x^3 y + a_{12} x y^3 + a_{13} x^3 y^2 + a_{14} x^2 y^3 + a_{15} x^3 y^3 \]

B.9 Lost area interpolation

Lost area interpolation extends a Multi Point coverage to a continuous function, \( f \), defined on the convex hull of the domain of the point coverage.

Let \( D = \{ x_1, x_2, \ldots, x_n \} \) be the domain of the point coverage, and let \( \{ V_1, V_2, \ldots, V_n \} \) be the Thiessen polygons generated by the set \( D \).

Suppose it is desired to calculate \( f(q) \), where \( q \) is a Direct Position in the convex hull of \( D \). Begin by forming the Thiessen polygons generated by \( D \); then add \( p \) to the \( D \) and form the Thiessen polygons for the set of \( n+1 \) points: \( \{ x_1, x_2, \ldots, x_n, p \} \). The two sets of polygons are identical, except that each of the polygons coterminous with the polygon containing \( q \) “loses area” to the new polygon containing \( p \).

The interpolation forms the weighted average such that each feature attribute value contributes to the feature attribute value at \( p \) according to the amount of area its polygon lost to the polygon at \( p \). More formally:

a) Suppose that the discrete point coverage is characterized by the point value pairs: \( \{(x_1, v_1), (x_2, v_2), \ldots, (x_n, v_n)\} \).

b) Among the Thiessen polygon set formed by \( \{ x_1, x_2, \ldots, x_n, p \} \), those coterminous with the polygon containing \( p \) are \( \{ V_1, V_2, \ldots, V_k \} \).

c) The corresponding Thiessen polygons from the set generated by \( \{ x_1, x_2, \ldots, x_n \} \) are \( \{ V'_1, V'_2, \ldots, V'_k \} \).

d) The area lost by the \( n \)th polygon is \( V'_i - V_i \).

e) The total area lost is \( \sum (V'_i - V_i) \) where the sum is over \( i \) from 1 to \( k \) (that is, the sum is over all polygons that lost area to the polygon containing \( q \)). Note that this sum is the same as the area of the Thiessen polygon containing \( p \).

f) Then the interpolated feature attribute value at \( p \) is:
\[ f(p) = \left( \sum vi \times (V'i - Vi) \right) / \sum (V'i - Vi) \] where the summations are over the same range: \( i = 1, \ldots, k \).

**B.10 Barycentric interpolation**

Let \( P, Q, \) and \( R \) denote the vertices of a triangle. For any direct position, \( S \), in the triangle, there is a unique triple of numbers, \( i, j, \) and \( k, \) with \( 0 \leq i \leq 1, \) \( 0 \leq j \leq 1, \) and \( 0 \leq k \leq 1, \) and with \( i + j + k = 1, \) such that

\[ S = iP + jQ + kR \]

The numbers \((i, j, k)\) are the barycentric coordinates of \( S \).

The name “barycentric” comes from the fact that using the equation above, \( S \) is the centre of mass of a triangle with point masses of size \( i, j, \) and \( k \) at the corners \( P, Q, \) and \( R \) respectively. As one allocates mass to the three corners, the centre of mass can occupy any direct position in the triangle. For details, see [5].

Given a value triangle composed of the CV_PointValuePairs \((p_1, v_1), (p_2, v_2), (p_3, v_3)\), and a Direct Position, \( S, \) inside it, the barycentric coordinates of \( S \) are \((i, j, k)\), where \( S = ip_1 + jp_2 + kp_3 \) and the feature attribute value at \( S \) is \( v = iv_1 + jv_2 + kv_3 \).

**B.11 Other**

Other interpolation methods may be defined in an Application Schema that makes use of this standard.
Annex C
(normative)

Sequential enumeration

C.1 General

A sequential enumeration specifies the order of an index of the axis into the mathematical space defining a
coverage. Two or more axis may be coded together to provide an index that provides an order to a space.
Such ordering is sometimes of value because it may provide properties to the number space that are or use in
some operations on the data. For example, Riemann hyperspace is traversed by Morton order. This allows for
variable size cells (such as in a quadtree in 2 dimensions) and obeys the Riemann criteria where values that
are close together in the Morton order are also close together in physical space. Technically this is an
extension of the Pythagorean theorem into hyperspace. CV_SequenceType provides a list of codes for
identifying types of sequencing methods. This annex explains those types in greater detail.

There are several sequencing rules based on incrementing or decrementing grid coordinate values in a simple
fashion. More complex space filling curves can also be used. Space filling curves are generated by
progressively subdividing a space in a regular way and connecting the elements resulting from each
subdivision according to some rule. They can be used to generate a grid, but they can also be used to assign
an ordering to the grid points or grid cells in a separately defined grid. They lend themselves more readily than
simple incrementing methods to sequencing in grids that have irregular shapes or cells of variable size.

In every case, ordering of the grid cells starts by incrementing coordinates along one grid axis. At some point
in the process, it begins to increment coordinates along a second grid axis, then a third, and so on until it has
progressed in the direction of each of the grid axes. The figures in this annex provide examples. The attribute
CV_SequenceRule.scanDirection (8.15.3) provides a list of signed axis names
that identifies the order in which scanning takes place. The list may include an additional element to support interleaving of feature
attribute values (see C.8 for a more detailed discussion of interleaving).

Ordering is continuous if consecutive pairs of grid cells in the sequence are maximally connected. It is semi-
continuous if consecutive pairs of grid cells are connected, but less than maximally connected, and
discontinuous if consecutive pairs of cells are not connected.

EXAMPLE In the 2-dimensional case, a quadrilateral grid cell is connected to the eight cells with which it shares at
least one corner. It is maximally connected to the four cells with which it shares an edge and two corners. In the three-
dimensional case, a cell is maximally connected to those cells with which it shares a face.

NOTE In the example diagrams of this annex, continuous segments of scan lines are shown as solid lines, and
discontinuous segments are shown as dashed lines.

C.2 Linear scanning

In linear scanning (Figure D.1), feature attribute value records are assigned to consecutive grid points along a
single grid line parallel to the first grid axis listed in scanDirection. Once scanning of that row is complete,
assignment of feature attribute value records steps to another grid line parallel to the first and continues to
step from grid line to grid line in a direction parallel to the second axis. If the grid is 3-dimensional, the
sequencing process completes the assignment of feature attribute value records to all grid points in one plane,
then steps to another plane, then continues stepping from plane to plane in a direction parallel to the third axis.
of the grid. The process can be extended to any number of axes. Linear scanning is continuous only along a single grid line.

![Figure D.1 — Examples of linear scanning in a 2-dimensional grid](image)

**NOTE** The axes of 2-dimensional grids are often called “row” (horizontal) and “column” (vertical). In this case, scanning in (x,y) order is sometimes called row or row-major scanning.

### C.3 Boustrophedonic scanning

In a variant of linear scanning, known as boustrophedonic or byte-offset scanning, the direction of the scan is reversed on alternate grid lines (Figure D.2). In the case of a 3-dimensional grid, it will also be reversed in alternate planes. Boustrophedonic scanning is continuous.

![Figure D.2 — Examples of boustrophedonic scanning in a 2-dimensional grid](image)

### C.4 Cantor-diagonal scanning

Cantor-diagonal scanning, also called zigzag scanning, orders the grid points in alternating directions along parallel diagonals of the grid (Figure D.3). The scan pattern is affected by the direction of first step. Like linear scanning, Cantor-diagonal scanning can be extended to grids of three or more dimensions by repeating the scan pattern in consecutive planes. Cantor-diagonal scanning is semi-continuous within a single plane.

![Figure D.3](image)
C.5 Spiral scanning

Spiral scanning (Figure D.4) can begin either at the centre of the grid (outward spiral), or at a corner (inward spiral). Like linear or Cantor-diagonal scanning, spiral scanning can be extended to grids of three or more dimensions by repeating the scan pattern in consecutive planes. Spiral scanning is continuous in any one plane, but continuity in grids of more than two dimensions can only be maintained by reversing the inward/outward direction of the scan in alternate planes.

C.6 Morton order

Morton ordering is typically based on a space-filling curve generated by progressively subdividing a space into quadrants and ordering the quadrants in a Z pattern as shown in Figure D.5. The ordering index for each grid point is computed by converting the grid coordinates to binary numbers and interleaving the bits of the resulting values. Given the list of the grid axes specified by CV_SequenceRule.scanDirection, the bits of the coordinate corresponding to an axis are less significant than those of the coordinate corresponding to the next axis in the list. Morton ordering can be extended to any number of dimensions. Morton ordering is discontinuous.

NOTE Because of the shape of the curve formed by the initial ordering of quadrants, Morton ordering is also known as Z ordering.
Morton ordering can also be used with subdivisions of higher order than 2x2. A 3x3 subdivision for example, or any other odd number, preserves the location of the central cell in systems with hierarchical subdivisions (Figure D.6). For 3x3 subdivision the ordering index for each grid point is computed by converting the grid coordinates to base3 digits and interleaving the base3 digits of the resulting values. In the 2-dimensional case pairs of base3 digits can be combined to form a base 9 digit, in 3- or 4-dimensions groups of 3- or 4- base3 digits can be combined to form base 27 or base 81 digits, any of which can be coded as a single ascii digit.

Figure D.6 — Examples of Morton ordering in irregular grids

C.7 Hilbert order

Like Morton ordering, Hilbert ordering is based on a space-filling curve generated by progressively subdividing a space into quadrants, but the initial pattern of subdivision is different for Hilbert curves. Further subdivision involves replacement of parts of the curve by different patterns (Figure D.7), unlike the simple replication of a single pattern as in Morton ordering. There are two sets of patterns. The left-hand column of the figure includes those for which the sense of the scan directions is the same – both are positive or both negative. The right-hand column of the figure includes those for which the sense of the scan directions is opposite – one is positive and one is negative. A Hilbert curve can only be constructed with patterns from the same set; it uses all the patterns in that set.

NOTE Because of the shape of the curve formed by the initial ordering of quadrants, Hilbert ordering is also known as Pi ordering.

Computation of the ordering index is more complicated for Hilbert ordering than for Morton ordering. Algorithms for the 2-dimensional case (Figure D.8) are described in [7] and [8]. 3-dimensional Hilbert curves are discussed in [9]. Hilbert ordering is continuous.

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C.8 Interleaving of feature attribute values

When the range of a grid coverage includes more than one feature attribute, the feature attribute values may be interleaved in various ways within a list. Such interleaving can be described by including an element for the range in the list of axes provided by the scanDirection attribute of CV_SequenceRule. The index for the record of attributes is then incremented in the same way as the coordinates.

EXAMPLE Consider the 2 × 2 grid in Figure D.9. It has a range (r) of two attributes, A and B. Assuming a linear scan positive first in the x and then in the y direction, the scan order can be selected to access the feature attribute values in the different ways shown in Table D.1.

<table>
<thead>
<tr>
<th>Order</th>
<th>Scan direction</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r, x, y</td>
<td>x, y, r</td>
<td>x, r, y</td>
</tr>
<tr>
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<td>A_{11}</td>
<td>A_{11}</td>
<td>A_{11}</td>
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<tr>
<td>2</td>
<td>B_{11}</td>
<td>A_{21}</td>
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<td>3</td>
<td>A_{21}</td>
<td>A_{12}</td>
<td>B_{11}</td>
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<td>4</td>
<td>B_{21}</td>
<td>A_{22}</td>
<td>B_{21}</td>
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<tr>
<td></td>
<td>A₁₂</td>
<td>B₁₁</td>
<td>A₁₂</td>
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<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>B₁₂</td>
<td>B₂₁</td>
<td>A₂₂</td>
</tr>
<tr>
<td>7</td>
<td>A₂₂</td>
<td></td>
<td>B₁₂</td>
</tr>
<tr>
<td>8</td>
<td>B₂₂</td>
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<td>B₂₂</td>
</tr>
</tbody>
</table>
Annex D
(informative)
Annex E
(normative)

Data-Centric Coverage Specification

E.1 Overview

Historically, modelling approaches in ISO have evolved. Earlier, data structures have been described. More recently, ISO has moved to specifying interfaces instead because this better hides implementation details. Such a step of abstraction is important in particular with the separation of the original, single 19123:2003 specification into an abstract specification in 19123-1 and an implementation guidance in 19123-2.

The interface-centric approach to coverage modelling is adopted in the body of this standard. At the same time it normatively retains the data-centric coverage description from the older version of 19123 as Annex E. As such, coverage data structures of 19123:2003 represent one valid generic data structure out of many possible realizations satisfying the interface of 19123-1. Specifically, the 19123:2003 coverage structure specification is retained for compatibility with the many implementations that have realized these generic classes, albeit in their individual ways.

The previous version of ISO 19123:2005 defines generic data classes which could be specialized by the developers of more detailed product specifications which could then be implemented. External organizations reference these generic data classes. These classes are REALIZED in these external standards. Since references to these classes exist in external standards it is important that these generic data classes be maintained.

The current version of ISO 19123-1 takes a different approach. It defines an interface which provides a standardized window through which a variety of different data structures could produce the same result. In that way it is more flexible than the previous approach. But it is not in conflict with the previous approach. The previous generic data classes are still valid, and the external standards or product specifications that referenced them also remain valid. The new version of ISO 19123-1 is simply more flexible allowing many different implementation structures, not just the defined generic data classes presented in this annex.

This annex specifies the abstract data classes from 19123:2005 that are retained. These form a compliant data structure that can be interpreted through the interface structure defined in the revised 19123-1. The classes and attributes are mapped from the older structure to the new interface structure.

E.2 Generic Data Structure Coverage Schema

This annex is described in a separate package from the rest of the model in the 19123-1 standard in order to ensure that the namespace is unique. That is, the class name CV_Coverage <<interface>> is used both to describe the root class of the interface structure, and the class name CV_Coverage <<featureType>> is used in this annex to describe the root class of the generic data structure. The names are used this way to ensure backward compatibility. A mapping is shown from the generic data structure classes to the new interface classes.

The class CV_Coverage <<featureType>> is an instance of the <<metaclass>> GF_FeatureType (ISO 19109), which therefore represents a feature type. CV_Coverage <<featureType>> supports five attributes, one operation, and three associations. This is illustrated in Figure E.1.
E.2.1.1 Attributes

E.2.1.1.1 domainExtent

The attribute `domainExtent[1..*]EX_Extent` contains the extent of the domain of the coverage. The data type `EX_Extent` is defined in ISO 19115-1. Extents may be specified in space, time or space-time. The attribute `domainExtent` has been generalized in ISO 19123-1. This older narrower extent has been retained for backward compatibility.
E.2.1.1.2 rangeType

The attribute rangeType: RecordType describes the range of the coverage. The data type RecordType is defined in ISO 19103. It consists of a list of attribute name/data type pairs. A simple list is the most common form of rangeType, but RecordType can be used recursively to describe more complex structures. The rangeType for a specific coverage shall be specified in an application schema.

E.2.1.1.3 commonPointRule

The optional attribute commonPointRule: CV_CommonPointRule identifies the procedure to be used for evaluating the CV_Coverage at a position that falls either on a boundary between geometric objects or within the boundaries of two or more overlapping geometric objects, where the geometric objects are either CV_DomainObjects or CV_ValueObjects. This attribute is optional and takes the default value of the attribute as “average”. The attribute is not required in the case when there is only one extent per coverage; that is, when geometric objects do not overlap.

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 attributes. In the case of a discrete coverage range attribute, 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.

Requirement 5: For a given CV_Coverage,

— In case of no Common Point Rule provided and more than one range value existing for a Direct Position p, evaluate(p) shall return the set of all these values.

— In case of a a discrete coverage with a Common Point Rule provided, evaluate( ) shall provide one range value for each Direct Position, selected from the set of available range values in accordance with the Common Point Rule value.

— In case of a continuous coverage (i.e., when at least one interpolation method is indicated in the coverage, see 5.6) with a Common Point Rule provided, a value for each attribute shall be obtained by applying one of the interpolation methods provided for each geometric object in the coverage that contains the Direct Position, and a range value shall be selected in accordance with the Common Point Rule value.

Requirement 6: The semantics of a CV_CommonPointRule shall be given by Figure E.3 and Table E.1, but may be extended with further values whose interpretation is implementation-defined.
Table E.1 — Semantics of CV_CommonPointRule

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning (given some position p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td>Arithmetic average over the set returned by evaluate(p)</td>
</tr>
<tr>
<td>low</td>
<td>Minimum value of the set returned by evaluate(p)</td>
</tr>
<tr>
<td>high</td>
<td>Maximum value of the set returned by evaluate(p)</td>
</tr>
<tr>
<td>all</td>
<td>the complete set returned by evaluate(p)</td>
</tr>
<tr>
<td>start</td>
<td>startValue of the second CV_ValueSegment (only applicable to Multi-Curve Coverages)</td>
</tr>
<tr>
<td>end</td>
<td>endValue of the first CV_ValueSegment (only applicable to Multi-Curve Coverages)</td>
</tr>
<tr>
<td>oldest</td>
<td>Value with the least future-directed time coordinate (only applicable to coverages with a temporal axis)</td>
</tr>
<tr>
<td>newest</td>
<td>Value with the most future-directed time coordinate (only applicable to coverages with a temporal axis)</td>
</tr>
</tbody>
</table>

E.2.1.1.4 interpolationType

The optional attribute interpolationType: CV_InterpolationMethod is a code that identifies the interpolation method that shall be used to derive a feature attribute value at any direct position within the CV_ValueObject. The attribute is optional. The default value is “nearestNeighbor”. No value is needed for an analytical coverage (one that maps direct position to attribute value by using a mathematical function rather than by interpolation).

E.2.1.1.5 interpolationParameterTypes

Although many interpolation methods use only the values in the coverage range as input to the interpolation function, there are some methods that require additional parameters. The optional attribute interpolationParameterTypes specifies the types of parameters that are needed to support the interpolation method identified by interpolationType. The data type RecordType is specified in ISO 19103. It is a dictionary of names and data types.

E.2.1.2 Operation

E.2.1.2.1 evaluate

The operation evaluate(p: DirectPosition, list: Sequence<CharacterString>): Set<Record> accepts a DirectPosition as input and return a set of Records of feature attribute values for that direct position. The parameter list is a sequence of feature attribute names each of which identifies a field of the rangeType. If list is null, the operation returns a value for every field of the rangeType. Otherwise, it returns a value for each field included in list. Class DirectPosition is defined in ISO 19107; the data type Record is defined in ISO 19103. If the direct position passed is not in the domain of the coverage, then an error message shall be generated. If the input DirectPosition falls within two or more geometric objects within the domain, the operation shall return records of feature attribute values computed according to the value of the attribute commonPointRule.
NOTE Normally, the operation will return a single record of feature attribute values.

E.2.1.3 Associations

E.2.1.3.1 Coordinate Reference System

The association Coordinate Reference System links the CV_Coverage to the coordinate reference system to which the objects in its domain are referenced. The class CRS is specified in ISO 19111-1:2019. The multiplicity of the CRS role in the Coordinate Reference System association is one. This means that a coverage with the same range but with its domain defined in a different coordinate reference system is a different coverage.

E.2.1.3.2 Domain

The association Domain links the CV_Coverage to the set of CV_DomainObjects in the domain.

E.2.1.3.3 Range

The association Range links the CV_Coverage to the set of CV_AttributeValues in the range. The range of a CV_Coverage shall be a homogeneous collection of records. That is, the range has a constant dimension over the entire domain, and each field of the record provides a value of the same attribute type over the entire domain.

NOTE This document does not specify how the Domain and Range associations are to be implemented. The relevant data may be generated in real time, it may be held in persistent local storage, or it may be electronically accessible from remote locations.

E.2.2 CV_DomainObject

E.2.2.1 General

CV_DomainObject represents an element of the domain of the CV_Coverage. It is an aggregation of objects that may include any combination of GM_Objects (ISO 19107), TM_GeometricPrimitives (ISO 19108), or spatial or temporal objects defined in other standards, such as the CV_GridPoint defined in this document.

E.2.2.2 Associations

E.2.2.2.1 TemporalComposition

The association TemporalComposition associates a CV_DomainObject to the set of TM_GeometricPrimitives of which it is composed.

E.2.2.3 CV_AttributeValues

E.2.2.3.1 General

CV_AttributeValues represents an element from the range of the CV_Coverage.

E.2.2.3.2 Attribute

E.2.2.3.2.1 values

The attribute values is a Record containing one value for each attribute.

EXAMPLE A coverage with a single (scalar) value (such as elevation). A coverage with a series (array/tensor) of values all defined in the same way (such as brightness values in different parts of the electromagnetic spectrum).
E.2.2.4 Associations

E.2.2.4.1 Range

The association Range links the set of CV_AttributeValues to the CV_Coverage that has the set as its range.

E.2.2.5 CV_CommonPointRule

The optional CV_Coverage attribute commonPointRule of type CV_CommonPointRule identifies the procedure to be used for evaluating the CV_Coverage at a position for which more than one range values exist. Its behaviour is defined as follows:

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. Common Point Rule is described in clause 5.5.

E.2.3 Subclassing CV_GeometryValueObject
E.2.4 Discrete and Continuous Coverages

E.2.4.1 General

The standard 19123:2005 made a major distinction between Discrete and Continuous coverages and organized the subtypes of coverage based on these types. This version of 19123-1 has generalized the concept. Any axis may be discrete or continuous. This is described in clause (xxxx). Since this is a generalization of the concept it is fully backward compatible with the older approach. Therefore this annex has simplified the description and no longer organizes coverages as Discrete or Continuous. The defined generic subtypes of CV_ValueObject and CV_GeometryValuePair are simply listed as subtypes. Each has a use in a particular type of coverage. This is shown below:

- CV_ValueCurve and CValueSegment together with CV_PointValuePair and CV_CurveValuePair are used in a Segmented Curve Coverage
- CV_TheissenValuePolygon together with CV_PointValuePair are used in a Theissen Polygon Coverage
E.2.4.2 Multi-Point Coverages

A point coverage is characterized by a finite domain consisting of points which may be regularly or irregularly distributed. A point coverage may be discrete in the domain; that is, valid only at the location of the points. Such as discrete point coverage provides a basis for continuous coverage functions through a control relationship, where the evaluation of the continuous coverage function is accomplished by interpolation between the points of the discrete point coverage. Most interpolation algorithms depend upon a structured pattern of spatial relationships between the points. This requires either that the points in the spatial domain of the discrete point coverage be arranged in a regular way, or that the spatial domain of the continuous coverage be partitioned in a regular way in relation to the points of the discrete point coverage. Grid coverages employ the first method; Thiessen polygon and TIN coverages employ the second.

EXAMPLE A set of hydrographic soundings is a discrete point coverage. Interpolation between the points establishes a bathymetric surface, which is a continuous coverage.

The classes CV_PointValuePair and CV_GridPointValuePair provide values for Multi-point Coverages.

E.2.4.3 Multi-Curve Coverage

A curve coverage is characterized by a finite spatial domain consisting of curves. In a discrete curve coverage the curves represent features such as roads, railroads or streams. They may be elements of a network.

EXAMPLE A discrete curve coverage assigns a route number, a name, a pavement width and a pavement material type to each segment of a road system. The curve is discrete in the domain and each domain element is associated with a single value in the range.

A continuous curve coverage assigns a value to locations along a curve. This is a coverage with a one dimensional domain. An example is a measurement of pavement thickness along a road. Such a continuous coverage may be interpolated.

The classes CV_ValueCurve and CV_ValueSegment provide values for Multi-curve Coverages. They reference CV_PointValuePair for the geometry of the points at the ends of curve segments.

E.2.4.4 Multi-Surface Coverage

A Multi-surface Coverage is a coverage whose domain consists of a collection of surfaces. In most cases, the surfaces that constitute the domain of a coverage are mutually exclusive and exhaustively partition the extent of the coverage. Surfaces or their boundaries may be of any shape. The boundaries of component surfaces often correspond to natural phenomena and are highly irregular.

EXAMPLE A discrete multi-surface coverage that represents soil types typically has a spatial domain composed of surfaces with irregular boundaries.

Any set of polygons can be used as a spatial domain for a discrete Multi-surface Coverage. Spatial domains composed of congruent polygons are very common. Often, these domains are composed of congruent rectangles or regular hexagons. The geometry of such a tessellation may be described in terms of a quadrilateral grid or a hexagonal grid. The spatial domain of a discrete surface coverage may also consist of the triangles that compose a TIN, or the polygons of a Thiessen polygon network. Based on the control points, a surface coverage may be interpolated at locations on the surface. That is, the control points at the corners of...
a TIN triangle may be used to drive an interpolation function that allows one to determine a value at any location on the TIN value triangle. Equivalently this may be done for a Thiessen value polygon where interpolation is based on interpolation between the centres of the CV_ThiessenValuePolygons surrounding the input position, or a grid value cell, value hexagon or general mesh where other interpolation methods may be applied. The geometric value of a surface is defined by the class CV_SurfaceValuePair.

E.2.4.5 Multi-Solid Coverage

A Multi-solid Coverage is a coverage whose domain consists of a collection of solids. Solids or their boundaries may be of any shape. Generally, the solids that constitute the domain of a coverage are mutually exclusive and exhaustively partition the extent of the coverage, but this is not required.

EXAMPLE Buildings in an urban area could be represented as a set of unconnected solids each with attributes such as building name, address, floor space and number of occupants.

As in the case of surfaces, the spatial domain of a discrete solid coverage may be a regular or semiregular tessellation of the extent of the coverage. The tessellation can be defined in terms of a three-dimensional grid, where the set of grid cells is the spatial domain of the coverage.

Based on the control points, a solid coverage may be interpolated at locations within the solid. That is, the control points along the edges of the solid may be used to drive an interpolation function that allows one to determine a value at any location within the solid. Additional control points may also be defined within the solid to drive an interpolation. The geometric value of a solid is defined by the class CV_SolidValuePair.

E.2.4.6 Grid Coverage

A mesh is a network composed of two or more sets of curves in which the members of each set intersect the members of the other sets. A grid is a type of mesh which is regular in some algorithmically defined manner. Grid coverages employ a systematic tessellation of the domain. The principal advantage of such tessellations is that they support a sequential enumeration of the elements of the domain.

The class CV_Grid describes the geometric characteristics of a quadrilateral grid. CV_GridValuesMatrix is a subclass of CV_Grid that ties feature attribute values to grid geometry. It holds a sequence of records associated with a sequencing rule that specifies an algorithm for assigning records of feature attribute values to grid points. CV_SequenceRule is a data type that contains information for mapping grid coordinates to a position within the sequence of records of feature attribute values.
Annex F
(informative)

Backward Compatibility

F.1 General

This revision of the ISO 19123-1 standard is completely backward compatible with the previous version ISO 19123:2005 in that all ISO 19123:2005 concepts can be expressed by ISO 19123-1; in particular, Annex E retains the data-centric view of 19123:2005.

The standard has been extended and clarified and some fields have been made optional and some items have been left out to achieve the appropriate level of abstraction; however, the elements of the standard that were defined in the previous version and are present in this version remain technically unchanged.

Any profile, application schema or other standard that made reference to the previous version of this standard, ISO 19123:2005, remains valid as long as the versions of other standards normatively referenced in this document (such as ISO 19107, ISO 19109, and ISO 19111-1) remain valid.

F.2 Changes

The changes that have been made to the previous version of the standard are listed below.

- The standard has been renamed to be “Part 1: Fundamentals”, since a new “Part 2: Coverage Implementation Schema” has been published.

- The scope has been revised to include Mesh, and the text has been simplified.

- The approach to standardization taken in the document has been changed. This version of 19123-1 defines an interface for coverages through which many different implementation structures may be referenced in a compatible manner. The previous version of the standard 19123:2005 defined a single generic data structure for coverages. The data structure defined in 19123:2005 remains valid as one of the many possible data structures that may be accessed through the interface. As such this data structure is summarized in normative Annex E. This allows for backward compatibility since implementations that referenced the foundation classes defined in 19123:2005 may still reference these same classes.

- The concept of Discrete and Continuous coverages has been generalized to address axes. That is, any axis (domain of range axis) may be discrete or continuous. This has greatly simplified the structure of the standard. Since this is a generalization of the previous concept it is backward compatible.

- The informative Annex on “UML notation” has been deleted since this material is now described in ISO 19103:2015.

- The UML diagrams have been redrawn for clarity and to follow the new conventions established in TC211. Some of the errors in the model consisted of duplicate definitions of attributes and operations in subclasses. This was a result of the older version of the UML modelling tool used when this
standard was first developed. Redundant attributes and operations have been removed except for those places where an attribute is deliberately overwritten to establish a default value.

- Some errors in 19123:2005 have been corrected. The original model was correct but original documentation did not align with the original model.

- The bibliography has been revised to include additional references and has been reformatted.

- ISO 19123-1 relies on the current versions of ISO 19111-1 and ISO 19107, which have been significantly updated as compared to the versions referenced in ISO 19123:2005.

- Definition of interpolation now is based on the interpolation definition of ISO 19107:2019 in order to avoid duplicate and diverging definitions.

- The annex on “Sequential enumeration” has been made normative.

- All operations except evaluate and interpolate are deleted.

- Information on an Image Coordinate Reference System from ISO 19111:2007 has been removed from the revised version of 19111-1:2019 and material added to clause xxx of this document.

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**Figure F.1 — Mapping between coverage types**
Bibliography


[8] GOODCHILD, M. F. and GRANDFIELD, A. W., Optimizing Raster Storage: An Examination of Four Alternatives, IAuto-Carto 6, 1983


