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Geographic information — Schema for coverage geometry and functions —

Part 3: **Processing fundamentals**

Information géographique — Schéma de la géométrie et des fonctions de couverture —

Partie 3: Principes de base du traitement

Reference number
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Contents

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 287, *Geographic Information,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement), in collaboration with the Open Geospatial Consortium (OGC), and in collaboration with the IEEE GRSS Earth Science Informatics Technical Committee.

A list of all parts in the ISO 19123 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document defines, at a high level, implementation-independent operations on coverages, i.e. digital representations of space-time varying geographic phenomena, as defined in ISO 19123-1. Specifically, regular and irregular grid coverages are addressed. The operations can be applied through an expression language allowing composition of unlimited complexity and combining an unlimited number of coverages for data fusion.

The language is functionally defined and free of any side effects. Its conceptual foundation relies on only two constructs: A “coverage constructor” builds a coverage, either from scratch or by deriving it from one or more other coverages. A “coverage condenser” derives summary information from a coverage by performing an aggregation such as count, sum, minimum, maximum and average.

The coverage processing language is independent from any request and response encoding, as no concrete request/response protocol is assumed. Hence, this document does not define a concrete service, but acts as the foundation for defining service standards functionality. One such standardization target is the OGC Web Coverage Service (WCS).[3]

Throughout this document, the following formatting conventions apply.

— Bold-Face in the text, such as **processCoveragesExpr**, represents syntax elements, normatively defined in Annex B.
— Text in italics, such as *succ*(), represents mathematical functions and variables.
— Courier font, such as **`return`** and `encode`(), is used for code in the sense of the coverage processing language.

Geographic information — Schema for coverage geometry and functions —

Part 3:
Processing fundamentals

1 Scope

This document defines a coverage processing language for server-side extraction, filtering, processing, analytics, and fusion of multi-dimensional geospatial coverages representing, for example, spatio-temporal sensor, image, simulation, or statistics datacubes. Services implementing this language provide access to original or derived sets of coverage information, in forms that are useful for client-side consumption.

This document relies on the ISO 19123-1 abstract coverage model. In this edition, regular and irregular multi-dimensional grids are supported for axes that can carry spatial, temporal or any other semantics. Future editions will additionally support further axis types as well as further coverage types from ISO 19123-1, specifically, point clouds and meshes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 19111, *Geographic information — Referencing by coordinates*

ISO 19123-1, *Geographic information — Schema for coverage geometry and functions — Part 1: Fundamentals*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19123-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
probing function
<coverage> function extracting information from the coverage

4 Conformance

4.1 Notation

Table 1 lists the other International Standards and packages in which UML classes used in this document have been defined.

Table 1 — Sources of externally defined UML classes

Prefix	International Standard	Package
	ISO 19123-1	Coverage Core, Grid Coverage

4.2 Interoperability and conformance testing

As an abstract standard, this document allows for multiple different implementations and does not define a standardized interoperable implementation. Rather, standardization targets are specifications of coverage operations and services which may use this language to describe the semantics of their operations.

Conformance testing shall be accomplished by validating a candidate concretization against all requirements by exercising the tests set out in Annex A. As a prerequisite, a candidate shall also pass all conformance tests of ISO 19123-1 Coverage Core and Grid Coverage.

4.3 Organization

Table 2 provides details of the conformance classes described in this document. The name and contact information of the maintenance agency for this document can be found at www.iso.org/maintenance_agencies.

Table 2 — Conformance classes

Conformance class	Clause	Identifying URL
Coverage Processing	6	https://standards.isotc211.org/19123/-3/1/conf/coverage-processing

5 Coverage model

5.1 Overview

This document defines a language whose expressions accept any number of input coverages (together with further common inputs like numbers and strings) to generate any number of output coverages or non-coverage results. Coverages are defined in ISO 19123-1.

5.2 Coverage model

Following the mathematical notion of a function that maps elements of a domain (such as spatio-temporal coordinates) to a range (such as values of a “pixel”, “voxel”, etc.), a coverage consists of (Figure 1):

— an *identifier* which uniquely identifies a coverage in some context (here, the context of an expression);

— a *domain* of coordinate points (expressed in a common Coordinate Reference System, CRS): "*where in the multi-dimensional space can I find values?*";

— a probing function which answers for each coverage coordinate in the domain ("*direct position*"): "*what is the value here?*";

— a *range type*: "*what do those values mean?*".

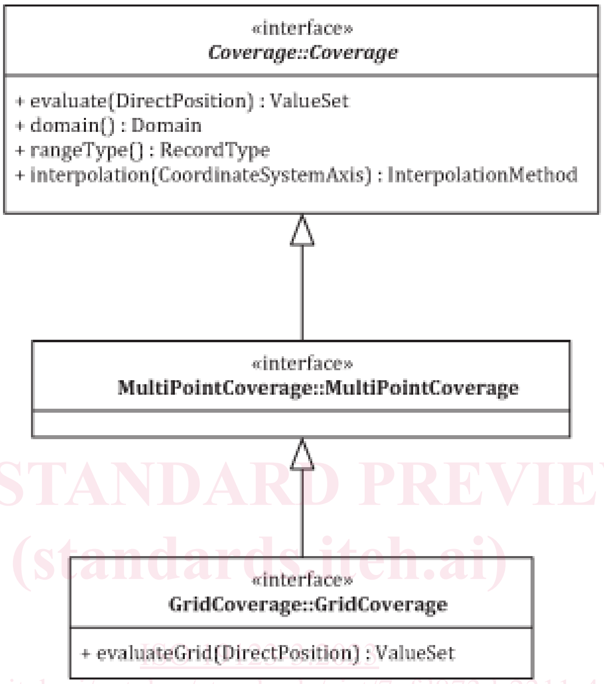

Figure 1 — Coverage and GridCoverage (ISO 19123-1)

NOTE 1 Coverage in ISO 19123-1 defines an interface which describes such an object's behaviour, but does not yet assume any particular data structure. One interoperable concretization of it is the implementation standard ISO 19123-2.

"Probing functions" are introduced below. Probing functions extract components from a given coverage. For every component of a coverage a corresponding probing function exists so that altogether all properties of a coverage can be retrieved. They serve to define this document's language semantics.

NOTE 2 In the processing definition of this document, further probing functions, beyond the ISO 19123-1 probing function *evaluate*(), are used as a concise means to describe all aspects of coverage-valued function results.

5.3 Coverage identifier

Coverages in this document have an identifier which is used in a query to address a coverage to derive from. Therefore, it is necessary for this identifier to be unique within some context (here: a query). No assumptions are made on the realization of this identifier. In particular, when the context of the coverage object changes (such as during delivery to a client) uniqueness is not necessarily guaranteed any longer. Therefore querying the object in the new context is potentially no longer possible.

NOTE In a concrete service, coverages available would typically be those which are stored on this server, where access control allows addressing the coverage according to the user sending the request, etc. All these aspects are out of scope of this document.

The corresponding probing function for a coverage C is:

$id(C)$

5.4 Domain

5.4.1 Direct position

A coverage offers values for positions in its domain. These are called “direct positions”. Further values can be derived through interpolation, depending on whether and what type of interpolation a coverage allows.

For some direct position $p = (p_1,\ldots,p_d)$ from a domain whose d-dimensional CRS contains axes $(a_1,\ldots,a_d)$, $p[a_i]$ is written for accessing the coordinate tuple component corresponding with axis a_i:

$p[a_i] = p_i$

5.4.2 Grid

The domain contains the coordinate tuples describing the coverage’s direct positions, which for the purpose of this document are on a multi-dimensional grid. Informally, this means that every direct position inside the grid has exactly one next neighbour in both directions of every axis, except for the rim, where obviously fewer neighbours are available. Figure 2 shows some regular and irregular grid examples.

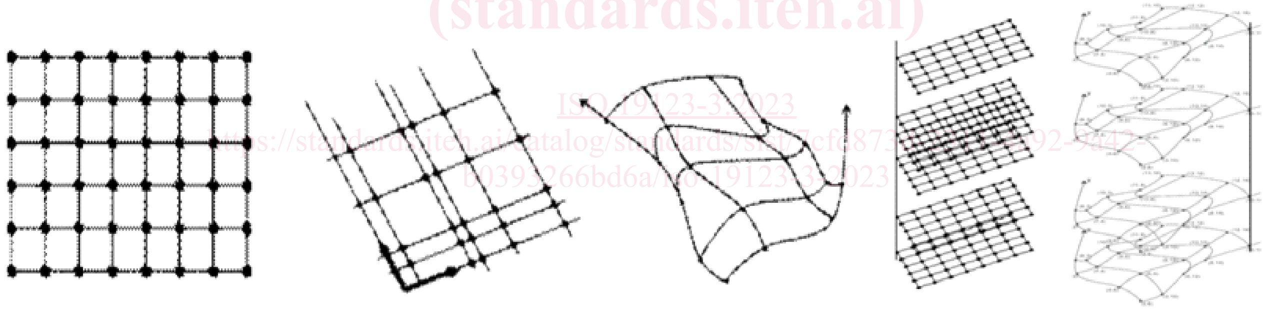

Figure 2 — Sample regular and irregular grid structures (ISO 19123-1)

The grid description depends on the complexity of the grid. As a grid is composed from an ordered sequence of axes, the resulting complexity is determined by the types of axes (such as integer versus Latitude versus time) as well as the rules determining the direct positions along these axes. The following axis types defined in ISO 19123-1 are currently supported by this document:

— a **Cartesian** (“index”) axis, which just requires lower and upper bound (which are of type integer);

— a **regular** axis, which can be described by lower and upper bounds together with a constant distance, the resolution;

— an **irregular** axis, which has individual distances, described by a sequence of coordinates.

As per ISO 19123-1, the coverage domain with its axes has a single CRS which can serve for geo-referencing. The definition and interpretation of CRSs is in accordance with ISO 19111.

The CRS of a domain is obtained through function $crs(C)$.

$crs(C)$

Auxiliary probing function *axisList*()extracts the ordered list of axes (a_1,…,a_d) from a *d*-dimensional CRS:

axisList(*crs*)

NOTE In accordance with ISO 19123-1, all axis names in such a list are pairwise disjoint so that the names can act as a unique identifier within their CRS.

Each axis contributes coordinates from a nonempty, totally ordered set of values which can be numeric or, in the general case, strings (such as "2020-08-05T").

For a given coverage *C*, probing function *domain*() delivers the coverage domain in its CRS:

domain(*C*)

The domain information describes the coverage's grid and its extent for each axis:

— the lower and upper bound of the direct positions;

— additionally, the following information:

  — for index axes: nothing further;

  — for regular axes: the resolution, expressed in the unit of measure (uom) of the axis;

  — for irregular axes: the sequence of points.

This information is accessible through extended variants of the abovementioned functions. For some coverage domain *D* with axis *a*, the following expressions return lower and upper bounds, respectively:

domain(*C*, *a*).lo
domain(*C*, *a*).hi

For convenience, a function pair identical in effect but based on the domain is defined:

D[*a*].*lo* = *domain*(*C*, *a*).*lo*
D[*a*].*hi* = *domain*(*C*, *a*).*hi*

The grid of the coverage domain is represented implicitly through functions "walking" the grid from one direct position to one of its neighbours. This is based on the topological structure of a grid where each direct position has exactly one lower and one higher neighbour along each axis, with the exception of the domain rims where no such neighbour is available. Therefore, at the rim, these functions are partial.

Let *D* be given as the domain of coverage *C*, so that *D* = *domain*(*C*). Let further *a* be some axis from the CRS of *D*. Then, functions *pred*() and *succ*() each return a neighbouring direct position for some given position. Function *pred*() returns the immediate preceding direct position along axis *a*, function *succ*() returns the immediate succeeding direct position along *a*. Where there is no such direct position (because the input position is sitting at the rim of the domain extent) the value is undefined, written as ⊥.

pred(*D*, *a*, *p*) = *x* where
  if *p*[*a*] = *D*[*a*].*lo* *domain*(*C*,*a*).*lo* then *x* = ⊥
  else *x* is given by: $x[a_x] = p[a_x]$ for all $a_x \in$ *domain*(*C*) \ {*a*}, and *x*[*a*] = max(*x*' | *x*' ∈ *domain*(*C*, *a*) and *x*' < *p*[*a*])

succ(*D*, *a*, *p*) = *x* where
  if *p*[*a*] = *D*[*a*].*hi* *domain*(*C*,*a*).*hi* then *x* = ⊥

else x is given by: $x[a_x] = p[a_x]$ for all $a_x \in domain(C) \setminus \{a\}$, and $x[a] = \min(x' \mid x' \in domain(C, a)$ and $x' > p[a])$

EXAMPLE In Figure 3, neighbours of p in coverage domain D with axes x and y can be reached as follows:
a = *succ*(*D*, *y*, *pred*(*D*, *x*, *p*)) = *pred*(*D*, *x*, *succ*(*D*, *y*, *p*))
b = *succ*(*D*, *y*, *p*)
c = *succ*(*D*, *y*, *succ*(*D*, *x*, *p*)) = *succ*(*D*, *x*, *succ*(*D*, *y*, *p*))
d = *pred*(*D*, *x*, *p*)
e = *succ*(*D*, *x*, *p*)
f = *pred*(*D*, *x*, *pred*(*D*, *y*, *p*)) = *pred*(*D*, *y*, *pred*(*D*, *x*, *p*))
g = *pred*(*D*, *y*, *p*)
h = *succ*(*D*, *x*, *pred*(*D*, *y*, *p*)) = pred(*D*, *y*, *succ*(*D*, *x*, *p*))

In this document, for the user's convenience, basic arithmetic functions are assumed on this grid navigation:

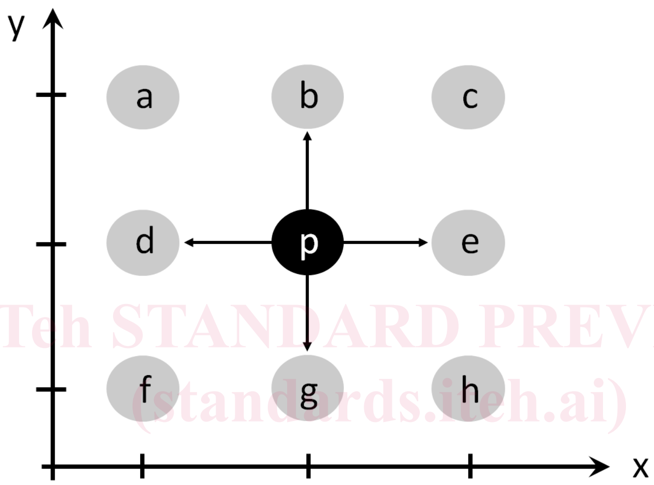

Figure 3 — Sample grid neighbourhood

5.5 Interpolation

In ISO 19123-1 a coverage contains an indication on possible interpolation between direct positions. Such interpolation can be set for all axes in a coverages simultaneously or, following a more fine-grain approach, individually per axis.

NOTE 1 In ISO 19123-1 every coverage has exactly one associated interpolation method (for all axes or per axis). In practice, coverages can allow users to pick one of several interpolation methods, such as with imagery where linear, quadratic and cubic interpolation are applicable on principle, and users can choose any one of those. Conceptually, however, two coverages differing only in the interpolation methods are distinct as they will deliver identical range values on their direct positions, but differing values inbetween those. At the abstract level of ISO 19123-1 and ISO 19123-3, this ambiguity is not desirable.

For the purpose of this document a special interpolation method `none` is assumed as defined, for example, in ISO 19123-1:2023, Annex B. `None` indicates that no interpolation is possible along the axis under consideration.

NOTE 2 The interpolation method `none` is different from `nearest-neighbor`: An interpolation of `nearest-neighbor` provides values inbetween direct positions which are derived from the closest direct position. Interpolation `none` means that no values are provided between direct positions. In other words: the evaluation function is undefined on any non-direct position and will in practice result in an exception.

Function *interpolation*(C,a) returns the interpolation method applicable on each axis of coverage C, in order of the CRS axis sequence. For *dimension*(C)=d the probing function delivers interpolation method list $(m_1,\ldots,m_d)$ with interpolation method m_i applying to axis number i:

interpolation(C)

This function is overloaded to extract the interpolation method associated with axis a of C:

interpolation(C, a)

NOTE 3 Interpolation is particularly relevant with functions *scale*() and *project*().

5.6 Range values

The range value at a direct position p can be obtained with function $evaluate_C(p)$ which, for a given coverage C, returns the value associated with $p \in domain(C)$ expressed in the coverage's CRS.

The corresponding probing function is:

$value(C, p) = evaluate_C(p)$ for some direct position $p \in domain(C)$

Interpolation guides whether the *value*() function is defined on coordinates outside the set of direct positions, and how this value is determined from the values available at the direct positions.

NOTE The range value set can contain one or more null values, as determined by the range type. This document does not make any assumption on this.

5.7 Range type

A coverage's range type description can be obtained through probing function *rangeType*() which delivers a set of tuples containing at least field names and field type:

rangeType(C)

This function gets overloaded to obtain the coverage range type of a particular range field component f:

rangeType(C, f)

For the purpose of this document, only the common programming language data types are considered, and only on a high, abstract level. These are Boolean, integer, float and complex, as well as records over those assumed to be available. However, an implementation specification based on this document may add its own data types as long as these are coherent with this document overall.

NOTE The concrete range types available in coverage processing are determined by concretizations of this document. Typically, the standard programming language data types will be available, such as (unsigned) short, int, and long, as well as float and double. For example, the range type (aka pixel) of an 8-bit RGB image normally is given by the triple < red: unsigned char; green: unsigned char; blue: unsigned char>. Further, a concretization can add more information such as null values, accuracy, etc.

5.8 Coverage probing functions synopsis

Requirement 1 https://standards.isotc211.org/19123/-3/1/req/core/probingFunctions
The semantics of the probing functions used for the ISO 19123-1 language semantics definition **shall** be given by Table 3.

Table 3 —Coverage probing functions synopsis

Coverage characteristic	Probing function for a coverage *C*, based on ISO 19123-1	Comment
Coverage identifier	*id*(*C*)	Identifier of the coverage.
Coverage CRS	*crs*(*C*) = *crs* (*domain*(*C*)) as per ISO 19123-1	CRS of the coverage.
CRS axis list	*axisList*(*c*) = $(a_1,\ldots,a_d)$ for some *d*-dimensional CRS *c* establishing this axis sequence	List of all axis names of the CRS, in proper sequence.
Domain extent of coverage	*domain*(*C*) *domain*(*C*, *a*) = domain extent along axis *a* *domain*(*C*, *a*).lo = lower bound of domain extent along axis *a* *domain*(*C*, *a*).hi = upper bound of domain extent along axis *a*	Extent of the coverage in CRS coordinates.
Grid neighbour	*pred*(*C*, *a*, *p*) *succ*(*C*, *a*, *p*) as defined in 5.4.2	These functions allow to traverse a grid in steps relative to some given position, such as for convolution operations and, generally, Tomlin's non-local operations.
Range type	*rangeType*(*C*) *rangeType*(*C*, *f*) = *t* where (*f*:*t*,...) ∈*rangeType*(*C*)	The range type record is described by a list describing its components in sequence; for the purpose of this document only component name and its data type are considered.
Range field name list	*rangeFieldNames*(*C*) = $(f_1, \ldots, f_n)$ where *rangeType*(*C*) = ($(f_1;t_1,\ldots)$, ..., $(f_n:t_n,\ldots)$), with field names f_i and types t_i	Ordered list of all the coverage's range fields names and their data types; possible further constituents in a record component are ignored in this document, their values are to be defined elsewhere (e.g. implementation dependent).
Range values	*value*(*C*,*p*) = $evaluate_C(p), p \in domain(C)$ with *evaluate*() as per 19123-1	Range values of the coverage at a direct position (or some position inbetween, interpolation permitting).

Coverage characteristic	Probing function for a coverage *C*, based on ISO 19123-1	Comment
Interpolation	*interpolation*(*C*) as per ISO 19123-1 *interpolation*(*C*, *a*) = interpolation method of axis *a*	List of the interpolation method allowed per axis, in axis order; in case the coverage has only one interpolation defined for all axes, this method is multiplied into all positions of the output list. Interpolation associated with a particular axis.

6 Coverage processing language

This clause establishes the conformance class *Coverage Processing*.

This coverage processing language defines expressions on coverages which evaluate to ordered lists of either coverages or scalars (whereby "scalar" here is used as a summary term of all data structures that are not coverages). In the remainder of this document, the terms *processing expression* and *query* are used interchangeably.

A coverage processing expression consists of a **processCoveragesExpr** (see 6.2). Each International Standard claiming to support this document shall provide the coverage processing operations as specified in the following subclauses. A sample application is provided in Annex D.

NOTE 1 This language has been designed to be "safe in evaluation", i.e. implementations are possible where any valid request can be evaluated in a finite number of steps, based on the operation primitives. Hence, services based on the language constructs can be built in a way that no single request can render the service permanently unavailable. This notwithstanding, it still is possible to send requests that will impose high workload on a server.

NOTE 2 Data items within a query result list can be heterogeneous in size and structure. In particular, the coverages within an evaluation result list can have different dimensions, domains, range types, etc. However, a result list always consists of either coverages or scalar values, not a mix of both.

6.1 Syntax and Semantics Definition Style

6.1.1 Expression Syntax

The language primitives plus the nesting capabilities form an expression language which is independent from any specific encoding and service protocol. Collectively it is referred to as the **coverage processing language**. In the following subclauses, the language elements are detailed. The complete syntax is listed in Annex B.

A coverage processing expression is called **admissible** if and only if it adheres to the syntax of the language definition of this document.

Requirement 2 https://standards.isotc211.org/19123/-3/1/req/core/syntax
Coverage processing expressions **shall** adhere to the syntax definition of Annex B.

NOTE A railroad diagram of the syntax in Annex B is provided in Annex C for visualization of the grammar.

EXAMPLE The coverage expression fragment `$c * 2`is admissible as it adheres to language syntax whereas `abc` seen as a coverage expression violates the syntax and, hence, is not admissible.

