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Geographic information — Discrete Global Grid Systems Specifications —

Part 1: Core Reference System and Operations, and Equal Area Earth Reference System

Information géographique — Spécifications des Systèmes de Grilles Globales Discrètes (DGGS) —

Partie 1: Système de références et opérations de base, et système de référence terrestre à surface équivalente

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Foreword

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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 documents 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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics.*

A list of all parts in the ISO 19170 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.

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Introduction

DGGSs (Discrete Global Grid Systems) provide a new way to organize, store and analyse spatio-temporal data. This document contains a normative definition for DGGS and informative annexes. Annex B discusses the theoretical basis for Equal-Area Earth DGGS, and Annex C discusses DGGS's historical background. At the heart of DGGS is a new Reference System (RS). Spatial and temporal RSs described elsewhere by ISO/TC 211 and the OGC (Open Geospatial Consortium) fall into two types:

1) Referencing by coordinates (ISO 19111), and

2) Referencing by identifiers (geographic in ISO 19112 and ordinal era in ISO 19108).

In spatial referencing by identifiers, the only required geometry is an extent, which can be expressed as a simple bounding box. Formal geometry need not be defined and sometimes follows societal whim. Similarly, in ordinal temporal RSs, the topology of the ordinal eras are known, but the start and finish times are often only an estimation and are not required by the data model. DGGSs introduce a third type: referencing by identifiers with structured geometry, illustrated in Figure 1.

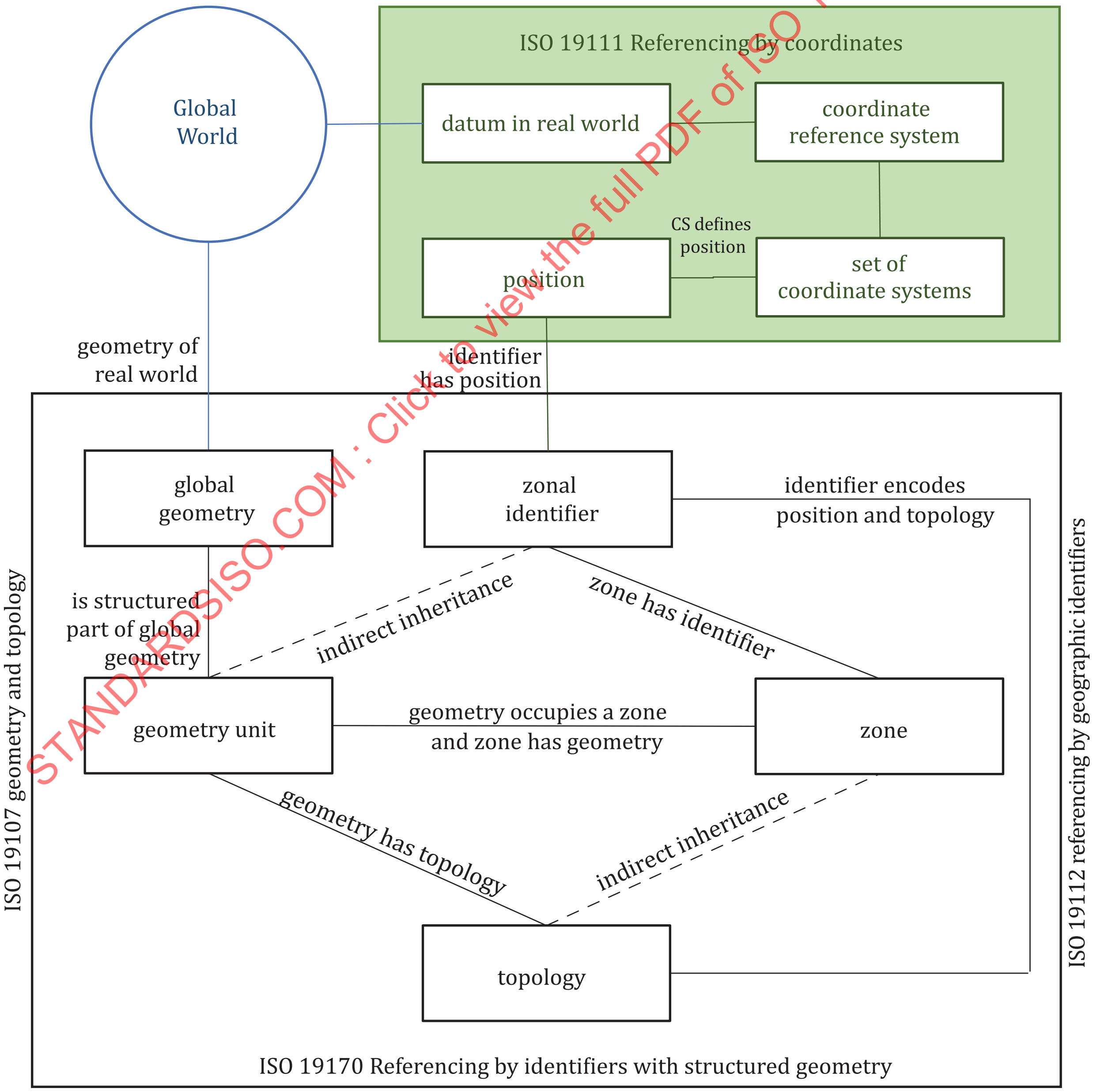
Global World
ISO 19111 Referencing by coordinates
datum in real world
coordinate reference system
CS defines position
position
set of coordinate systems
geometry of real world
identifier has position
global geometry
zonal identifier
identifier encodes position and topology
is structured part of global geometry
indirect inheritance
zone has identifier
geometry unit
geometry occupies a zone and zone has geometry
zone
geometry has topology
indirect inheritance
topology
ISO 19107 geometry and topology
ISO 19112 referencing by geographic identifiers
ISO 19170 Referencing by identifiers with structured geometry

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Figure 1 — Referencing by identifiers with structured geometry

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A single parent global geometry is chosen to define the dimensionality and orientation of the region of space-time occupied by the DGGS: it's global world. The structure for the DGGS geometry is provided by a strictly controlled process of recursive tessellation of the parent geometry that creates the DGGS RS's units of geometry. The region occupied by each unit of geometry is called a zone. Each zone is given a unique name, called a zonal identifier. Each zonal identifier is associated with a representative spatio-temporal position in a base CRS (Coordinate Reference System) defined by a datum for the DGGS's global world. Best practice is for a zonal identifier to be an encoding of both its position and its topology. Referencing by identifiers with structured geometry gives rise to RSs using zonal identifiers with structured geometry. Geographic information is inherently four-dimensional and includes time. So, a unified spatio-temporal data model for coordinate systems, geometry, topology, identifiers and RSs using identifiers is a pre-requisite for spatio-temporal DGGSs.

The approach taken in this document to specifying spatio-temporal data classes is to apply the spatio-temporal data model pattern in ISO 19111 to spatial data classes in both ISO 19107 and ISO 19112 to produce their spatio-temporal equivalents. The set of common spatio-temporal classes for geometry, topology, identifiers and RSs using identifiers specified in this document are therefore consistent with spatio-temporal CRS and coordinate systems in ISO 19111. Like ISO 19111, the temporal data model in this document does not reference ISO 19108. The similarities and differences are described in Annex D.

In this document the spatio-temporal scope is constrained to spatial classes that are invariant through all time, and to temporal classes that are invariant throughout space. While this approach excludes certain spatio-temporal situations, it is flexible enough for a very large body of social and environmental modelling. Oceanic, climate and weather modelling often need geometries with a constant mass of gaseous fluid under changing pressure and temperature. These models can be run outside a DGGS. However, the results coming from these environmental models can be stored in a DGGS for efficient later use with other data.

This document specifies data models for a consistent set of common spatio-temporal classes, a DGGS core built on the common spatio-temporal classes, and a DGGS EAERS (Equal-Area Earth RS). The Common Spatio-temporal Classes, DGGS Core, and Equal-Area Earth DGGS packages each have their own conformance classes with their associated specifications and requirements.

The DGGS Core package comprises an RS and functions for quantization, topological query and interoperability.

The DGGS Core RS is an RS using zonal identifiers with structured geometry located in its real world by coordinates in a base CRS. The DGGS Core RS is designed to support:

— temporal, surface, volumetric and spatio-temporal DGGS,

— DGGSs with different grid constraints,

— DGGSs with different refinement strategies, and

— DGGSs referencing either the Earth or other celestial bodies.

The RS in Equal-Area Earth DGGSs is a specialization of the DGGS Core RS. It describes an RS, comprising:

— a base unit polyhedron,

— a discrete hierarchical sequence of global grids,

— global grids with equal-area zones each with a unique identifier, and

— located in a geodetic CRS, that is typically also a geographic CRS.

This document does not prescribe any specific Earth surface model, base polyhedron or class of polyhedra, but is intended to allow for a range of options that produce DGGSs with compatible and interoperable functional characteristics.

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Future additions to the ISO 19170 series are intended to cover:

- Part 2: Three-dimensional and equal-volume Earth RS.
- Part 3: Spatio-temporal Earth RS.
- Part 4: Axis-aligned RS with all zone edges parallel to the base CRS's axes.
- Specification for a DGGS-API to formalize client-server, and server-server operations, both between DGGSs and between DGGSs and non-DGGS architectures.
- Creation of a register system for DGGS definitions analogous to the register for CRSs.
- Additions to other specifications, such as for OWS[52], [54] architectures, spatial features and data formats to support DGGS data structures.

This document was prepared in close collaboration with the Open Geospatial consortium (OGC).

In accordance with the ISO/IEC Directives, Part 2, 2018, *Rules for the structure and drafting of International Standards*, in International Standards the decimal sign is a comma on the line. However, the General Conference on Weights and Measures (*Conférence Générale des Poids et Mesures*) at its meeting in 2003 passed unanimously the following resolution: "The decimal marker shall be either a point on the line or a comma on the line." In practice, the choice between these alternatives depends on customary use in the language concerned. In the technical areas of geodesy and geographic information it is customary for the decimal point always to be used, for all languages. That practice is used throughout this document.

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Geographic information — Discrete Global Grid Systems Specifications —

Part 1: Core Reference System and Operations, and Equal Area Earth Reference System

1 Scope

This document supports the definition of:

- A Discrete Global Grid Systems (DGGS) core comprising:
  - an RS using zonal identifiers with structured geometry, and
  - functions providing import, export and topological query,
- Common spatio-temporal classes for geometry, topology, RS using zonal identifiers, zonal identifiers and zones, based on ISO 19111 CRS. The spatio-temporal scope is constrained to:
  - spatial elements that are invariant through all time, and
  - temporal elements that are invariant across all space.
- Equal-Area Earth Reference Systems (EAERSs) for Equal-Area Earth DGGS.

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 19107:2019, *Geographic information — Spatial schema*

ISO 19111:2019, *Geographic information — Referencing by coordinates*

ISO 19112:2019, *Geographic information — Spatial referencing by geographic identifiers*

ISO 19115-1:2014, *Geographic information — Metadata — Part 1: Fundamentals*

ISO 19156:2011, *Geographic information — Observations and measurements*

3 Terms and definitions

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

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

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org

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3.1
boundary
set that represents the limit of an entity

Note 1 to entry: Boundary is most commonly used in the context of geometry, where the set is a collection of points or a collection of objects that represent those points. In other arenas, the term is used metaphorically to describe the transition between an entity and the rest of its domain of discourse.

[SOURCE: ISO 19107:2019, 3.6]

3.2
cell
<DGGS> spatial, spatio-temporal or temporal unit of geometry with dimensionality greater than 0, associated with a *zone* (3.52)

Note 1 to entry: All cells within a *DGGS* (3.13) share the dimensionality of the DGGS's parent global geometry. DGGSs with dimensionality of 0 are not supported.

Note 2 to entry: Cells are the unit of geometry in a DGGS, and the geometry of the region of space-time occupied by a zone is a cell.

Note 3 to entry: While the terms cell and zone are often used interchangeably, "zone" is the strictly preferred term. Cell is entirely appropriate when specifically discussing a zone's geometry or topology.

3.3
cell refinement
<DGGS> process of subdividing *parent cells* (3.33) into descendant *child cells* (3.4) using a specified *refinement ratio* (3.38) and suite of refinement strategies

Note 1 to entry: Iterative application of cell refinements creates a *hierarchy* (3.26) of descendant *discrete global grids* (3.12).

Note 2 to entry: Cell refinement methods may result in *child cells* (3.4) that each have a single parent or that have multiple parents.

3.4
child cell
child
<DGGS> immediate descendant of a *parent cell* (3.33)

Note 1 to entry: Child cells are either within a single parent cell or overlapped by multiple parent cells

3.5
class
description of a set of objects that share the same attributes, operations, methods, relationships, and semantics

Note 1 to entry: A class may use a set of interfaces to specify collections of operations it provides to its environment. The term was first used in this way in the general theory of object-oriented programming, and later adopted for use in this same sense in UML.

[SOURCE: ISO 19103:2015, 4.7, modified — Note 1 to entry has been added from ISO 19117:2012, 4.2]

3.6
compound coordinate reference system
compound CRS
coordinate reference system (3.7) using at least two independent coordinate reference systems

Note 1 to entry: Coordinate reference systems are independent of each other if coordinate *values* (3.49) in one cannot be converted or transformed into coordinate values in the other.

[SOURCE: ISO 19111:2019, 3.1.3]

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3.7
coordinate reference system
CRS
coordinate system (3.8) that is related to an object by a *datum* (3.10)

Note 1 to entry: Geodetic and vertical datums are referred to as reference frames.

Note 2 to entry: For geodetic and vertical datums, the object is the Earth. In planetary applications, geodetic and vertical reference frames may be applied to other celestial bodies.

[SOURCE: ISO 19111:2019, 3.1.9]

3.8
coordinate system
set of mathematical rules for specifying how coordinates are to be assigned to points

[SOURCE: ISO 19111:2019, 3.1.11]

3.9
data type
specification of a *value* (3.49) domain with operations allowed on values in this domain

EXAMPLE Integer, Real, Boolean, String and Date (conversion of a date into a series of codes).

Note 1 to entry: Data types include primitive predefined types and user-definable types. All instances of a data type lack identity.

[SOURCE: ISO 19103:2015, 4.14, modified — EXAMPLE and Note 1 to entry have been added from ISO 19156:2011, 4.3]

3.10
datum
reference frame
parameter or set of parameters that realize the position of the origin, the scale, and the orientation of a *coordinate system* (3.8)

[SOURCE: ISO 19111:2019, 3.1.15]

3.11
datum ensemble
group of multiple realizations of the same terrestrial or vertical reference system that, for approximate spatial referencing purposes, are not significantly different

EXAMPLE "WGS 84" as an undifferentiated group of realizations including WGS 84 (TRANSIT), WGS 84 (G730), WGS 84 (G873), WGS 84 (G1150), WGS 84 (G1674) and WGS 84 (G1762). At the surface of the Earth these have changed on average by 0.7 m between the TRANSIT and G730 realizations, a further 0.2 m between G730 and G873, 0.06 m between G873 and G1150, 0.2 m between G1150 and G1674 and 0.02 m between G1674 and G1762).

Note 1 to entry: Datasets referenced to the different realizations within a datum ensemble may be merged without coordinate transformation.

Note 2 to entry: 'Approximate' is for users to define but typically is in the order of under 1 decimetre but may be up to 2 metres.

[SOURCE: ISO 19111:2019, 3.1.16]

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3.12

discrete global grid

<DGGS> set of *cells* (3.2) at the same *refinement level* (3.37) that uniquely and completely cover a *globe* (3.24)

Note 1 to entry: The set of cell *zonal identifiers* (3.50) comprising a discrete global grid form a single *Zone* (3.51) *Class* (3.5) with its associated *refinement level* (3.37).

Note 2 to entry: The configuration of the set of cells comprising a discrete global grid satisfy at least one *grid* (3.25) constraint in the DGG_GridConstraint codelist.

3.13

discrete global grid system

DGGS

integrated system comprising a *hierarchy* (3.26) of *discrete global grids* (3.12), *spatio-temporal referencing* (3.42) by *zonal identifiers* (3.50) and functions for *quantization* (3.36), *zonal query* (3.51), and *interoperability* (3.28)

3.14

duration

non-negative quantity of time equal to the difference between the final and initial *instants* (3.29) of a time *interval* (3.30)

Note 1 to entry: The duration is one of the base quantities in the International System of Quantities (ISQ) on which the International System of Units (SI) is based. The term "time" instead of "duration" is often used in this context and also for an infinitesimal duration.

Note 2 to entry: For the term "duration", expressions such as "time" or "time interval" are often used, but the term "time" is not recommended in this sense and the term "time interval" is deprecated in this sense to avoid confusion with the concept of "time interval".

Note 3 to entry: The exact duration of a time scale unit depends on the time scale used. For example, the durations of a year, month, week, day, hour or minute, may depend on when they occur [in a Gregorian calendar, a calendar month can have a duration of 28, 29, 30, or 31 days; in a 24-hour clock, a clock minute can have a duration of 59, 60, or 61 seconds, etc.]. Therefore, the exact duration can only be evaluated if the exact duration of each is known.

Note 4 to entry: This definition is closely related to NOTE 1 of the terminological entry "duration" in IEC 60050-113:2011, 113–01–13.

[SOURCE: ISO 8601-1:2019, 3.1.1.8]

3.15

dynamic coordinate reference system

dynamic CRS

coordinate reference system (3.7) that has a *dynamic reference frame* (3.16)

Note 1 to entry: Coordinates of points on or near the crust of the Earth that are referenced to a dynamic coordinate reference system may change with time, usually due to crustal deformations such as tectonic motion and glacial isostatic adjustment.

Note 2 to entry: Metadata for a dataset referenced to a dynamic coordinate reference system should include coordinate epoch information.

[SOURCE: ISO 19111:2019, 3.1.19]

3.16

dynamic reference frame

dynamic datum

reference frame (3.10) in which the defining parameters include time evolution

Note 1 to entry: The defining parameters that have time evolution are usually a coordinate set.

[SOURCE: ISO 19111:2019, 3.1.20]

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3.17
error budget
<metric> statement of or methodology for describing the nature and magnitude of the errors which affect the results of a calculation

[SOURCE: ISO 19107:2019, 3.35, modified — Note 1 to entry has been removed.]

3.18
feature
abstraction of real-world phenomena

Note 1 to entry: A feature can occur as a type or an instance. In this document, feature instance is meant unless otherwise specified.

[SOURCE: ISO 19101-1:2014, 4.1.11, modified — Note 1 to entry has been added from ISO 19156:2011, 4.6, and modified.]

3.19
feature type
class (3.5) of *features* (3.18) having common characteristics

[SOURCE: ISO 19156:2011, 4.7]

3.20
geodetic coordinate reference system
geodetic CRS
three-dimensional *coordinate reference system* (3.7) based on a geodetic reference frame and having either a three-dimensional Cartesian or a spherical *coordinate system* (3.8)

Note 1 to entry: In this document a coordinate reference system based on a geodetic reference frame and having an ellipsoidal coordinate system is geographic.

[SOURCE: ISO 19111:2019, 3.1.31]

3.21
geographic coordinate reference system
geographic CRS
coordinate reference system (3.7) that has a geodetic reference frame and an ellipsoidal *coordinate system* (3.8)

[SOURCE: ISO 19111:2019, 3.1.35]

3.22
geographic identifier
spatial reference (3.41) in the form of a label or code that identifies a *location* (3.31)

EXAMPLE “Spain” is an example of a label (country name); “SW1P 3AD” is an example of a code (postcode).

[SOURCE: ISO 19112:2019, 3.1.2]

3.23
geometric primitive
<geometry> geometric object representing a single, connected, homogeneous (isotropic) element of space

Note 1 to entry: Geometric primitives are non-decomposed objects that present information about geometric configuration. They include points, curves, surfaces, and solids. Many geometric objects behave like primitives (supporting the same interfaces defined for geometric primitives) but are actually composites composed of some number of other primitives. General collections may be aggregates and incapable of acting like a primitive (such as the lines of a complex network, which is not connected and thus incapable of being traceable as a single line). By this definition, a geometric primitive is topological open, since the *boundary* (3.1) points are not isotropic to the interior points. Geometry is assumed to be closed. For points, the boundary is empty.

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[SOURCE: ISO 19107:2019, 3.50]

3.24
globe
<DGGS> region of space-time enclosing a celestial body

Note 1 to entry: In this document globe is used in its most general form to refer to any celestial body or region of space-time enclosing a celestial body that may be referenced by a *DGGS* (3.13). When a specific body, such as the Earth is referred to, an explicit term is used.

3.25
grid
network composed of two or more sets of curves in which the members of each set intersect the members of the other sets in an algorithmic way

Note 1 to entry: The curves partition a space into grid *cells* (3.2).

[SOURCE: ISO 19123:2005, 4.1.23]

3.26
hierarchy
<DGGS> organization and ranking of successive levels of *cell refinement* (3.3) of *discrete global grids* (3.12)

3.27
initial discrete global grid
<DGGS> *discrete global grid* (3.12) *tessellation* (3.8) created by circumscribing a defined path along the chosen surface model of the Earth between the vertices of the scaled base unit polyhedron

3.28
interoperability
capability to communicate, execute programmes, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units

Note 1 to entry: In this document, interoperability specifically refers to functions that initiate and process transfers of data from a *DGGS* (3.13).

[SOURCE: ISO/IEC 2382:2015, 2121317, modified—The original domain and Notes to Entry have been deleted. A new Note 1 to entry has been added.]

3.29
instant
<DGGS> temporal geometry primitive representing a point in time

Note 1 to entry: On *temporal coordinate systems* (3.46) as specified in ISO 19107, the temporal *geometric primitives* (3.23) instant and *interval* (3.30) are the equivalent of points and lines as specified in ISO 19107.

3.30
interval
<DGGS> temporal geometry primitive representing a line in time

Note 1 to entry: On *temporal coordinate systems* (3.46) as specified in ISO 19107, the temporal *geometric primitives* (3.23) *instant* (3.29) and interval are the equivalent of points and lines as specified in ISO 19107.

3.31
location
particular place or position

EXAMPLE “Madrid”, “SW1P 3AD”.

Note 1 to entry: A location identifies a geographic place.

Note 2 to entry: In the context of *DGGS* (3.13), locations have dimension greater than one, and so are not points.

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[SOURCE: ISO 19112:2019, 3.1.3, modified — Note 2 to entry has been added and an additional example provided.]

3.32
observation
act of measuring or otherwise determining the *value* (3.49) of a property

[SOURCE: ISO 19156:2011, 4.11]

3.33
parent cell
parent
<DGGS> *cell* (3.2) in a higher *refinement level* (3.37) of *discrete global grid* (3.12) with immediate descendants

Note 1 to entry: Parent cells either overlap or contain their *child cells* (3.4).

3.34
period
<DGGS> particular era or span of time

Note 1 to entry: Periods are *intervals* (3.30) named with a *period identifier* (3.35).

3.35
period identifier
<DGGS> temporal reference in the form of a label or code that identifies a *period* (3.34)

Note 1 to entry: Period identifiers are the temporal equivalent of *geographic identifiers* (3.22) as specified in ISO 19112.

3.36
quantization
<DGGS> function assigning data from external sources to *cell* (3.2) *values* (3.49)

3.37
refinement level
<DGGS> numerical order of a *discrete global grid* (3.12) in the *tessellation* (3.8) sequence

Note 1 to entry: The tessellation with the smallest number of cells has a refinement level = 0.

3.38
refinement ratio
<DGGS> ratio of the number of *child cells* (3.4) to *parent cells* (3.33)

Note 1 to entry: A positive integer ratio *n* refinement of *DGGS* (3.13) parent cells yield *n* times as many child cells as parent cells.

Note 2 to entry: For a two-dimensional DGGS (as defined for EAERS in this document) this is the surface area ratio.

Note 3 to entry: In DGGS literature[34] the term aperture has been used instead of refinement ratio. Refinement ratio is preferred because it is clearer in meaning to audiences outside the early DGGS community.

3.39
sibling cell
sibling
<DGGS> *cell* (3.2) in a *discrete global grid* (3.12) with the same *parent cell* (3.33)

Note 1 to entry: All the *child cells* (3.4) of a parent cell are each-others' sibling cells.

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3.40
simple
<topology, geometry> homogeneous (all points have isomorphic neighbourhoods) and with a simple *boundary* (3.1)

Note 1 to entry: The interior is everywhere locally isomorphic to an open disc in a Euclidean coordinate space of the appropriate dimension `Dn = {P|□P□ < 1.0}`. The boundary is a dimension one smaller. This essentially means that the object does not intersect nor touch itself. Generally used for a curve that does not cross nor touch itself with the possible exception of boundary points. Simple closed curves are isomorphic to a circle.

[SOURCE: ISO 19107:2019, 3.84]

3.41
spatial reference
description of position in the real world

Note 1 to entry: This may take the form of a label, code or coordinate tuple.

[SOURCE: ISO 19111:2019, 3.1.56]

3.42
spatio-temporal reference
system for identifying position in the real world that may include time

Note 1 to entry: This may take the form of a label, code or coordinate tuple.

3.43
spatio-temporal coordinate reference system
spatio-temporal CRS
compound coordinate reference system (3.6) in which one constituent *coordinate reference system* (3.7) is a spatial coordinate reference system and one is a *temporal coordinate reference system* (3.47)

[SOURCE: ISO 19111:2019, 3.1.59]

3.44
static coordinate reference system
static CRS
coordinate reference system (3.7) that has a *static reference frame* (3.45)

Note 1 to entry: Coordinates of points on or near the crust of the Earth that are referenced to a static coordinate reference system do not change with time.

Note 2 to entry: Metadata for a dataset referenced to a static coordinate reference system does not require coordinate epoch information.

[SOURCE: ISO 19111:2019, 3.1.61]

3.45
static reference frame
static datum
reference frame (3.10) in which the defining parameters exclude time evolution

[SOURCE: ISO 19111:2019, 3.1.62]

3.46
temporal coordinate system
<geodesy> one-dimensional *coordinate system* (3.8) where the axis is time

[SOURCE: ISO 19111:2019, 3.1.64]

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3.47
temporal coordinate reference system
temporal CRS
coordinate reference system (3.7) based on a temporal datum

[SOURCE: ISO 19111:2019, 3.1.63]

3.48
tessellation
partitioning of a space into a set of conterminous subspaces having the same dimension as the space being partitioned

EXAMPLE Graphic examples of tessellations may be found in Figures 11, 13, 20, and 22 of ISO 19123:2005.

Note 1 to entry: A tessellation composed of congruent regular polygons or polyhedra is a regular tessellation. One composed of regular, but non-congruent polygons or polyhedra is a semi-regular tessellation. Otherwise the tessellation is irregular. Tessellations on curved surfaces cannot be congruent, so all tessellations in DGGS are either semi-regular or irregular.

[SOURCE: ISO 19123:2005, 4.1.39, modified — Note 1 to entry has been modified.]

3.49
value
element of a type domain

Note 1 to entry: A value considers a possible state of an object within a *class* (3.5) or type (domain).

Note 2 to entry: A data value is an instance of a datatype, a value without identity.

Note 3 to entry: A value can use one of a variety of scales including nominal, ordinal, ratio and *interval* (3.30), spatial and temporal. Primitive datatypes can be combined to form aggregate datatypes with aggregate values, including vectors, tensors and images.

[SOURCE: ISO 19156:2011, 4.18]

3.50
zonal identifier
<DGGS> *spatio-temporal reference* (3.42) in the form of a label or code that identifies a *zone* (3.52)

Note 1 to entry: A zonal identifier may be a *geographic identifier* (3.22), *period identifier* (3.35), or a compound of the two.

Note 2 to entry: A zone's ZonalIdentifier provides the coordinates of a representative position for the zone, and spatio-temporal *feature* (3.18) geometry is represented by sets of ZonalIdentifiers.

3.51
zonal query
<DGGS> geometry or topology function using a cell's *zonal identifiers* (3.50) to specify geometry

Note 1 to entry: ISO 19107 specifies a suite of geometry and topology functions in the Query2D and Query3D classes, where geometry elements used in each function's parameters are described by sets of coordinates. In DGGS all geometry can be referenced as sets of *cells* (3.2) represented solely by a list (or set) of their zonal identifiers. This document specifies ZoneQuery to implement the operations in both Query2D and Query3D using zonal identifiers to reference each operation's source and target geometry.

3.52
zone
<DGGS> particular region of space-time

Note 1 to entry: The primitives of zone are spatial *location* (3.31) and temporal *period* (3.34).

Note 2 to entry: A zone may be either a single zonal primitive or a compound zone comprising one spatial location and one temporal period. Zones can be regions of space-time associated with any celestial body.

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Note 3 to entry: Zones are the primary container for storing and retrieving data within a DGGS implementation. DGGSs reference zones by their *zonal identifier* (3.50), for instance in databases or through tile nomenclature.

Note 4 to entry: Each zone's geometry is represented by a *cell* (3.2).

4 Conventions

4.1 Abbreviated terms

DE-9IM	Dimensionally Extended 9-Intersection Model
EAERS	Equal-Area Earth RS
ECEF	earth-centered earth fixed
EC	earth-centered
GEM	Geodesic Elevation Model
GIS	geographic information system
GUID	globally unique identifier
HPC	high-performance computing
HPD	high-performance data
ICT	information and communications technology
ISEA	Icosahedral Snyder Equal Area
ISEA3H	Icosahedral Snyder Equal Area Aperture 3 Hexagon
ISO	International Organization for Standardization
OGC	Open Geospatial Consortium
OWS	OGC Web-Service
QTM	Quaternary Triangular Mesh
rHEALPix	rearanged Hierarchical Equal Area isoLatitude Pixelization
RS	Reference System
UML	Unified Modelling Language
URI	Uniform Resource Identifier

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4.2 Uniform Resource Identifiers

The normative provisions in this specification are denoted by the URI:

http://www.opengis.net/spec/dggs/2.0

All requirements and conformance tests that appear in this document denoted by partial URIs are relative to this base.

4.3 Unified Modelling Language notation

In this document, the conceptual schema for describing DGGSs are presented in UML. ISO 19103 presents the specific profile of UML used in this document.

The UML diagrams in this document refer to classifiers in five other standards. Each standard has been assigned a colour that is used consistently across all UML diagrams. Each diagram has a key listing the standards referred to in that diagram and their colours. Interface names in the figure have the structure <module-name>::<interface-name>. For reference, Table 1 lists all the module names and the standard they belong to. Both colour and module name can be used as quick reference to a classifier's standard.

4.4 Naming conventions

Where possible, when a classifier represents the common behaviour of a set of defined things from the terms defined in Clause 3, the UML classifier generally uses the defined terms as its name. Since classifier names are capitalized and contain no space, and the defined term may contain several words, the classifier name separates words using upper-camel-case concatenations (no spaces but each word beginning with a capital with all other letters in lowercase). Similarly, the name may be some simplified key phrase. This "UpperCamelCase" rule is generally followed but may be violated if clarity or consistency with other standards is improved by minor violations. For example:

- Zone identifier values are represented by the interface ZonalIdentifier or stored using the datatype DirectPosition defined in ISO 19107.
- Instances of primitives realize the interface Primitive in the package Common Spatio-temporal Classes and other interfaces for their specific dimension and interpolation mechanism. For example, Point, Instant, Interval, Line, NodeT, LocationS.
- Any classifier name referenced from another standard retains its original format.

Classifier names for attributes and operations in the UML models may similarly use key phrases in lowerCamelCase (same as UpperCamelCase, but the first word begins in a lowercase letter). For example: parent; child; parentOf; childOf and relatePosition are all used as operation names.

Module and package names can contain spaces. In some situations, a phrase that has an abbreviation is used in its unabbreviated form as a package name. Where a package or module is referred to in the text, both the capitalization and unabbreviated form are preserved. This distinguishes them from a phrase in general use. For example: DGGS Equal-Area Earth Reference System; Zone and Temporal Geometry; and Reference System defined in this standard and Coordinate Reference Systems defined in ISO 19111.

In summary, the use of capitals for a term in the general text indicates a reference to a classifier from the UML.

4.5 Attribute and association role status

In this document, conceptual schema in Clauses 6–8 are defined by tables. In these tables:

- attributes and association roles are given an **Obligation** status:
  - **M:** mandatory — this attribute or association role shall be supplied.
  - **C:** conditional — this attribute or association role shall be supplied if the condition (given in the description) is true. It may be supplied if the condition is false.
  - **O:** optional — this attribute or association role may be supplied.
- the **Maximum Occurrence** column in the tables indicates the maximum number of occurrences of attribute values that are permissible, with * indicating no upper limit.
- non-navigable associations are not included in the UML diagrams or tables.

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The tables provide a summary of the UML diagrams. In particular, association roles, attributes, operations, and constraints that are inherited from another class unchanged are not described in the tables. In the event of any discrepancies between the UML diagrams and text, the UML shall prevail.

5 DGGS specification overview

5.1 Package overview

The specification for DGGSs is described in this document in the form of a UML model with supplementary defining tables and text. The UML data model is organized into three primary packages. The Common Spatio-temporal Classes package contains two UML sub-packages, DGGS Core contains four UML sub-packages, and Equal-Area Earth DGGS is a single UML package, as shown in Figure 2.

a) The Common Spatio-temporal Classes package, containing:

   1) Zone and Temporal Geometry package, comprising temporal and spatio-temporal primitives for geometry and topology,

   2) Zone, Identifier and RS package, comprising temporal and spatio-temporal RS using identifiers and their primitives.

b) The DGGS Core package, containing:

   1) Core RS using zonal identifiers with structured geometry package,

   2) Core Quantization Functions package,

   3) Core Query Functions package,

   4) Core Interoperation Functions package.

c) The Equal-Area Earth DGGS package.

In Figure 2, each box represents a package and contains the package name. Each arrowed line shows the normative dependency of one package upon another package (at the head of the arrow). The Common Spatio-temporal Classes, DGGS Core and Equal-Area Earth DGGS packages shall be normatively dependent on packages in five other ISO standards.

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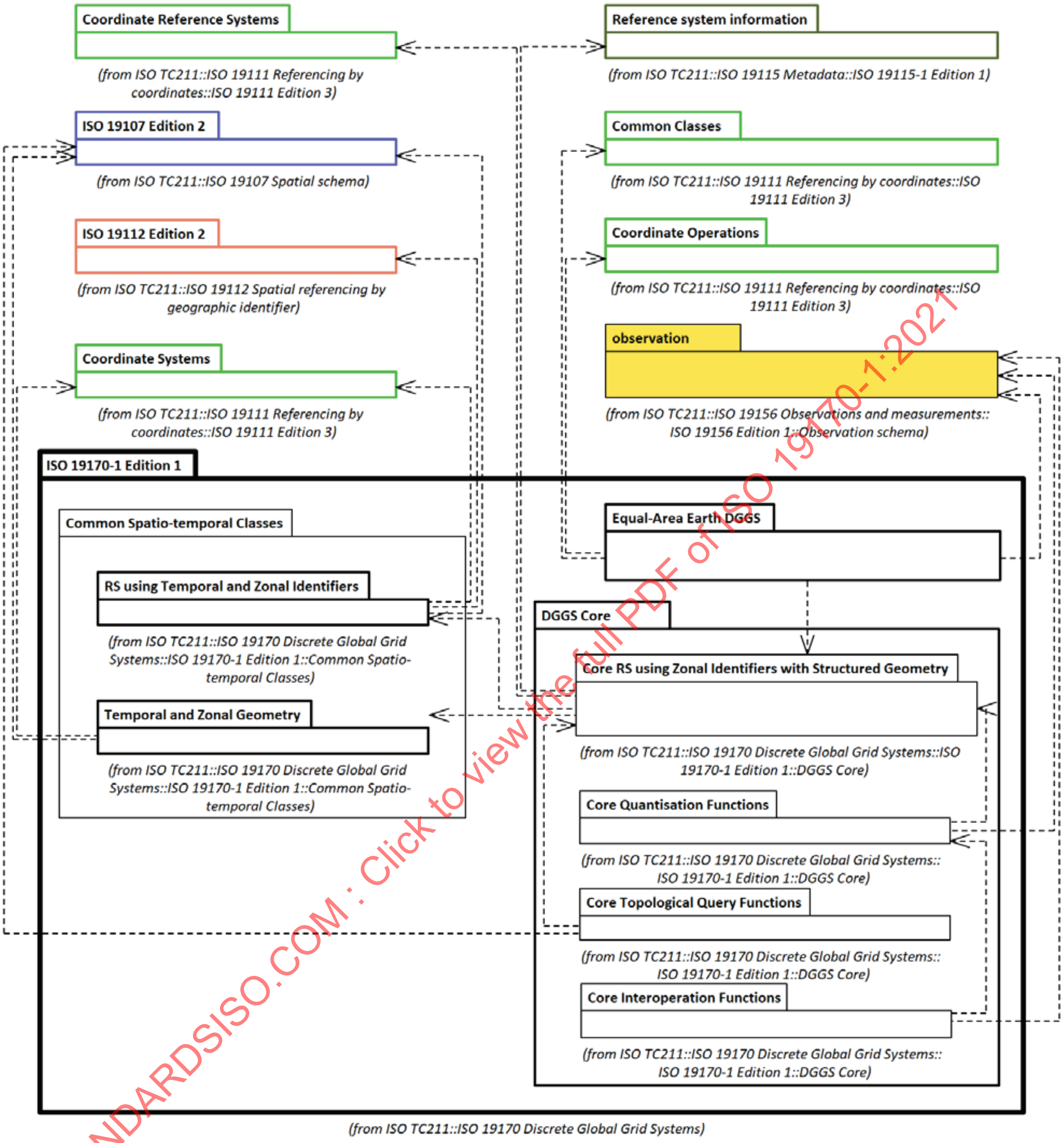
Coordinate Reference Systems
(from ISO TC211::ISO 19111 Referencing by coordinates::ISO 19111 Edition 3)
Reference system information
(from ISO TC211::ISO 19115 Metadata::ISO 19115-1 Edition 1)
ISO 19107 Edition 2
(from ISO TC211::ISO 19107 Spatial schema)
Common Classes
(from ISO TC211::ISO 19111 Referencing by coordinates::ISO 19111 Edition 3)
ISO 19112 Edition 2
(from ISO TC211::ISO 19112 Spatial referencing by geographic identifier)
Coordinate Operations
(from ISO TC211::ISO 19111 Referencing by coordinates::ISO 19111 Edition 3)
observation
Coordinate Systems
(from ISO TC211::ISO 19111 Referencing by coordinates::ISO 19111 Edition 3)
(from ISO TC211::ISO 19156 Observations and measurements::ISO 19156 Edition 1::Observation schema)
ISO 19170-1 Edition 1
Common Spatio-temporal Classes
Equal-Area Earth DGGS
RS using Temporal and Zonal Identifiers
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::Common Spatio-temporal Classes)
DGGS Core
Core RS using Zonal Identifiers with Structured Geometry
Temporal and Zonal Geometry
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::Common Spatio-temporal Classes)
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::DGGS Core)
Core Quantisation Functions
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::DGGS Core)
Core Topological Query Functions
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::DGGS Core)
Core Interoperation Functions
(from ISO TC211::ISO 19170 Discrete Global Grid Systems::ISO 19170-1 Edition 1::DGGS Core)
(from ISO TC211::ISO 19170 Discrete Global Grid Systems)

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Key

🟦	ISO 19107:2019
🟩	ISO 19111:2019
🟧	ISO 19112:2019
🟩	ISO 19115-1:2014
🟨	ISO 19156:2011
□	ISO 19170-1:2021 (this document)

Figure 2 — DGGS package diagram

Packages are grouped in a hierarchy of sub-packages, with modules containing interfaces at the leaves of the hierarchy. In the UML diagrams that follow, interface names are often shown as <module-name>::<interface-name>. For reference, Table 1 lists all the module names that are referred to in the diagrams and names the International Standard they come from.

Table 1 — Module names used in UML diagrams in this document

Standard name		Module name
ISO 19107:2019 (Spatial Schema, Ed. 2)		Edge
		Geometry
		Node
		Topology
ISO 19111:2019 (Referencing by Coordinates, Ed. 3)		Common Classes
		Coordinates
		Coordinate Operations
		Coordinate Reference System
		Coordinate Systems
ISO 19112:2019 (Spatial referencing by geographic identifier, Ed. 2)		ISO 19112, Edition 2
ISO 19115-1:2014 (Metadata, Ed. 1)		Reference system information
ISO 19156:2011 (Observation and Measurements, Ed. 1)		Observation
ISO 19170-1 (Discrete Global Grid Systems, Ed. 1) [this document]	Common Spatio-temporal Classes	Temporal Geometry and Topology
		Zonal Geometry and Topology
		Temporal RS using Identifiers
		Spatial Location
		Zonal RS using Identifiers
	DGGS Core	Core RS using Zonal Identifiers with Structured Geometry
		Core Quantization Functions
		Core Topological Query Functions
		Core Interoperation Functions
		Interoperation Query
		Interoperation Broadcast
	Equal-Area Earth DGGS	Equal-Area Earth RS
		Equal-Area Tessellation
		Equal-Area Cell

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Conformance classes for the modules in the Common Spatio-temporal Classes, DGGS Core, and Equal-Area Earth DGGS packages are described in Annex A.

One product conformance class is also defined for an Equal-Area Earth DGGS product that brings modules together as a system.

6 Common Spatio-temporal Classes package

6.1 Common Spatio-temporal Classes overview

This clause specifies the common spatio-temporal classes to support temporal and spatio-temporal geometry, topology, zones, zonal identifiers, zonal query and RSs using temporal or zonal identifiers.

These classes are defined here in such a way that they can be used in any context which requires an internally consistent set of temporal and spatio-temporal classes for use with spatial classes from

ISO 19107:2019, ISO 19111:2019 and ISO 19112:2019. They are further specialized in the DGGS Core for use in DGGS. In this restricted model for spatio-temporal systems, the spatio-temporal scope is constrained to spatial classes that are invariant through all time, and to temporal classes that are invariant throughout space.

The Common Spatio-temporal Classes are organized into two packages with five modules:

a) The Temporal and Zonal Geometry package, comprising:

   1) Temporal Geometry and Topology module

   2) Zonal Geometry and Topology module

b) The RS using Temporal and Zonal Identifiers package, comprising:

   1) Spatial Location module

   2) Temporal RS using Identifiers module

   3) Zonal RS using Identifiers module

In each package, separate spatial and temporal classes are defined first, followed by spatio-temporal classes that bring temporal and spatial classes together.

6.2 Temporal and Zonal Geometry package

6.2.1 Temporal Geometry and Topology module

6.2.1.1 Context and data model

Temporal geometry is geometry constrained to one of the temporal coordinate systems, defined by TemporalCS in ISO 19111. Temporal geometry primitives instant and interval implement the temporal analogues of point and line respectively in ISO 19107. All geometry has topology, and the temporal topology primitives nodeT and edgeT implement the temporal analogues of node and edge respectively. These are shown in Figure 3.

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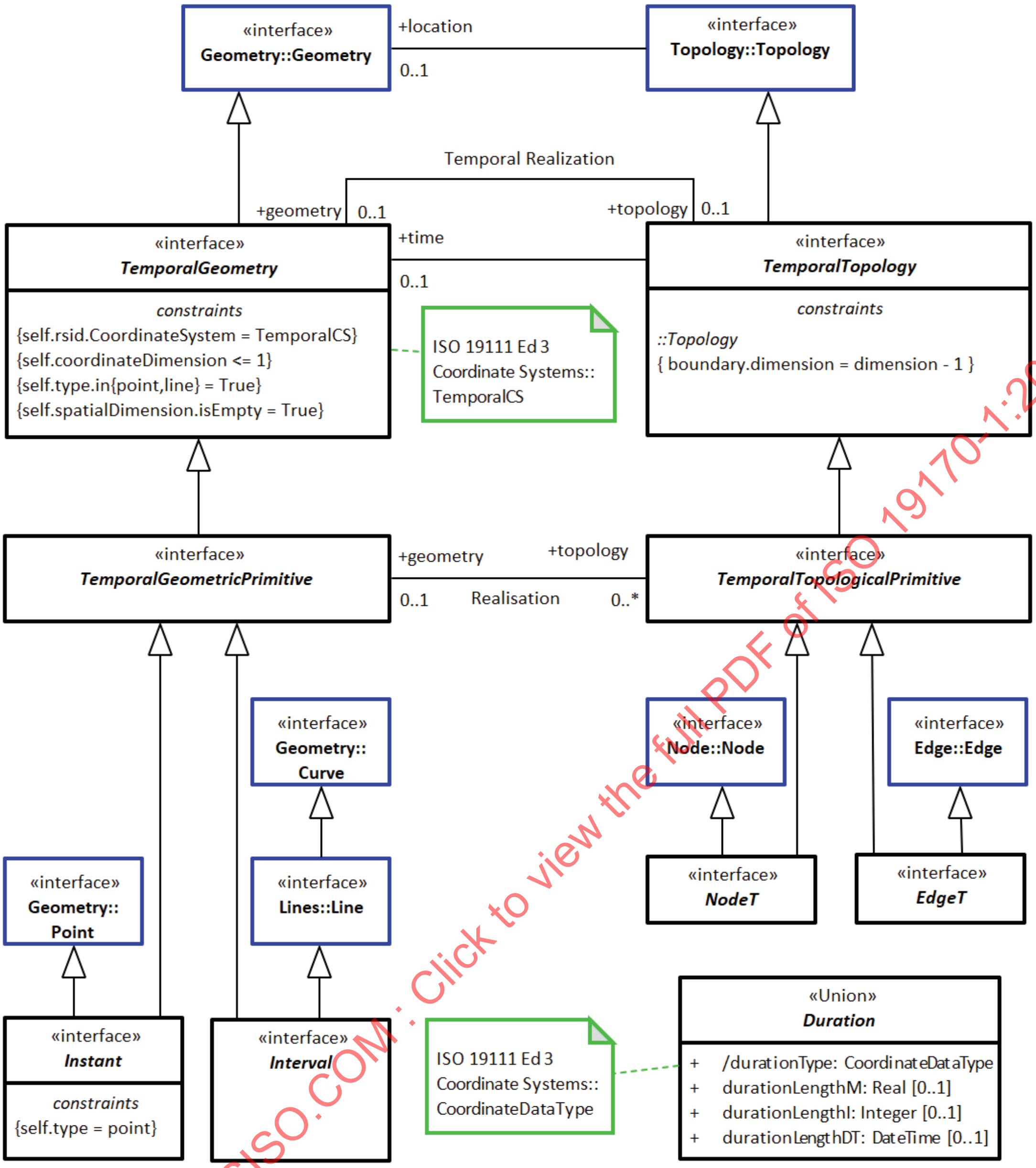

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Key

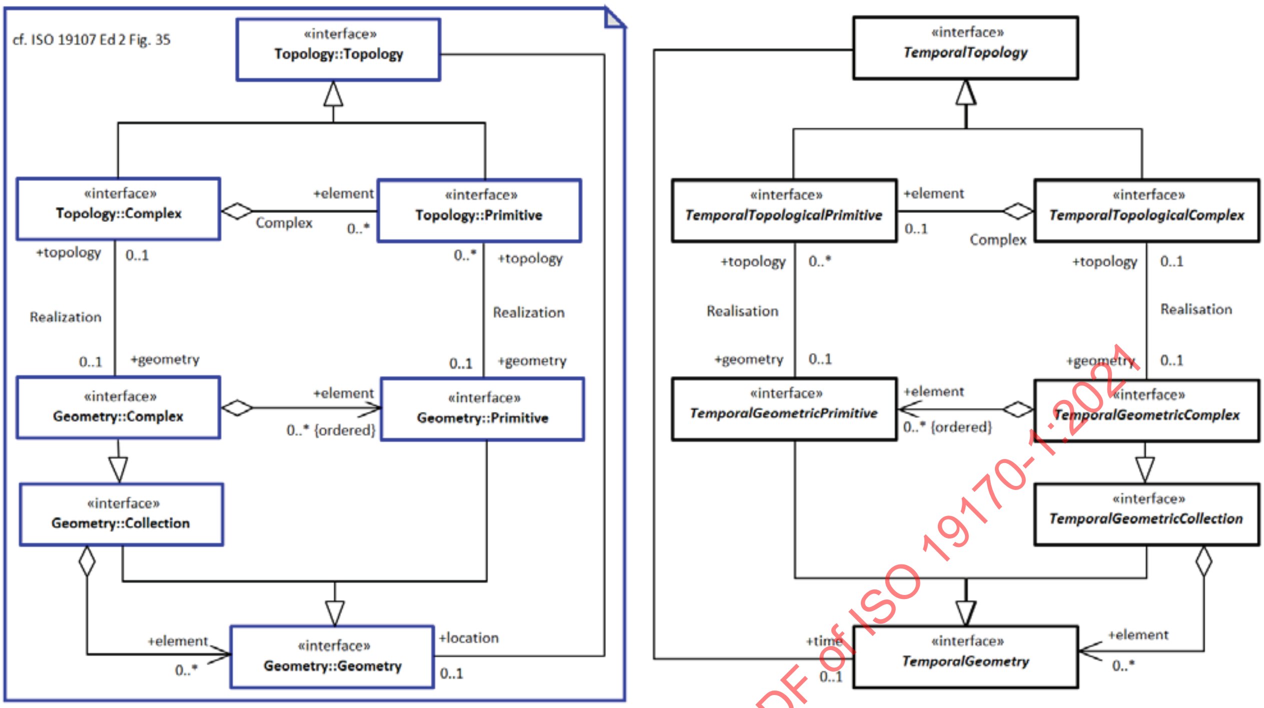
🟦 ISO 19107:2019

🟩 ISO 19111:2019

⬛ ISO 19170-1:2021 (this document)

Figure 3 — Primitives of Temporal Geometry and Topology

Temporal interfaces paralleling the spatial geometry and topology interface structure are built from these temporal primitives. Each temporal interface has the same meaning and semantics as their equivalent spatial interface, with the constraint that all temporal interfaces are constrained to the same coordinate system as their temporal primitives. Figure 4 shows the spatial classes on the left and their temporal equivalents on the right.


cf. ISO 19107 Ed 2 Fig. 35
«interface» Topology::Topology
«interface» Topology::Complex
«interface» Topology::Primitive
+element
Complex
0..*
+topology
0..1
Realization
0..1
+geometry
«interface» Geometry::Complex
«interface» Geometry::Primitive
+element
0..* {ordered}
«interface» Geometry::Collection
+element
0..*
«interface» Geometry::Geometry
+location
0..1
«interface» TemporalTopology
«interface» TemporalTopologicalPrimitive
«interface» TemporalTopologicalComplex
+element
0..1
Complex
+topology
0..*
Realisation
+geometry
0..1
«interface» TemporalGeometricPrimitive
«interface» TemporalGeometricComplex
0..* {ordered}
«interface» TemporalGeometricCollection
+time
0..1
«interface» TemporalGeometry
+element
0..*

Key

□ ISO 19107:2019

□ ISO 19170-1:2021 (this document)

Figure 4 — ISO 19107:2019, Context for Temporal Geometry and Topology

6.2.1.2 Defining tables

a) Table 2 Elements of Temporal Geometry and Topology::Duration

b) Table 3 Elements of Temporal Geometry and Topology::EdgeT

c) Table 4 Elements of Temporal Geometry and Topology::Instant

d) Table 5 Elements of Temporal Geometry and Topology::Interval

e) Table 6 Elements of Temporal Geometry and Topology::NodeT

f) Table 7 Elements of Temporal Geometry and Topology::TemporalGeometricCollection

g) Table 8 Elements of Temporal Geometry and Topology::TemporalGeometricComplex

h) Table 9 Elements of Temporal Geometry and Topology::TemporalGeometricPrimitive

i) Table 10 Elements of Temporal Geometry and Topology::TemporalGeometry

j) Table 11 Elements of Temporal Geometry and Topology::TemporalTopologicalComplex

k) Table 12 Elements of Temporal Geometry and Topology::TemporalTopologicalPrimitive

l) Table 13 Elements of Temporal Geometry and Topology::TemporalTopology

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Table 2 — Elements of Temporal Geometry and Topology::Duration

<table>
<tr><td><b>Name:</b></td><td colspan="6">Duration</td></tr>
<tr><td><b>Definition:</b></td><td colspan="6">Duration implements Length on a Temporal Coordinate System.</td></tr>
<tr><td><b>Stereotype:</b></td><td colspan="6">Union</td></tr>
<tr><td><b>Abstract:</b></td><td colspan="6">true</td></tr>
<tr><td><b>Associations:</b></td><td colspan="6">(none)</td></tr>
<tr><td rowspan="5"><b>Public attributes:</b></td><td><i>Name</i></td><td><i>Definition</i></td><td><i>Derived</i></td><td><i>Obligation</i></td><td><i>Maximum occurrence</i></td><td><i>Data type</i></td></tr>
<tr><td>durationLengthDT</td><td>Length of time for Duration of type DateTime.</td><td></td><td>C</td><td>1</td><td>DateTime</td></tr>
<tr><td>durationLengthI</td><td>Length of time for Duration of type Integer count.</td><td></td><td>C</td><td>1</td><td>Integer</td></tr>
<tr><td>durationLengthM</td><td>Length of time for Duration of type Real measure.</td><td></td><td>C</td><td>1</td><td>Real</td></tr>
<tr><td>durationType</td><td>Type of unit of measure for time.</td><td>true</td><td>M</td><td>1</td><td>CoordinateDataType</td></tr>
<tr><td><b>Constraints:</b></td><td colspan="6">(none)</td></tr>
</table>

Table 3 — Elements of Temporal Geometry and Topology::EdgeT

Name:	EdgeT
Definition:	Topological temporal edge, one-dimensional topological primitive.
Stereotype:	Interface
Inheritance from:	TemporalTopologicalPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 4 — Elements of Temporal Geometry and Topology::Instant

Name:	Instant
Definition:	Instant implements Point geometry on a Temporal Coordinate System.
Stereotype:	Interface
Inheritance from:	TemporalGeometricPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	self.type = point

Table 5 — Elements of Temporal Geometry and Topology::Interval

Name:	Interval
Definition:	Interval implements Line geometry on a Temporal Coordinate System.
Stereotype:	Interface

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Table 5 *(continued)*

Inheritance from:	TemporalGeometricPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 6 — Elements of Temporal Geometry and Topology::NodeT

Name:	NodeT
Definition:	Topological temporal node, zero-dimensional topological primitive, its boundary being empty.
Stereotype:	Interface
Inheritance from:	TemporalTopologicalPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 7 — Elements of Temporal Geometry and Topology::TemporalGeometricCollection

<table>
<tr><td>Name:</td><td colspan="4">TemporalGeometricCollection</td></tr>
<tr><td>Definition:</td><td colspan="4">Temporal Geometric Collection implements geometric Collection for Temporal Geometry.</td></tr>
<tr><td>Stereotype:</td><td colspan="4">Interface</td></tr>
<tr><td>Inheritance from:</td><td colspan="4">TemporalGeometry</td></tr>
<tr><td>Generalization of:</td><td colspan="4">TemporalGeometricComplex</td></tr>
<tr><td>Abstract:</td><td colspan="4">true</td></tr>
<tr><td rowspan="2">Associations:</td><td><i>Association with:</i></td><td><i>Obligation</i></td><td><i>Maximum occurrence</i></td><td><i>Provides:</i></td></tr>
<tr><td>TemporalGeometry (feature type)</td><td>C</td><td>*</td><td>element</td></tr>
<tr><td>Public attributes:</td><td colspan="4">(none)</td></tr>
<tr><td>Constraints:</td><td colspan="4">(none)</td></tr>
</table>

Table 8 — Elements of Temporal Geometry and Topology::TemporalGeometricComplex

<table>
<tr><td>Name:</td><td colspan="4">TemporalGeometricComplex</td></tr>
<tr><td>Definition:</td><td colspan="4">Temporal Geometric Complex implements geometric Complex for Temporal Geometry.</td></tr>
<tr><td>Stereotype:</td><td colspan="4">Interface</td></tr>
<tr><td>Inheritance from:</td><td colspan="4">TemporalGeometricCollection</td></tr>
<tr><td>Abstract:</td><td colspan="4">true</td></tr>
<tr><td rowspan="3">Associations:</td><td><i>Association with:</i></td><td><i>Obligation</i></td><td><i>Maximum occurrence</i></td><td><i>Provides:</i></td></tr>
<tr><td>TemporalGeometricPrimitive (feature type)</td><td>C</td><td>*</td><td>element</td></tr>
<tr><td>TemporalTopologicalComplex (feature type)</td><td>C</td><td>1</td><td>topology</td></tr>
<tr><td>Public attributes:</td><td colspan="4">(none)</td></tr>
<tr><td>Constraints:</td><td colspan="4">(none)</td></tr>
</table>

Table 9 — Elements of Temporal Geometry and Topology::TemporalGeometricPrimitive

Name:	TemporalGeometricPrimitive

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Table 9 *(continued)*

Definition:	Temporal Geometric Primitive implements geometric Primitive for Temporal Geometry.					
Stereotype:	Interface					
Inheritance from:	TemporalGeometry					
Generalization of:	Instant, Interval					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	TemporalTopologicalPrimitive (feature type)			C	*	topology
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	spatialDimension	Dimension of its spatial geometry component.		M	1	Integer
	temporalDimension	Dimension of its temporal geometry component.		M	1	Integer
Constraints:	(none)					

Table 10 — Elements of Temporal Geometry and Topology::TemporalGeometry

Name:	TemporalGeometry			
Definition:	Temporal Geometry implements 1D Geometry on a Temporal Coordinate System.			
Stereotype:	Interface			
Inheritance from:	ZoneSimpleGeometry			
Generalization of:	TemporalGeometricCollection, TemporalGeometricPrimitive			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	TemporalTopology (feature type)	C	1	topology
Public attributes:	(none)			
Constraints:	self.coordinateDimension < = 1			
	self.rsid.CoordinateSystem = TemporalCS			
	self.spatialDimension.isEmpty = True			
	self.type.in{point,line} = True			

Table 11 — Elements of Temporal Geometry and Topology::TemporalTopologicalComplex

Name:	TemporalTopologicalComplex			
Definition:	Temporal Topological Complex implements topological Complex for Temporal Topology.			
Stereotype:	Interface			
Inheritance from:	TemporalTopology			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	TemporalTopologicalPrimitive (feature type)	C	1	element
	TemporalGeometricComplex (feature type)	C	1	geometry
Public attributes:	(none)			
Constraints:	(none)			

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Table 12 — Elements of Temporal Geometry and Topology::TemporalTopologicalPrimitive

Name:	TemporalTopologicalPrimitive			
Definition:	Temporal Topological Primitive implements topological Primitive for Temporal Topology.			
Stereotype:	Interface			
Inheritance from:	TemporalTopology			
Generalization of:	EdgeT, NodeT			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	TemporalGeometricPrimitive (feature type)	C	1	geometry
Public attributes:	(none)			
Constraints:	(none)			

Table 13 — Elements of Temporal Geometry and Topology::TemporalTopology

Name:	TemporalTopology			
Definition:	Temporal Topology implements 1D Topology for Temporal Geometry.			
Stereotype:	Interface			
Inheritance from:	ZoneSimpleTopology			
Generalization of:	TemporalTopologicalComplex, TemporalTopologicalPrimitive			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	TemporalGeometry (feature type)	C	1	geometry
	TemporalGeometry (feature type)	C	1	time
Public attributes:	(none)			
Constraints:	(none)			

The following requirement applies:

Requirement 1: www.opengis.net/spec/DGGS/2.0/req/cc/temporal/geometry

The common classes for temporal geometry and topology shall conform to the data model in Figure 3 and Figure 4 and defining tables in Table 2–Table 13.

6.2.2 Zonal Geometry and Topology module

6.2.2.1 Context and data model

Referring to Figure 5, ZoneGeometry is either a primitive of ZoneSingleGeometry or a compound of two ZoneSingleGeometry primitives — one spatial and one temporal.

Zones exhibit topology of the same spatio-temporal dimension as their geometry.

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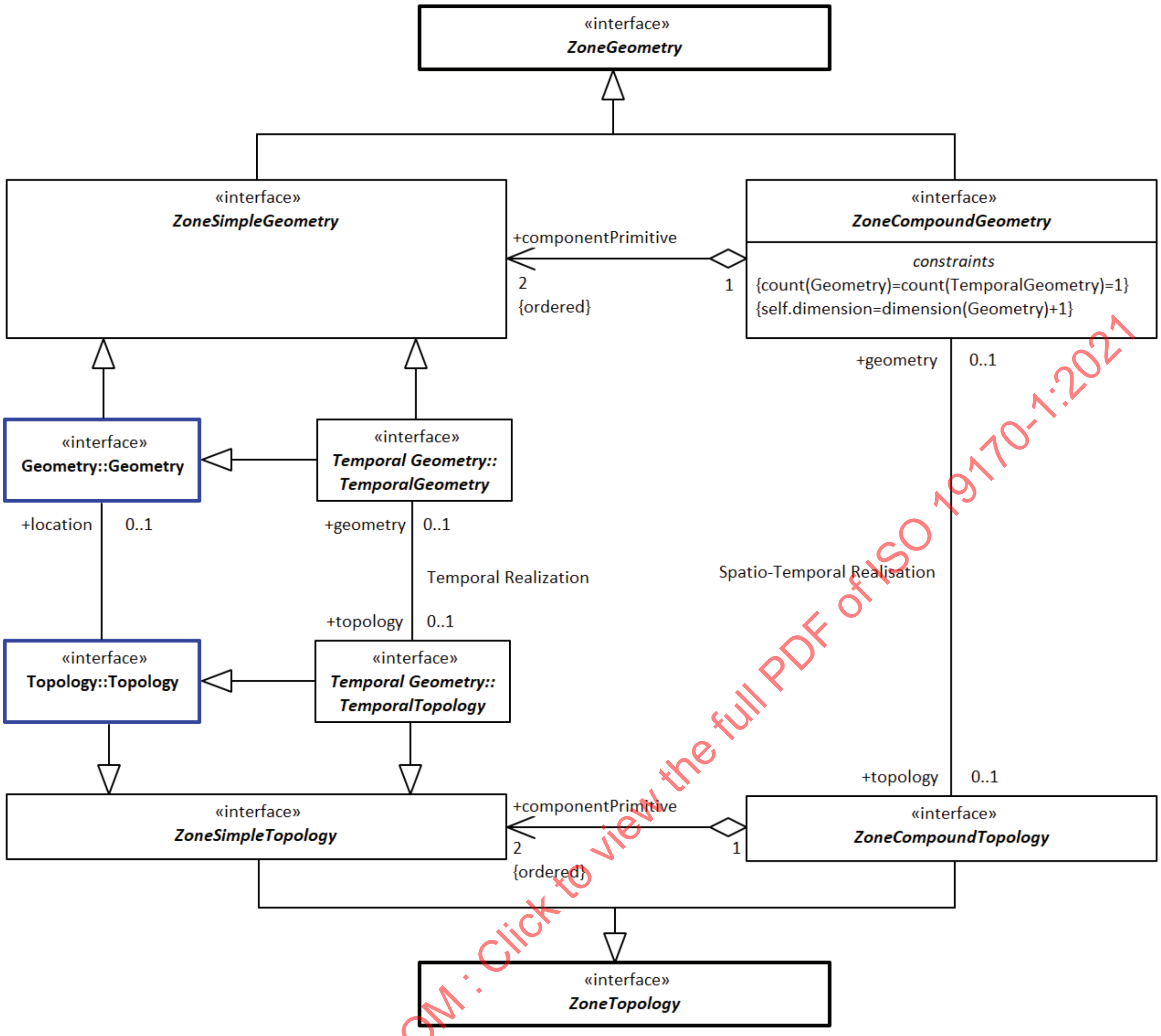

Key

□ ISO 19107:2019

□ ISO 19170-1:2021 (this document)

Figure 5 — Components of Zonal Geometry and Topology module

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6.2.2.2 Defining tables

a) Table 14 Elements of Zonal Geometry and Topology::ZoneCompoundGeometry

b) Table 15 Elements of Zonal Geometry and Topology::ZoneCompoundTopology

c) Table 16 Elements of Zonal Geometry and Topology::ZoneGeometry

d) Table 17 Elements of Zonal Geometry and Topology::ZoneSimpleGeometry

e) Table 18 Elements of Zonal Geometry and Topology::ZoneSimpleTopology

f) Table 19 Elements of Zonal Geometry and Topology::ZoneTopology

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Table 14 — Elements of Zonal Geometry and Topology::ZoneCompoundGeometry

Name:	ZoneCompoundGeometry			
Definition:	ZoneCompoundGeometry is a Compound of two ZoneSimpleGeometry elements, comprising one one-, two- or three-dimensional spatial geometry and one one-dimensional temporal geometry. NOTE This is analogous to an ISO 19111 Compound set of orthogonal space time axes comprising a set of orthogonal spatial axes and one temporal axis orthogonal to the spatial axes. ZoneCompoundGeometry has ZoneCompoundTopology.			
Stereotype:	Interface			
Inheritance from:	ZoneGeometry			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	ZoneSimpleGeometry (feature type)	M	2	componentPrimitive
	ZoneCompoundTopology (feature type)	C	1	topology
Public attributes:	(none)			
Constraints:	count(Geometry) = count(TemporalGeometry) = 1			
	self.dimension = dimension(Geometry) + 1			

Table 15 — Elements of Zonal Geometry and Topology::ZoneCompoundTopology

Name:	ZoneCompoundTopology			
Definition:	ZoneCompoundTopology exhibits both spatial topology with respect to the spatial component of its geometry and temporal topology with respect to the temporal component of its geometry.			
Stereotype:	Interface			
Inheritance from:	ZoneTopology			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	ZoneSimpleTopology (feature type)	M	2	componentPrimitive
	ZoneCompoundGeometry (feature type)	C	1	geometry
Public attributes:	(none)			
Constraints:	(none)			

Table 16 — Elements of Zonal Geometry and Topology::ZoneGeometry

Name:	ZoneGeometry
Definition:	ZoneGeometry is a ZoneSimpleGeometry or a ZoneCompoundGeometry. It is the root geometry for all spatio-temporal geometry.
Stereotype:	Interface
Generalization of:	ZoneCompoundGeometry, ZoneSimpleGeometry
Abstract:	true
Associations:	(none)

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Table 16 *(continued)*

	Name	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
Public attributes:	spatialDimension	Topological dimension of the spatial geometry component.		M	1	Integer
	temporalDimension	Dimension of the temporal geometry component.		M	1	Integer
	topologicalDimension	Sum dimension of topological primitive.		M	1	Integer
Constraints:	(none)					

Table 17 — Elements of Zonal Geometry and Topology::ZoneSimpleGeometry

Name:	ZoneSimpleGeometry
Definition:	ZoneSimpleGeometry is a 1D, 2D or 3D spatial geometry that is invariant over all time, OR a 1D temporal geometry invariant over all space. A ZoneSimpleGeometry has topology appropriate for its geometry.
Stereotype:	Interface
Inheritance from:	ZoneGeometry
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

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Table 18 — Elements of Zonal Geometry and Topology::ZoneSimpleTopology

Name:	ZoneSimpleTopology
Definition:	ZoneSimpleTopology is a 1D, 2D or 3D spatial topology that is invariant over all time, OR a 1D temporal topology that is invariant over all space.
Stereotype:	Interface
Inheritance from:	ZoneTopology
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 19 — Elements of Zonal Geometry and Topology::ZoneTopology

Name:	ZoneTopology
Definition:	ZoneTopology is a ZoneSimpleTopology or a ZoneCompoundTopology
Stereotype:	Interface
Generalization of:	ZoneCompoundTopology, ZoneSimpleTopology
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

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The following requirement applies:

Requirement 2: www.opengis.net/spec/DGGS/2.0/req/cc/zone/geometry

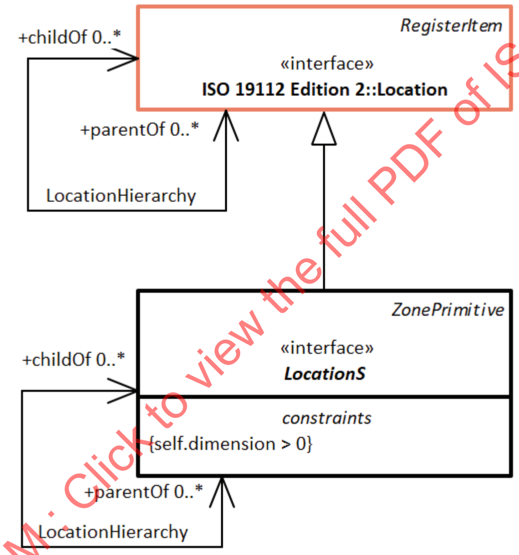
The common classes for zonal geometry and topology shall conform to the data model in Figure 5 and defining tables in Table 14–Table 19.

6.3 Temporal and Zonal RS using Identifiers package

6.3.1 Spatial Location module

6.3.1.1 Context and data model

ISO 19112 describes spatial refencing by geographic identifiers, locations and location classes. The LocationS interface is a specialization of the Location interface from ISO 19112. See Figure 6. In the next subclauses, the Period interface is introduced as the temporal equivalent of LocationS.



Key

□ ISO 19112:2019

□ ISO 19170-1:2021 (this document)

Figure 6 — Context for LocationS

6.3.1.2 Defining tables

a) Table 20 Elements of Spatial Location::LocationS

Table 20 — Elements of Spatial Location::LocationS

Name:	LocationS
Definition:	Particular place or position. NOTE Unlike a Location as specified in ISO 19112:2019, all LocationS are owned and defined by their ReferenceSystem and not by an independent authority.
Stereotype:	Interface

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Table 20 *(continued)*

Inheritance from:	ZonePrimitive					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	LocationS (feature type)			C	*	childOf
	LocationS (feature type)			C	*	parentOf
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	coordinateTuple	Point within the extent of the spatial location.		M	1	DirectPosition
	extent	Spatial extent of the location.	true	M	1	EX_Extent
	identifier	Identifier of the spatial location.		M	1	GeographicIdentifier
Constraints:	self.dimension > 0					

The following requirement applies:

Requirement 3: www.opengis.net/spec/DGGS/2.0/req/cc/spatial/location

The common classes for spatial location shall conform to the data model in Figure 6 and defining table in Table 20.

6.3.2 Temporal RS using Identifiers module

6.3.2.1 Context and data model

Semantically, the terms period and zone are defined as the temporal and spatio-temporal equivalents of a location. These are represented in the data model by the interfaces Period and Zone.

Referring to Figure 7 showing the spatial classes on the left and the temporal classes on the right, it is noted that Period is augmented by:

— PeriodIdentifier data-type as the temporal equivalent of GeographicIdentifier,

— Period interface as the temporal equivalent of LocationS, see Figure 6,

— PeriodClass interface as the temporal equivalent of LocationClass, and

— TemporalReferenceSystemusingPeriodIdentifiers interface as the temporal equivalent of SpatialReferenceusingGeographicIdentifiers.

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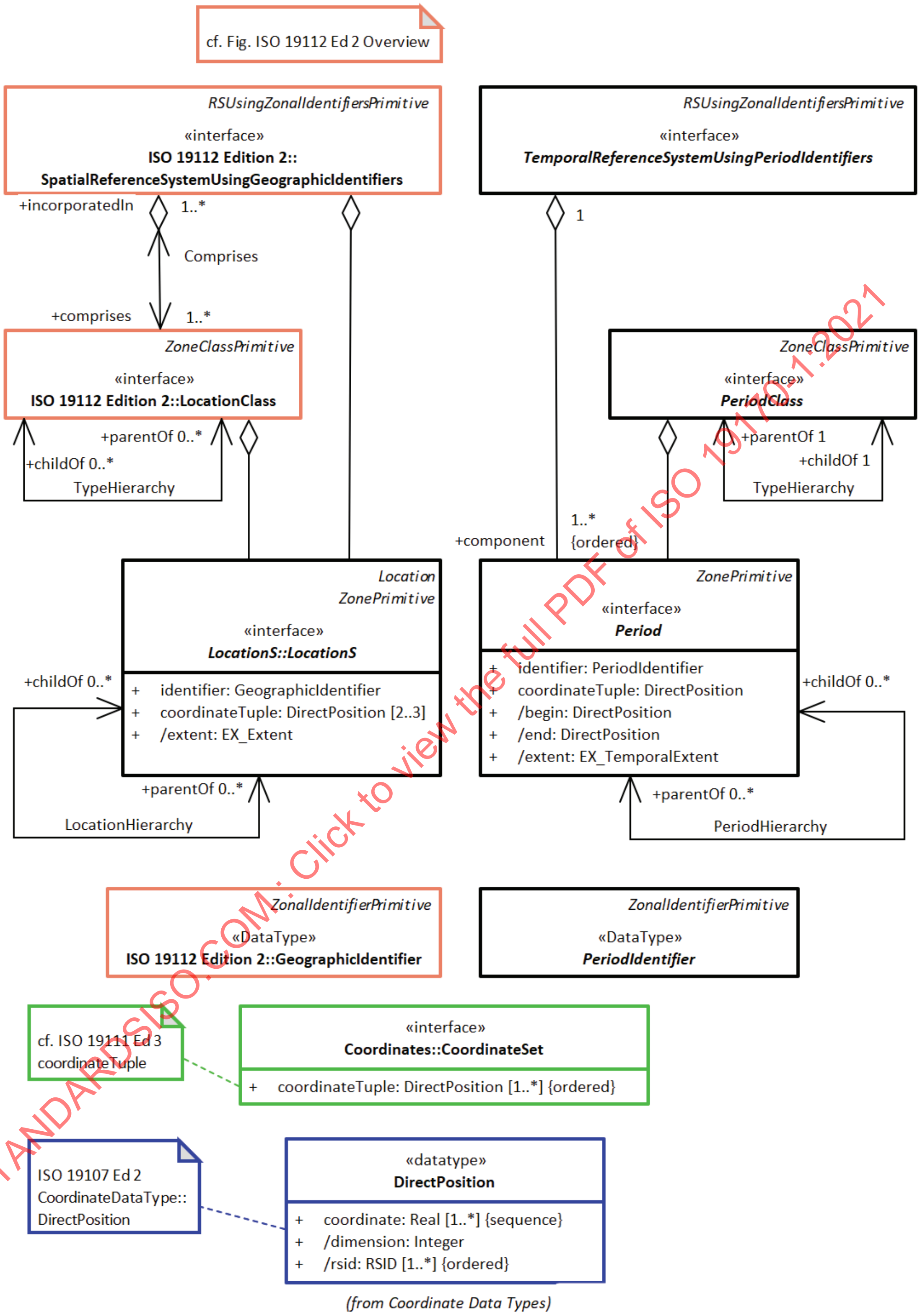

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Key

🟦	ISO 19107:2019	🟧	ISO 19112:2019
🟩	ISO 19111:2019	□	ISO 19170-1:2021 (this document)

Figure 7 — Context for Temporal RS using Identifiers module

6.3.2.2 Defining tables

a) Table 21 Elements of Temporal RS using Identifiers::Period

b) Table 22 Elements of Temporal RS using Identifiers::PeriodClass

c) Table 23 Elements of Temporal RS using Identifiers::PeriodIdentifier

d) Table 24 Elements of Temporal RS using Identifiers::TemporalReferenceSystemUsingPeriodIdentifiers

Table 21 — Elements of Temporal RS using Identifiers::Period

Name:	Period					
Definition:	Particular time span or era between two instants.					
Stereotype:	Interface					
Inheritance from:	ZonePrimitive					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	Period (feature type)			C	*	childOf
	Period (feature type)			C	*	parentOf
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	begin	Instant at the beginning of the period.	true	M	1	DirectPosition
	coordinateTuple	Position within the extent of the period.		M	1	DirectPosition
	end	Instant at the end of the period.	true	M	1	DirectPosition
	extent	Temporal extent of the period.	true	M	1	EX_TemporalExtent
	identifier	Identifier of the period.		M	1	PeriodIdentifier (data type)
Constraints:	(none)					

Table 22 — Elements of Temporal RS using Identifiers::PeriodClass

Name:	PeriodClass			
Definition:	Categorization of Periods.			
Stereotype:	Interface			
Inheritance from:	ZoneClassPrimitive			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	PeriodClass (feature type)	M	1	childOf
	TemporalReferenceSystemUsingPeriodIdentifiers (feature type)	M	*	incorporatedIn
	PeriodClass (feature type)	M	1	parentOf

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Table 22 *(continued)*

Public attributes:	(none)
Constraints:	(none)

Table 23 — Elements of Temporal RS using Identifiers::PeriodIdentifier

Name:	PeriodIdentifier
Definition:	Temporal reference in the form of a label or code that identifies a period
Stereotype:	DataType
Inheritance from:	ZonalIdentifierPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 24 — Elements of Temporal RS using Identifiers::TemporalReferenceSystemUsingPeriodIdentifiers

Name:	TemporalReferenceSystemUsingPeriodIdentifiers			
Definition:	A temporal RS based on period identifiers.			
Stereotype:	Interface			
Inheritance from:	RSUsingZonalIdentifiersPrimitive			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	Period (feature type)	M	*	component
	PeriodClass (feature type)	M	*	comprises
Public attributes:	(none)			
Constraints:	(none)			

The following requirement applies:

Requirement 4: www.opengis.net/spec/DGGS/2.0/req/cc/temporal/rsupi

The common classes for reference systems using period identifiers shall conform to the data model in Figure 7 and defining tables in Table 21–Table 24.

6.3.3 Zonal RS using Identifiers module

6.3.3.1 Context and data model

Semantically, zones are the spatio-temporal equivalent of periods and locations. Zones are represented in the data model by the interface Zone and along with it the following interfaces are also established.

— ZonalIdentifier,

— ZoneClass, and

— RSUsingZonalIdentifiers.

Referring to Figure 8, a ZonalIdentifier is either a zonal identifier primitive or a compound of two zonal identifier primitives, one spatial and one temporal.

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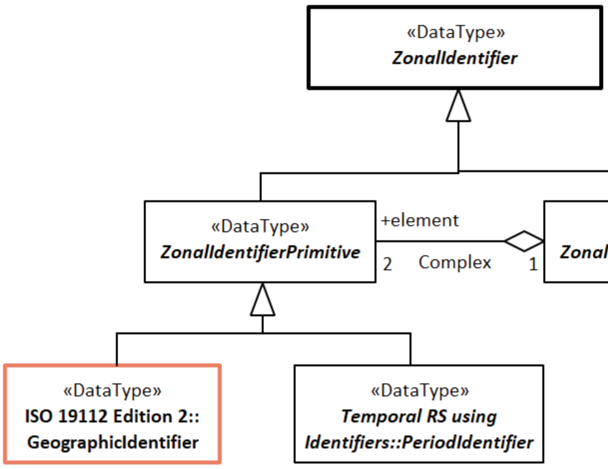

Key

□ ISO 19112:2019

□ ISO 19170-1:2021 (this document)

Figure 8 — Primitives of ZonalIdentifier

Referring to Figure 9, a Zone is either a zonal primitive or a compound of two zonal primitives, one spatial and one temporal.

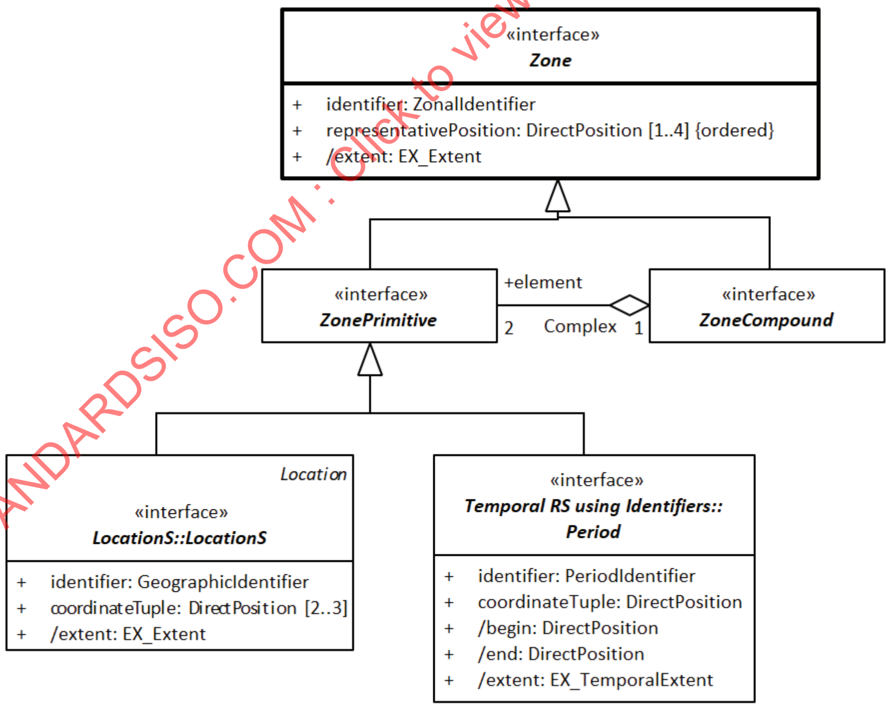
«interface»
Zone
+ identifier: ZonalIdentifier
+ representativePosition: DirectPosition [1..4] {ordered}
+ /extent: EX_Extent
«interface»
ZonePrimitive
+element
2
Complex
1
«interface»
ZoneCompound
Location
«interface»
LocationS::LocationS
+ identifier: GeographicIdentifier
+ coordinateTuple: DirectPosition [2..3]
+ /extent: EX_Extent
«interface»
Temporal RS using Identifiers::
Period
+ identifier: PeriodIdentifier
+ coordinateTuple: DirectPosition
+ /begin: DirectPosition
+ /end: DirectPosition
+ /extent: EX_TemporalExtent

Figure 9 — Primitives of Zone

Referring to Figure 10, a ZoneClass is either a zonal class primitive or a compound of two zonal class primitives, one spatial and one temporal.

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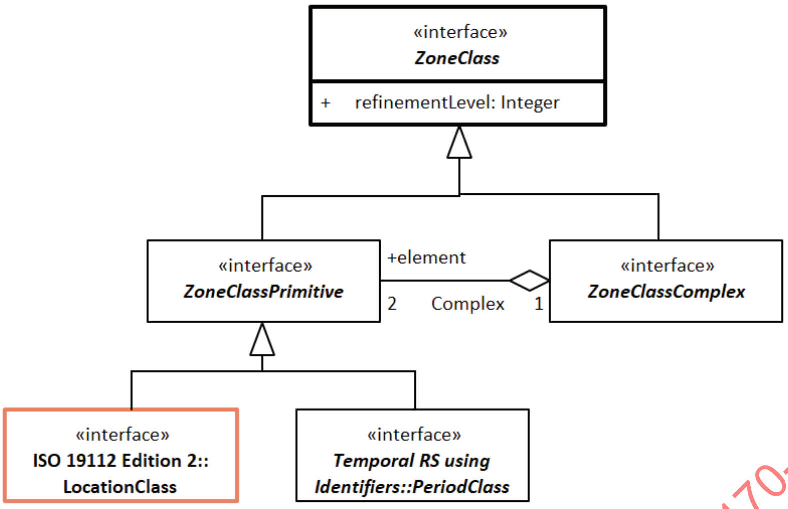


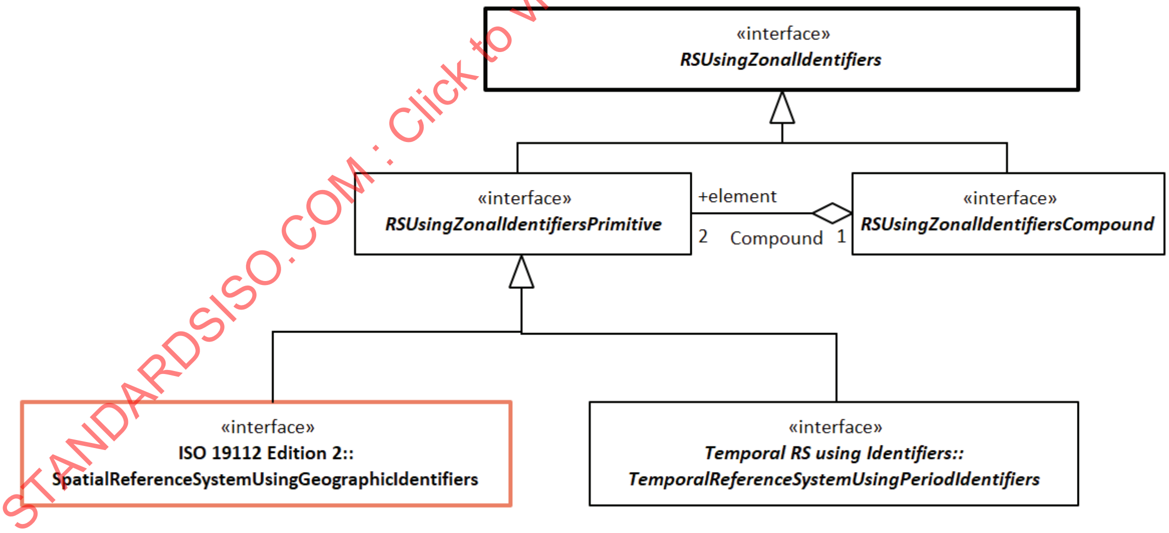
Key

□ ISO 19112:2019

□ ISO 19170-1:2021 (this document)

Figure 10 — Primitives of ZoneClass

Referring to Figure 11, an RSUsingZonalIdentifiers is either a zonal RS using identifiers primitive or a compound of two of its primitives, one spatial and one temporal.


«interface»
RSUsingZonalIdentifiers
«interface»
RSUsingZonalIdentifiersPrimitive
+element
2
Compound
1
«interface»
RSUsingZonalIdentifiersCompound
«interface»
ISO 19112 Edition 2::
SpatialReferenceSystemUsingGeographicIdentifiers
«interface»
Temporal RS using Identifiers::
TemporalReferenceSystemUsingPeriodIdentifiers

Key

□ ISO 19112:2019

□ ISO 19170-1:2021 (this document)

Figure 11 — Primitives of RSUsingZonalIdentifiers

Referring to Figure 12, Zone, ZonalIdentifier and ZoneClass come together to form RSUusingZonalIdentifiers.

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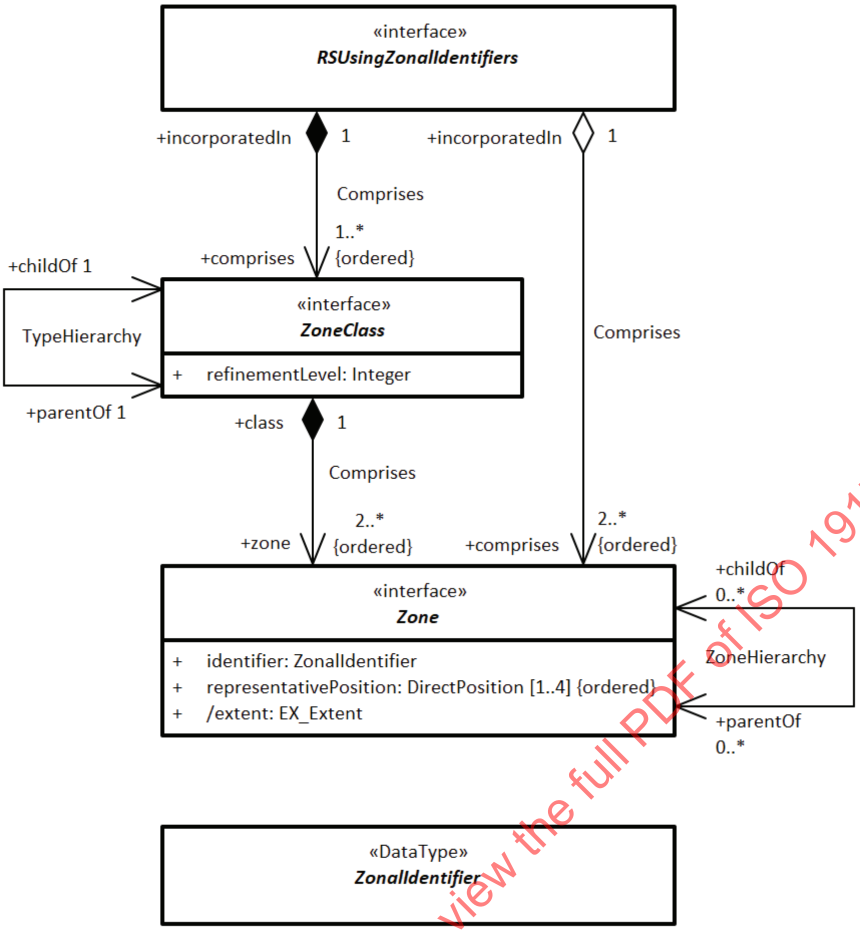

Figure 12 — Components of RSUsingZonalIdentifiers

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6.3.3.2 Defining tables

a) Table 25 Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiers

b) Table 26 Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiersCompound

c) Table 27 Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiersPrimitive

d) Table 28 Elements of Zonal RS using Identifiers::ZonalIdentifier

e) Table 29 Elements of Zonal RS using Identifiers::ZonalIdentifierComplex

f) Table 30 Elements of Zonal RS using Identifiers::ZonalIdentifierPrimitive

g) Table 31 Elements of Zonal RS using Identifiers::Zone

h) Table 32 Elements of Zonal RS using Identifiers::ZoneClass

i) Table 33 Elements of Zonal RS using Identifiers::ZoneClassComplex

j) Table 34 Elements of Zonal RS using Identifiers::ZoneClassPrimitive

k) Table 35 Elements of Zonal RS using Identifiers::ZoneCompound

l) Table 36 Elements of Zonal RS using Identifiers::ZonePrimitive

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Table 25 — Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiers

Name:	RSUsingZonalIdentifiers			
Definition:	A reference system using zonal identifiers is either a reference system using zonal identifiers primitive or a compound of one spatial reference system using zonal identifiers and one temporal reference system using period identifiers primitives.			
Stereotype:	Interface			
Generalization of:	RSUsingZonalIdentifiersCompound, RSUsingZonalIdentifiersPrimitive			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	Zone (feature type)	M	*	comprises
		M	*	comprises
Public attributes:	(none)			
Constraints:	(none)			

Table 26 — Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiersCompound

Name:	RSUsingZonalIdentifiersCompound			
Definition:	A reference system using zonal identifiers compound is a compound of one spatial reference system using zonal identifiers and one temporal reference system using zonal identifiers primitives.			
Stereotype:	Interface			
Inheritance from:	RSUsingZonalIdentifiers			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	RSUsingZonalIdentifiersPrimitive (feature type)	M	2	element
Public attributes:	(none)			
Constraints:	(none)			

Table 27 — Elements of Zonal RS using Identifiers::RSUsingZonalIdentifiersPrimitive

Name:	RSUsingZonalIdentifiersPrimitive
Definition:	A reference system using zonal identifiers primitive is either a spatial reference system using geographic identifiers or a temporal reference system using period identifiers.
Stereotype:	Interface
Inheritance from:	RSUsingZonalIdentifiers
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 28 — Elements of Zonal RS using Identifiers::ZonalIdentifier

Name:	ZonalIdentifier

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Table 28 *(continued)*

Definition:	Spatial, temporal or spatio-temporal reference in the form of a label or code that identifies a zone.
Stereotype:	DataType
Generalization of:	ZonalIdentifierComplex, ZonalIdentifierPrimitive
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 29 — Elements of Zonal RS using Identifiers::ZonalIdentifierComplex

<table>
<tr><td><b>Name:</b></td><td colspan="4">ZonalIdentifierComplex</td></tr>
<tr><td><b>Definition:</b></td><td colspan="4">Zonal identifier complex is a complex of two zonal identifier primitives, one geographic identifier and one period identifier.</td></tr>
<tr><td><b>Stereotype:</b></td><td colspan="4">DataType</td></tr>
<tr><td><b>Inheritance from:</b></td><td colspan="4">ZonalIdentifier</td></tr>
<tr><td><b>Abstract:</b></td><td colspan="4">true</td></tr>
<tr><td rowspan="2"><b>Associations:</b></td><td><i>Association with:</i></td><td><i>Obligation</i></td><td><i>Maximum occurrence</i></td><td><i>Provides:</i></td></tr>
<tr><td>ZonalIdentifierPrimitive (feature type)</td><td>M</td><td>2</td><td>element</td></tr>
<tr><td><b>Public attributes:</b></td><td colspan="4">(none)</td></tr>
<tr><td><b>Constraints:</b></td><td colspan="4">(none)</td></tr>
</table>

Table 30 — Elements of Zonal RS using Identifiers::ZonalIdentifierPrimitive

Name:	ZonalIdentifierPrimitive
Definition:	A zonal identifier primitive is either a geographic identifier or a period identifier.
Stereotype:	DataType
Inheritance from:	ZonalIdentifier
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 31 — Elements of Zonal RS using Identifiers::Zone

Name:	Zone
Definition:	A zone is a particular spatial, temporal or spatio-temporal place.
Stereotype:	Interface
Generalization of:	ZoneCompound, ZonePrimitive
Abstract:	true
Associations:	(none)

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Table 31 *(continued)*

Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	extent		true	M	1	EX_Extent
	identifier	Name or label for the Zone.		M	1	ZonalIdentifier (data type)
	representativePosition	Interior position the Zone.		M	4	DirectPosition
Constraints:	(none)					

Table 32 — Elements of Zonal RS using Identifiers::ZoneClass

Name:	ZoneClass					
Definition:	Categorization of zones.					
Stereotype:	Interface					
Generalization of:	ZoneClassComplex, ZoneClassPrimitive					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
				M	*	zone
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	refinementLevel	Refinement level used to define the zone class.		M	1	Integer
Constraints:	(none)					

Table 33 — Elements of Zonal RS using Identifiers::ZoneClassComplex

Name:	ZoneClassComplex			
Definition:	A zone class complex is a complex of two zone class primitives, one location class and one period class.			
Stereotype:	Interface			
Inheritance from:	ZoneClass			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	ZoneClassPrimitive (feature type)	M	2	element
Public attributes:	(none)			
Constraints:	(none)			

Table 34 — Elements of Zonal RS using Identifiers::ZoneClassPrimitive

Name:	ZoneClassPrimitive
Definition:	A zone class primitive is either a location class or a period class.
Stereotype:	Interface
Inheritance from:	ZoneClass
Abstract:	true
Associations:	(none)

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Table 34 *(continued)*

Public attributes:	(none)
Constraints:	(none)

Table 35 — Elements of Zonal RS using Identifiers::ZoneCompound

Name:	ZoneCompound			
Definition:	A zone compound is a compound of two zone primitives, one spatial location and one temporal period.			
Stereotype:	Interface			
Inheritance from:	Zone			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	ZonePrimitive (feature type)	M	2	element
Public attributes:	(none)			
Constraints:	(none)			

Table 36 — Elements of Zonal RS using Identifiers::ZonePrimitive

Name:	ZonePrimitive
Definition:	A zone primitive is either a spatial location or a temporal period.
Stereotype:	Interface
Inheritance from:	Zone
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

The following requirement applies:

Requirement 5: www.opengis.net/spec/DGGS/2.0/req/cc/zone/rsuzi

The common classes for reference systems using zonal identifiers shall conform to the data model in Figure 8–Figure 12 and defining tables in Table 25–Table 36.

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7 DGGS Core package

7.1 DGGS Core package conformance classes

This clause specifies the DGGS Core RS conformance class and the DGGS Core Functions conformance class. These cover:

a) DGGS Core RS — comprising parent global geometry, base CRS, and RS using zonal identifiers with structured geometry; and

b) DGGS Core Functions — comprising quantization, topological query, and interoperation.

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7.2 Core RS using Zonal Identifiers with Structured Geometry module

7.2.1 Core RS data model and base CRS

The DGGS Core RS shown in Figure 13 is a RS using zonal identifiers with structured geometry for a globe. It is defined by the attributes of the DGG_ReferenceSystem interface Table 37 and its metadata. In the context of the DGGS, and particularly in the DGGS Core, the term globe is used in its most general sense to represent a mathematical model of any planetary body and, depending on need, potentially its surroundings out to the orbit of a planet's outer moons, and for spatio-temporal DGGS over a defined time span. The spatio-temporal extent of the entire globe is referred to as the domain of the DGGS. The DGGS Core itself is dimension agnostic.

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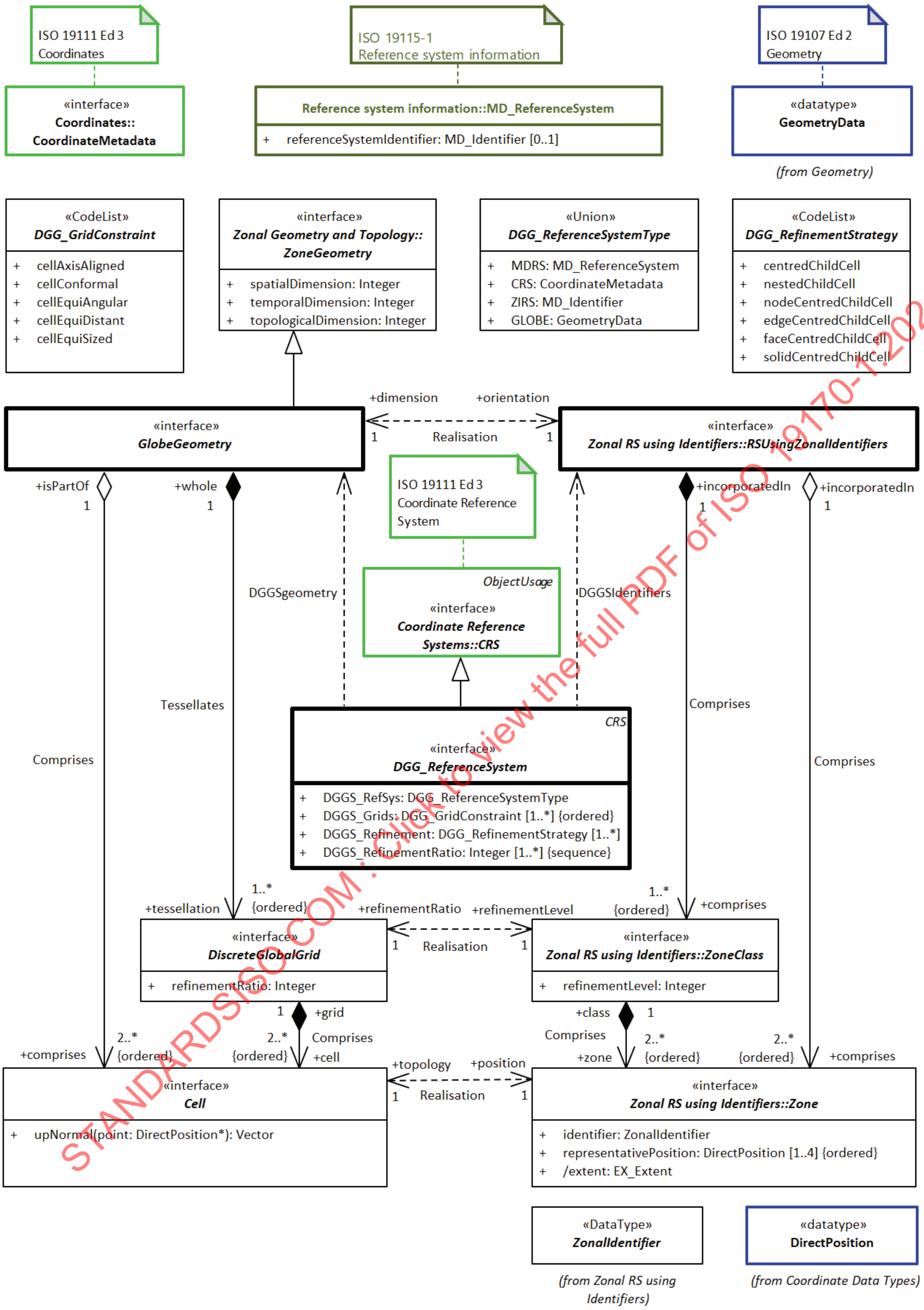

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Key

□	ISO 19107:2019	□	ISO 19115-1:2014
□	ISO 19111:2019	□	ISO 19170-1:2021 (this document)

Figure 13 — Core RS using Zonal Identifiers with Structured Geometry module

The DGGS Core RS model in Figure 13 describes a hierarchy of paired elements: at each tier of the hierarchy a geometry element, shown on the left of the figure, is paired with the equivalent zonal element, shown on the right of the figure.

At the root of the hierarchy, the globe's reference model and base CRS for the DGGS are defined. A single parent geometry (GlobeGeometry) is defined to coincide with the globe's reference model. The parent geometry's dimensionality governs the dimensionality of the DGGS (see 7.2.3). The parent global geometry is paired with an RS using zonal identifiers (RSUsingZonalIdentifiers).

A sequence of discrete global grids (DiscreteGlobalGrids), each paired with a ZoneClass, define the lower levels of the hierarchy.

Each DiscreteGlobaGrid is made up of Cells. Each Cell occupies a region of space-time (a Zone). The Zones corresponding to Cells in a DiscreteGlobaGrid all belong to the corresponding ZoneClass (See 7.2.5).

Cells provide zones with geometry and topology, and zones provide cells with names in the form of zonal identifiers and representative positions in the base CRS in the form of direct positions (See 7.2.4).

Each cell is the child of one or more parent cells in the parent discrete global grid in the level above in the hierarchy. The cells of a discrete global grid are topologically related to the cells in the parent(s) by the collection of refinement strategies defined in DGG_ReferenceSystem(DGGS_Refinement).

Each cell's geometry, orientation and size is governed by the constraint defined in DGG_ReferenceSystem(DGGS_Grids) and by the sequence of refinement ratios defined in DGG_ReferenceSystem(DGGS_RefinementRatio). If a sequence of refinementRatio is defined, the values are applied to each level in the hierarchy in a recurring sequence starting at the top with the first refinementRatio in the sequence and working down through the levels in order.

7.2.2 Defining tables

a) Table 37 — Elements of Core RS using Zonal Identifiers with Structured Geometry::Cell

b) Table 38 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystem

c) Table 39 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystemType

d) Table 40 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DiscreteGlobalGrid

e) Table 41 — Elements of Core RS using Zonal Identifiers with Structured Geometry::GlobeGeometry

f) Table 42 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_GridConstraint

g) Table 43 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_RefinementStrategy

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Table 37 — Elements of Core RS using Zonal Identifiers with Structured Geometry::Cell

Name:	Cell
Definition:	Reference system unit of geometry associated with a Zone. As part of GlobeGeometry, it has the same spatial, temporal and topological dimensionality as GlobeGeometry.
Stereotype:	Interface
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 38 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystem

Name:	DGG_ReferenceSystem
Definition:	Defining characteristics of a Reference system using zonal identifiers with structured geometry.
Stereotype:	Interface
Abstract:	true
Associations:	(none)

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Table 38 *(continued)*

	Name	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
Public attributes:	DGGS_Grids	List of characteristics that constrain the grid cells in this DGGS in decreasing order of priority.		M	*	DGG_GridConstraint (code list)
	DGGS_Refinement	List of topological relationships between parent and child cells in this DGGS.		M	*	DGG_RefinementStrategy (code list)
	DGGS_RefinementRatio	List of refinement ratios of parent cell size to child cell size, in the order that they are used in constructing child cells in the DGGS. If the list is shorter than the number of discrete global grids in the DGGS, then it is used as a recurring sequence.		M	*	Integer
	DGGS_RefSys	Reference system metadata.		M	1	DGG_ReferenceSystemType (union data type)
Constraints:	(none)					

Table 39 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystemType

Name:	DGG_ReferenceSystemType
Definition:	Defining metadata elements of the base CRS for this DGGS
Stereotype:	Union
Abstract:	true
Associations:	(none)

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Table 39 *(continued)*

	Name	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
Public attributes:	CRS	Metadata required to reference coordinates.		M	1	CoordinateMetadata
	GLOBE	GeometryData for the chosen GlobeGeometry that specifies geometry, spatial, temporal and topological dimensionality and domain of the globe for this DGGS.		M	1	Geometry::GeometryData
	MDRS	RS information describing this whole DGGS.		M	1	MD_ReferenceSystem
	ZIRS	Identifier for the RSUsingZonalIdentifiers used by this DGGS.		M	1	MD_Identifier
Constraints:	(none)					

Table 40 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DiscreteGlobalGrid

Name:	DiscreteGlobalGrid					
Definition:	Set of Cells at the same refinement level					
Stereotype:	Interface					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
				M	*	cell
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	refinementRatio	Ratio of the number of cells in the parent DiscreteGlobalGrid to the number in this DiscreteGlobalGrid.		M	1	Integer
Constraints:	(none)					

Table 41 — Elements of Core RS using Zonal Identifiers with Structured Geometry::GlobeGeometry

Name:	GlobeGeometry			
Definition:	Parent geometry specifying the geometry, dimensionality and domain of the globe for this DGGS.			
Stereotype:	Interface			
Inheritance from:	ZoneGeometry			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	Cell (feature type)	M	*	comprises
		M	*	tessellation
Public attributes:	(none)			
Constraints:	(none)			

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Table 42 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_GridConstraint

Name:	DGG_GridConstraint	
Definition:	CodeList for constraints that are used to define different categories of DGGS. Each constraint is a constraint on the shape, size, or orientation of cells in a DiscreteGlobalGrid.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	cellAxisAligned	Cell edges are parallel to the base CRS's coordinate system axes.
	cellConformal	Variation in shape between all the cells in each DiscreteGlobalGrid is minimized.
	cellEquiAngular	Variation in bearing from one cell's representative position to the next neighbouring cells' representative positions in each DiscreteGlobalGrid is minimized.
	cellEquiDistant	Variation in distance from a cell's representative position to all of it's neighbouring cells' representative positions in each DiscreteGlobalGrid is minimized.
	cellEquiSized	Variation in interior size between all cells in each DiscreteGlobalGrid is minimized.

Table 43 — Elements of Core RS using Zonal Identifiers with Structured Geometry::DGG_RefinementStrategy

Name:	DGG_RefinementStrategy	
Definition:	CodeList for strategies that are used to define different categories of DGGS. Each strategy defines the topological relationship of one or more elements of cell geometry belonging to a child cell with one or more elements of geometry of its parent cell.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	centredChildCell	`parent⇐zone.representativePosition() = child⇐zone.representativePosition()` for one child.
	nestedChildCell	`parent.boundary = <<set of all parent. child>>.boundary.`
	nodeCentredChildCell	Each parent cell has a `child□zone.representativePosition` coincident with each of the parent's nodes (zero-dimensional topological boundary element).
	edgeCentredChildCell	Each parent cell of dimension greater than 1 has a child cell for which the `cell⇐zone.representativePosition` lies on each of the parent's edges (one-dimensional topological boundary element).
	faceCentredChildCell	Each parent cell of dimension greater than 2 has a child cell for which the `cell⇐zone.representativePosition` lies on each of the parent's faces (two-dimensional topological boundary element).
	solidCentredChildCell	Each parent cell of dimension greater than 3 has a child cell for which the `cell⇐zone.representativePosition` lies on each of the parent's solids (three-dimensional topological boundary element).

The following requirements apply:

Requirement 6: www.opengis.net/spec/DGGS/2.0/req/core/rs/harmonised_model

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The data model for a DGGS RS and its element definitions shall comply with the DGGS Core RS data model in Figure 13 and definitions in Table 37- Table 43.

Requirement 7: www.opengis.net/spec/DGGS/2.0/req/core/rs/crs

A DGGS RS shall define a CRS, and comply with requirements for provision of coordinate epoch as specified for MD_ReferenceSystem.

7.2.3 Global domain

The domain of the DGGS shall be defined as the entire globe, with cells that *"exhaustively cover the globe without overlapping or underlapping"* (Goodchild[28]). Applying these criteria to the cells in each discrete global grid, there shall be no gaps between cells and no positions that are covered by more than one cell.

Each cell inherits its dimensionality from the choice of geometry for the GlobalGeometry class, so a reference system that specifies a geometry and domain as the globe's surface has two-dimensional cells on the surface of the globe, and one that specifies a geometry and domain as a globe's volume has three-dimensional cells filling the globe. A reference system that specifies a linear geometry and domain, for instance for time, results in one-dimensional cells.

The following requirements apply:

Requirement 8: www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain

DGGS RS global domain — the reference system shall specify a global domain, and its spatial, temporal and topological dimensionality.

Requirement 9: www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain/complete

DGGS RS domain completeness — the level zero discrete global grid shall cover the entire global domain.

Requirement 10: www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain/unique

DGGS RS location uniqueness — every location in the domain of the reference system shall be in exactly one cell of the level zero discrete global grid.

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7.2.4 Cells and zones

7.2.4.1 Cell simple geometry

Semantically, the terms cell and zone refer to different characteristics of the same region of space-time. Cells in a DGGS shall be geometrically simple. Simple geometries have the following properties:

a) they do not self-intersect;

b) they are topologically the same as a circle, or the circle's equivalent in the dimension of the cell, e.g. to a sphere in three-dimensions; and

c) they enclose a region which is always measurable using a metric of the same dimensionality as the cell.

The following requirement applies:

Requirement 11: www.opengis.net/spec/DGGS/2.0/req/core/rs/cell/simple

For each successive level of grid refinement, a DGGS specification shall define cells with simple geometry.

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7.2.4.2 Cell position

Each cell's zone has a fixed representative position in the space of the base CRS, recorded as a direct position.

The following requirement applies:

Requirement 12: www.opengis.net/spec/DGGS/2.0/req/core/rs/cell/direct_position

All zones in each discrete global grid shall be assigned a direct position that is within the zone's boundary.

7.2.4.3 Cell address

Each cell's zone shall be assigned a unique address in the form of a zonal identifier. The value assigned to each address shall be structured on one or more of these four general indexing methods: hierarchy-based, space-filling curve based, coordinate[35] and encoded address schemas (such as those used for IP addresses[38]).

The following requirement applies:

Requirement 13: www.opengis.net/spec/DGGS/2.0/req/core/rs/cell/address

All zones in all discrete global grids shall have a globally unique zonal identifier (or cell index) that provides a spatio-temporal reference.

7.2.5 Discrete global grid and its sequence

Cells at the same level in the tessellation hierarchy are aggregated into discrete global grids. The hierarchy of discrete global grids is an ordered sequence, typically also of decreasing cell size, representing the lowest resolution to higher resolutions. The discrete sequence of grids forms a multi-resolution grid hierarchy that is the basis for the DGGS RS.

The following requirements apply:

Requirement 14: www.opengis.net/spec/DGGS/2.0/req/core/rs/discrete_global_grid

A DGGS RS shall define discrete global grids as aggregations of all the cells at the same level in the hierarchy.

Requirement 15: www.opengis.net/spec/DGGS/2.0/req/core/rs/discrete_global_grid/sequence

A DGGS RS shall sort its hierarchy of discrete global grids in order of increasing refinement level.

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7.3 DGGS Core functions

7.3.1 Core Quantization Functions module

A DGGS is defined based on the geometry of the globe in a data-agnostic manner. Therefore, a DGGS specification shall define quantization methods for assigning data to cells so that the data are accessible for future use. Different quantization strategies may be used for sampling content into cells. For example, a single DGGS may be used as a data structure for integrating multiple datasets of different types (e.g. vector and raster datasets[41]) and in different ways (e.g. DGGS cells as data tiles, or one raster pixel per DGGS cell or DGGS cell indices as vector coordinate-pairs). This abstract specification makes use of the concepts defined by ISO 19156 to facilitate the association of observations/spatial data to a DGGS cell(s). Some DGGS/polyhedron choices are more efficient for sampling than others (e.g. DGGS based on an icosahedron).

Multiple observation contexts are recognized for quantization, each corresponding to a distinct role for DGGS cells to play. In any particular DGGS specification, one or more (and potentially all) roles may be described for either internal or external use to support interoperability, as follows:

a) **asDataTiles:** In data tile quantization, spatial feature/observations (e.g. point clouds, images, vectors, etc.) are aggregated and clipped to cell boundaries and stored in tiles without any changes made to the feature type parameters. The cells of the DGGS provide a multi- or single-resolution tiling schema with the cell index used as the identifier in the tile naming convention. In the context of "Big Data Analytics", 'asDataTile' support is likely to be the most efficient type of granularity for job submission on HPC/HPD or Cloud ICT infrastructure, particularly for dominantly embarrassingly parallel analyses. It is also likely to be the most efficient granularity for many data transfer requests.

b) **asDataCells:** In data cell quantization, the spatial features/observations (e.g. point clouds, images, vectors, etc.) are sampled to each DGGS cell by assignment of data value(s) using the cell's geometry to govern the quantization operation.

c) **asCoordinates:** In coordinate quantization, each coordinate tuple from the spatial feature/observation is converted to a cell index of an appropriate level of precision. The cell data package includes appropriate vector topology to preserve the structure of the spatial feature in the context of the DGGS.

d) **asTags:** In tag quantization, cell index values are "tagged" to data objects in a similar fashion to social media records. The refinement level of the cell index is indicative of the precision with which the location of a spatial feature/observation and/or its spatial extent are known. This can be thought of as a convex hull with the same geometry of the DGGS cell surrounding the objects to be assigned to that cell.

e) **asGraphicCells:** In graphic cell quantization, data are rendered to cells, and refinement levels are leveraged to support corresponding levels of detail or zoom levels.

f) **asGraphicTiles:** In graphic tile quantization, graphic cells are tiled, and often cached for delivery to a display system. As with data tiles, the cell index is used as the identifier in the tile naming convention.

The extent of the data assigned at any time to a particular DGGS implementation, defines the DGGS's extent. The extent is likely to vary over the DGGS's lifecycle as the extent of data assigned to it changes. The domain of the DGGS, is however, always fixed and always defined over the entire surface model of the DGGS's globe.

Figure 14 shows the key elements required to perform data quantization operations in a DGGS specification.

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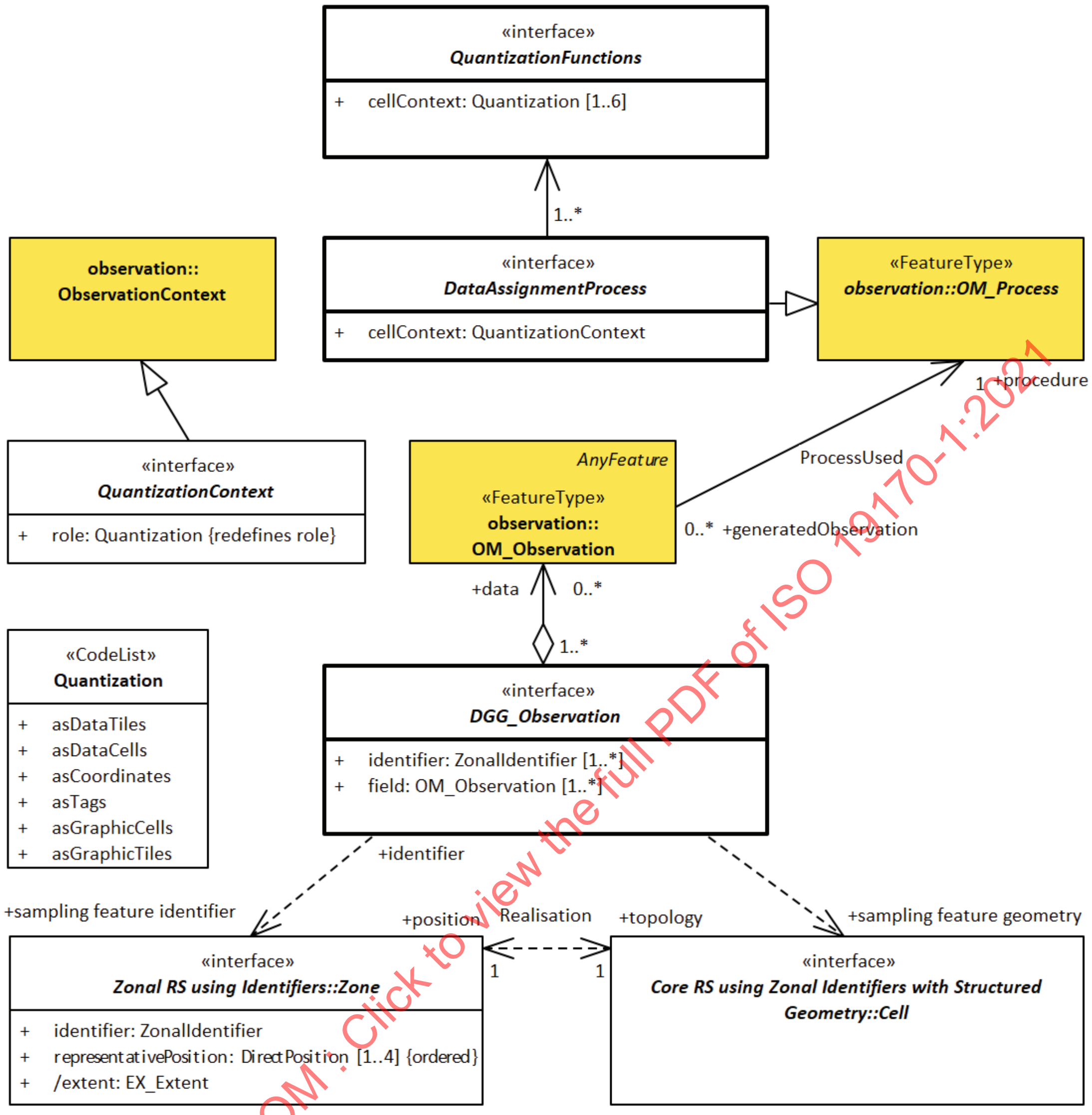

Key

🟨 ISO 19156:2011

□ ISO 19170-1:2021 (this document)

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Figure 14 — Components of Core Quantization Functions module

7.3.2 Defining tables

a) Table 44 — Elements of Core Quantization Functions::DataAssignmentProcess

b) Table 45 — Elements of Core Quantization Functions::DGG_Observation

c) Table 46 — Elements of Core Quantization Functions::QuantizationContext

d) Table 47 — Elements of Core Quantization Functions::QuantizationFunctions

e) Table 48 — Elements of Core Quantization Functions::Quantization

Table 44 — Elements of Core Quantization Functions::DataAssignmentProcess

Name:	DataAssignmentProcess					
Definition:	The class DataAssignmentProcess is a generalization of OM_Process, which represents a feature type. DataAssignmentProcess is abstract, and has no attributes, operations or associations. It serves as the base class for DataAssignment processes. The purpose of a data assignment process is to generate an assignment result. An instance of DataAssignmentProcess is often a data import function to import data from a pre-existing spatial dataset, but as in OM_Process "*it may also be an instrument or sensor, a human observer, a simulator, or a process or algorithm applied to more primitive results used as inputs*" [Source ISO 19156:2011, Clause 7.2.3].					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	cellContext	Roll that cell provides in this DataAssignmentProcess.		M	1	QuantizationContext
Constraints:	(none)					

Table 45 — Elements of Core Quantization Functions::DGG_Observation

Name:	DGG_Observation					
Definition:	DGG_Observation is an abstract class holding ZonalIdentifier, OM_Observation tuples. In the context of Quantization, DGG_Observation holds records of Observations made with DataAssignmentProcess in assigning values to cells.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	field	Values that were observed.		M	*	OM_Observation
	identifier	Cells that were observed.		M	*	ZonalIdentifier (data type)
Constraints:	(none)					

Table 46 — Elements of Core Quantization Functions::QuantizationContext

Name:	QuantizationContext					
Definition:	ObservationContext for this DataAssignmentProcess.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	role	Defines the role or roles that cells play in the quantization.		M	1	Quantization (code list)
Constraints:	(none)					

Table 47 — Elements of Core Quantization Functions::QuantizationFunctions

Name:	QuantizationFunctions

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Table 47 *(continued)*

Definition:	Process for quantizing external data by using a cell's geometry to sample external data and assign the results to zonal identifiers. The quantization code list identifies different potential roles for the cell geometry in the quantization process.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	cellContext	List of roles that cell geometry is to be used in in associated DataAssignmentProcesses.		M	6	Quantization (code list)
Constraints:	(none)					

Table 48 — Elements of Core Quantization Functions::Quantization

Name:	Quantization	
Definition:	CodeList for roles that cell geometries may play in a DataAssignmentProcess.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	asDataTiles	Zone assigned features clipped to the boundary of the zone's cell. NOTE 1 Features are clipped to the cell boundary and stored as a feature tile. NOTE 2 The zone's zonal identifier can be used in the naming convention for data tiles.
	asDataCells	Zone assigned a data value, either resampled or remapped, from a feature based on the geometry of the cell.
	asCoordinates	Each coordinate tuple in a vector feature's geometry data are replaced by a zonal identifier. The size of zone is chosen to represent the uncertainty in the knowledge of the position represented by the coordinate tuple.
	asTags	Minimal set of zonal identifiers applied to an object. NOTE 3 The zone operates in this context as a minimum bounding container (similar to a minimum bounding rectangle in 2D) where the boundary of the zone wholly encloses a set of features assigned to that zone. NOTE 4 The refinement level of a zone index used to tag a feature (or set of features) provides an indication of the level of precision and/or the spatial extents of the feature.
	asGraphicCells	Zone assigned the colour of a pixel in a map image ready for delivery to a map display system, with the colour representing an attribute value, either sampled or mapped, from a feature. NOTE 5 Refinement levels can be aligned with zoom levels or scales in a map display system.
	asGraphicTiles	Tiling scheme used for a map display system using cells to define the tile boundaries. NOTE 6 Graphic tiles can be cached or stored and sent to the display system as a map tile.

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The following requirement applies:

Requirement 16: www.opengis.net/spec/DGGS/2.0/req/core/functions/quantization

A DGGS specification shall define quantization operations for assigning data from external sources to DGGS cells that conform to the data model in Figure 14 and definitions in tables Table 44–Table 48.

7.3.3 Core Topological Query Functions module

7.3.3.1 Overview of topological query functions

The Topological Query Functions module implements the DE9IM[13] functionality defined in ISO 19107:2019 Geometry::Query2D and Geometry::Query3D for zonal topology. This is achieved through a single interface called ZoneQuery (Figure 16, Table 49). By default, ZoneQuery operates at the dimensionality of the DGGS's zones. Changes in dimensionality are controlled with an optional parameter, *projectTo*, that constrains ZoneQuery to a specified reference direction, surface or volume.

Two additional operations are provided that are based on the temporal concept of relative position. These are called relatePosition and relativePosition. These are generalized for use on any single reference direction specified by *projectTo*, not just the temporal direction.

Six additional operations are provided in ZoneQuery that leverage the ZoneClass hierarchy. These are called parent, child and sibling and parentOf, childOf and siblingOf.

ZoneQuery operations are defined in Figure 16 and 7.3.4. The following parameters are shared by many of the operations as specified in Table 49:

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another type ZonalIdentifier, mandatory.

Specifies the target region for the query. In zonal query a zone's identifier provides sufficient description of its topology. ZonalIdentifier therefore takes the place of the geometry data used in Query2D and Query3D for both the source and the target.

inheritID type Boolean, optional, default ⇐ *False*

When *inheritID* has a value of *True,* the result «set» only contains cells for which the IDs have shared inheritance, and a value of *False* indicates that inheritance is ignored.

projectTo type directPosition[4], optional, default ⇐ *(0,0,0,1)* for relatePosition and relativePosition, otherwise *(1,1,1,1)*

projectTo specifies an optional reference direction, surface or volume for an operation.

Allowed values for each direction are *0* and *1*, and spatial directions may also have a value of *n*.

projectTo defines a vector whose starting point is inferred as the point with each *projectTo* direction whose value is *1* set to *0*. It takes one of three forms.

In its one-dimensional form for specifying a reference direction, one direction has a value of *1*. For example *(0,0,0,1)* projects to the temporal axis, and *(0,0,1,0)* projects to the vertical axis.

In its two-dimensional form for specifying a reference surface, two directions have a value of *1*. For example a surface at height *n* is specified by a *projectTo* value of *(1,1,n,0)* representing the vector *[(0,0,n,0), (1,1,n,0)]*.

In its three-dimensional form for specifying a reference volume, three directions have a value of *1*. For example *(1,1,1,0)* projects to a spatial volume without reference to time, and *(1,1,n,1)* projects to a surface spanning all time at height *n*.

Only the one-dimensional form is supported by relativePosition and relatePosition.

While this construct could be used to implement more complex spatio-temporal queries, that is not the intent of Query2D, and is not specified for ZoneQuery either.

rangeRefine type refinementLevelRange, optional, default ⇐

[min(source.refinementLevel, target.refinementLevel):

max(source.refinementLevel, target.refinementLevel)].

Specifies the range of refinement levels to include in the return «set» . The lower and upper bounds in the refinementLevelRange datatype are both included in the range.

levels type Integer, optional, default ⇐ *1*

levels indicates the relative number of levels in the hierarchy to be traversed in assembling the result «set» Figure 15 illustrates the parent, child and sibling suite of functions through examples.

7.3.3.2 Summary of operations in ZoneQuery

The following operations have the same topological meaning as their equivalent operations in ISO 19107 Geometry::Query2D and Geometry::Query3D: distance, contains, crosses, disjoint, equals, intersects, overlaps, touches, within, withinDistance, difference, intersection, symDifference, union and relate.

a) **relativePosition:** *A*.relativePosition(*B*, *projectTo*), returns the relativePosition enumerator that describes *B*'s relative position to *A* with respect to the direction defined by *projectTo*.

b) **relatePosition:** *A*.relatePosition(*B*, *relation*, *projectTo*) returns whether *B* has the relative position to *A* given by *relation* with respect to the direction *projectTo*.

c) **parentOf:** *A*.parentOf(*B*, *inheritID*, *projectTo*), returns whether A is a parent cell of B, optionally filtered by *inheritID* and *projectTo*.

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d) **childOf:** *A*.childOf(*B*, *inheritID*, *projectTo*), returns whether A is a child cell of B, optionally filtered by *inheritID* and *projectTo*.

e) **siblingOf:** *A*.siblingOf(*B*, *inheritID*, *projectTo*), returns whether A is a sibling cell of B, optionally filtered by *inheritID* and *projectTo*.

f) **parent:** *A*.parent(*inheritID*, *projectTo*, *levels*), returns the unique «set» of zoneIdentifiers for zones that satisfy A.parentOf(B, *inheritID*, *projectTo*) applied recursively *levels* times up the parent hierarchy. The «set» has at most one member from each level of the hierarchy if *inheritID* is *True* and may have more than one if the cell refinementStrategy is not nested.

g) **child:** *A*.child(*inheritID, projectTo*, *levels*), returns the unique «set» of zoneIdentifiers for zones that satisfy A.parentOf(*B*, *inheritID*, *projectTo*) applied recursively *levels* times down the parent hierarchy.

h) **sibling:** *A*.sibling(*inheritID*, *projectTo*, *levels*), returns the unique «set» of zoneIdentifiers for zones that satisfy A.parentOf(*B*, *inheritID*, *projectTo*) applied recursively *levels* times outward on zones at the same refinement level. Multiple levels of sibling can also be thought of as the children of its parent(s) the specified number of levels up the hierarchy.

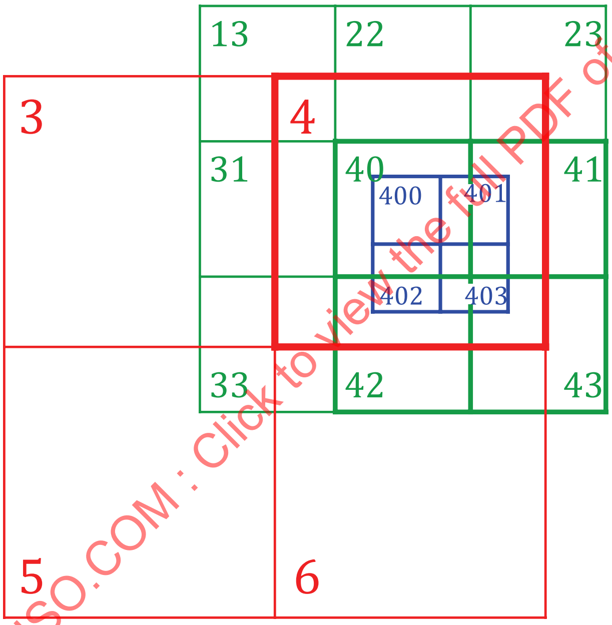

Figure 15 — Examples of parent, child, and sibling query operations

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EXAMPLE 1 *Parent, sibling and child queries for zone **40***:

40.parent() returns {**4**}

40.sibling(*inheritID = true*) returns {**40**, **41**, **42**, **43**}

40.sibling() returns {**13**, **22**, **23**, **31**, **40**, **41**, **42**, **43**}

40.child(*inheritID = true*) returns {**400**, **401**, **402**, **403**}

EXAMPLE 2 *Parent, sibling and child tests for zone **40***:

40.parentOf(**400**) returns *true*

40.siblingOf(**41**) returns *true*

40.siblingOf(**31**, *inheritID = true*) returns *false*

40.siblingOf(**41**) returns *true*

40.childOf(**4**) returns *true*

EXAMPLE 3 *Parent and child tests for zones **31** and **33** with multiple parents*:

31.childOf(**4**, *inheritID = true*) returns *false*

31.childOf(**4**) returns *true*

31.parent(*inheritID = true*) returns {**3**}

31.parent() returns {**3**, **4**}

33.parent() returns {**3**, **4**, **5**, **6**}

EXAMPLE 4 *Parent and child queries with levels set to a value greater than 1:*

400.parent(*inheritID = true* , *levels = 2*) returns {**40**, **4**}

4.child(*inheritID = true* , *levels = 2*) returns {**40**, **41**, **42**, **43**, **400**, **401**, **402**, **403**, **410**, **411**, **412**, **413**, **420**, **421**, **422**, **423**, **430**, **431**, **432**, **433**}

400.sibling(*inheritID = true* , *levels = 2*) returns {**400**, **401**, **402**, **403**, **410**, **411**, **412**, **413**, **420**, **421**, **422**, **423**, **430**, **431**, **432**, **433**}

While some of these results extend to zones that are not drawn in the figure, the location indicated by their zonal identifier should be readily apparent from the pattern.

NOTE In all examples the optional parameters *inheritID* and *levels* take their default values of *false* and *1* respectively, unless they are specified. Since these are two-dimensional examples without any depth or time, *projectTo* has no influence.

Further query and analysis functions may then be applied to the returned data through additional software bindings. This abstract specification does not specify any requirements for the binding or implementation of further, extension, query or analytic functions.

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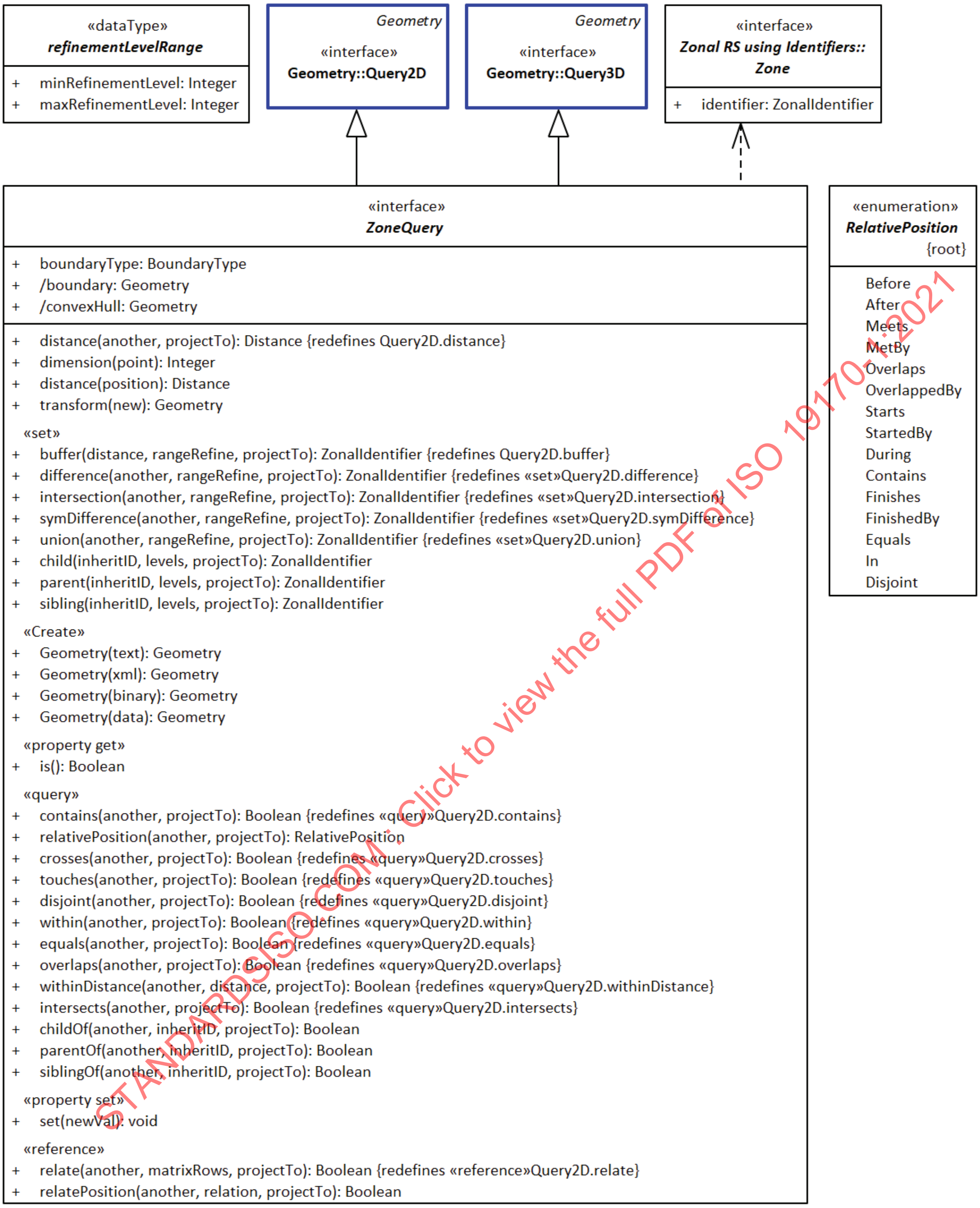
«dataType»
refinementLevelRange
+ minRefinementLevel: Integer
+ maxRefinementLevel: Integer
Geometry
«interface»
Geometry::Query2D
Geometry
«interface»
Geometry::Query3D
«interface»
Zonal RS using Identifiers::
Zone
+ identifier: ZonalIdentifier
«interface»
ZoneQuery
+ boundaryType: BoundaryType
+ /boundary: Geometry
+ /convexHull: Geometry
+ distance(another, projectTo): Distance {redefines Query2D.distance}
+ dimension(point): Integer
+ distance(position): Distance
+ transform(new): Geometry
«set»
+ buffer(distance, rangeRefine, projectTo): ZonalIdentifier {redefines Query2D.buffer}
+ difference(another, rangeRefine, projectTo): ZonalIdentifier {redefines «set»Query2D.difference}
+ intersection(another, rangeRefine, projectTo): ZonalIdentifier {redefines «set»Query2D.intersection}
+ symDifference(another, rangeRefine, projectTo): ZonalIdentifier {redefines «set»Query2D.symDifference}
+ union(another, rangeRefine, projectTo): ZonalIdentifier {redefines «set»Query2D.union}
+ child(inheritID, levels, projectTo): ZonalIdentifier
+ parent(inheritID, levels, projectTo): ZonalIdentifier
+ sibling(inheritID, levels, projectTo): ZonalIdentifier
«Create»
+ Geometry(text): Geometry
+ Geometry(xml): Geometry
+ Geometry(binary): Geometry
+ Geometry(data): Geometry
«property get»
+ is(): Boolean
«query»
+ contains(another, projectTo): Boolean {redefines «query»Query2D.contains}
+ relativePosition(another, projectTo): RelativePosition
+ crosses(another, projectTo): Boolean {redefines «query»Query2D.crosses}
+ touches(another, projectTo): Boolean {redefines «query»Query2D.touches}
+ disjoint(another, projectTo): Boolean {redefines «query»Query2D.disjoint}
+ within(another, projectTo): Boolean {redefines «query»Query2D.within}
+ equals(another, projectTo): Boolean {redefines «query»Query2D.equals}
+ overlaps(another, projectTo): Boolean {redefines «query»Query2D.overlaps}
+ withinDistance(another, distance, projectTo): Boolean {redefines «query»Query2D.withinDistance}
+ intersects(another, projectTo): Boolean {redefines «query»Query2D.intersects}
+ childOf(another, inheritID, projectTo): Boolean
+ parentOf(another, inheritID, projectTo): Boolean
+ siblingOf(another, inheritID, projectTo): Boolean
«property set»
+ set(newVal): void
«reference»
+ relate(another, matrixRows, projectTo): Boolean {redefines «reference»Query2D.relate}
+ relatePosition(another, relation, projectTo): Boolean
«enumeration»
RelativePosition
{root}
Before
After
Meets
MetBy
Overlaps
OverlappedBy
Starts
StartedBy
During
Contains
Finishes
FinishedBy
Equals
In
Disjoint

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Figure 16 — Components of Topological Zonal Query Functions module

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7.3.4 Defining tables

a) Table 49 — Elements of Core Topological Query Functions::refinementLevelRange

b) Table 50 — Elements of Core Topological Query Functions::ZoneQuery

c) Table 51 — Elements of Core Topological Query Functions::RelativePosition

Table 49 — Elements of Core Topological Query Functions::refinementLevelRange

Name:	refinementLevelRange					
Definition:	Datatype to define a range of refinement levels, specified through a lower- and an upper-bound. Both bounds are included within the range. The range acts as a filter on the ZoneClass's refinementLevel attribute.					
Stereotype:	DataType					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	maxRefinementLevel	Upper-bound of the refinement level range.		M	1	Integer
	minRefinementLevel	Lower-bound of the refinement level range.		M	1	Integer
Constraints:	(none)					

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Table 50 — Elements of Core Topological Query Functions::ZoneQuery

Name:	ZoneQuery					
Definition:	ZoneQuery redefines the DE9IM operations in Geometry::Query2D and Geometry::Query3D and provides relativePosition and relatePosition operations for the topology of zones.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	boundary	Boundary of the combined spatial geometries of the zones in the query.	true	M	1	Geometry
	boundaryType	Boundary type of the combined spatial geometries of the zones in the query.		M	1	BoundaryType
	convexHull	Convex hull of the combined spatial geometries of the zones in the query.	true	M	1	Geometry
Operations:	*Name*	*Parameters:ParameterType*	*Return type*	*Definition*		
	distance	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Distance	A.distance(B)		
«query» (1D)	relativePosition	(another:ZonalIdentifier, projectTo:DirectPosition[4])	RelativePosition	A.relativePosition(B,(0,0,0,1))		

Table 50 *(continued)*

«query»	contains	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.contains(B) ⇔ A⊇B
	crosses	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.crosses(B)
	disjoint	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.disjoint(B) ⇔ A∩B = 0
	equals	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.equals(B) ⇔ A = B
	intersects	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.intersects(B) ⇔ A∩B≠0
	overlaps	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.overlaps(B)
	touches	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.touches(B)
	within	(another:ZonalIdentifier, projectTo:DirectPosition[4])	Boolean	A.within(B) ⇔ B.contains(A)
	withinDistance	(another:ZonalIdentifier, dist:Distance, projectTo: DirectPosition[4])	Boolean	A.withinDistance(B) ⇔ A.distance(B) < dist
	parentOf	(another:ZonalIdentifier, inheritID:Boolean, projectTo: DirectPosition[4])	Boolean	A.parentOf(B)
	childOf	(another:ZonalIdentifier, inheritID:Boolean, projectTo: DirectPosition[4])	Boolean	A.childOf(B)
	siblingOf	(another:ZonalIdentifier, inheritID:Boolean, projectTo: DirectPosition[4])	Boolean	A.siblingOf(B)
«set»	buffer	(dist:Distance, projectTo: DirectPosition[4])	ZonalIdentifier	A.buffer(dist)
	difference	(another:ZonalIdentifier, rangeRefine: refinementLevelRange, projectTo:DirectPosition[4])	ZonalIdentifier	A.difference(B) ⇔ A-B
	intersection	(another:ZonalIdentifier, rangeRefine: refinementLevelRange, projectTo:DirectPosition[4])	ZonalIdentifier	A.intersection(B) ⇔ A∩B
	symDifference	(another:ZonalIdentifier, rangeRefine: refinementLevelRange, projectTo:DirectPosition[4])	ZonalIdentifier	A.symDifference(B) ⇔ (A-B)∪(B-A)
	union	(another:ZonalIdentifier, rangeRefine: refinementLevelRange, projectTo:DirectPosition[4])	ZonalIdentifier	A.union(B) ⇔ A∪B
	parent	(inheritID:Boolean, levels:Integer, projectTo: DirectPosition[4])	ZonalIdentifier	A.parent(B)
	child	(inheritID:Boolean, levels:Integer, projectTo: DirectPosition[4])	ZonalIdentifier	A.child(B)
	sibling	(inheritID:Boolean, levels:Integer, projectTo: DirectPosition[4])	ZonalIdentifier	A.sibling(B)
«reference» (1D)	relatePosition	(another:ZonalIdentifier, relate: RelativePosition, projectTo: DirectPosition[4])	Boolean	A.relatePosition(B,enum,(0,0,1,0))

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Table 50 *(continued)*

«reference»	relate	(another:ZonalIdentifier, matrix: CharacterString, projectTo: DirectPosition[4])	Boolean	A.relate(B,matrix)
Constraints:	(none)			

Table 51 — Elements of Core Topological Query Functions::RelativePosition

Name:	RelativePosition	
Definition:	Enumeration for the relative position of two geometries projected to a single uni-directional dimension, e.g. time. NOTE In this document the relative position names follow those jointly adopted by W3C and OGC 16-071r3[54], which is more recent than ISO 19108.	
Stereotype:	Enumeration	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition:* Self and another are two ZoneGeometries projected to a single uni-dimensional dimension.
	Before	self.end < another.begin
	After	self.begin > another.end
	Meets	self.end = another.begin
	MetBy	self.begin = another.end
	Overlaps	self.begin < another.begin AND self.end > another.begin AND self.end < another.end
	OverlappedBy	self.begin < another.end AND self.end > another.end
	Starts	self.begin = another.begin AND self.end < another.end
	StartedBy	self.begin = another.begin AND self.end > another.end
	During	self.begin > another.begin AND self.end < another.end
	Contains	self.begin < another. begin AND self.end > another.end
	Finishes	self.end = another.end AND self.begin > another.begin
	FinishedBy	self.begin > another.begin AND self.end = another.end
	Equals	self.begin = another.begin AND self.end = another.end
	In	self.relativePosion(another) IN [Starts, During, Finishes]
	Disjoint	self.relativePosion(another) IN [Before, After]

The following requirement applies:

Requirement 17: www.opengis.net/spec/DGGS/2.0/req/core/functions/query/zonequery

A DGGS specification shall implement query operations that conform to the data model in Figure 16 and definitions in Table 49–Table 51, across its entire domain.

7.3.5 Core Interoperation Functions module

7.3.5.1 Overview of interoperation functions

While the quantization and topological query functions enable a DGGS implementation to successfully operate internally, in order to facilitate connectivity with other spatial data infrastructures, additional interoperation functions are required. As shown in Figure 17, the interoperation functions are split into two modules:

a) Interoperation Query: Interpret and translate external data queries sent to the DGGS implementation; and

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b) Interoperation Broadcast: Convert the result set returned from a DGGS query operation from internal data format(s) (optimized for that DGGS implementation) to format(s) suitable for external data delivery.

This document does not specify the specific interface protocol encodings required to connect a DGGS implementation to an external client and to facilitate the transfer of information into and out of a DGGS. This abstract specification makes use of the tools available in ISO 19156 to facilitate the linkage between external query operations and the data/observations assigned to the DGGS zone(s) of interest. Specific interface encodings are anticipated to be elaborated as extensions to this abstract specification.

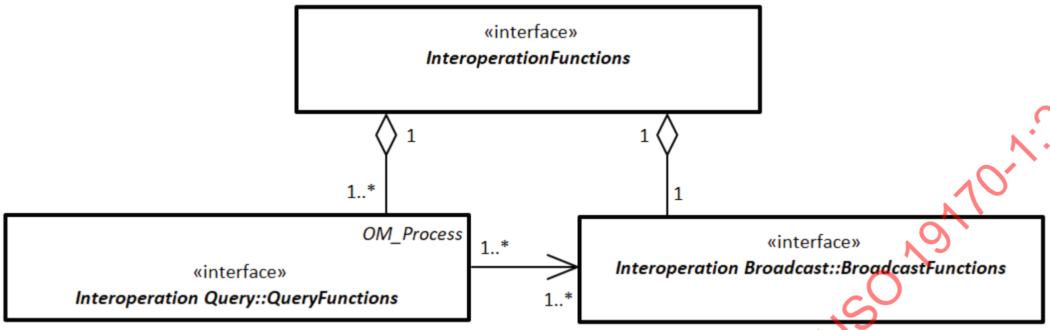

Figure 17 — Components of Core Interoperation Functions module

7.3.5.2 Defining tables

a) Table 52— Elements of Core Interoperation Functions::InteroperationFunctions

Table 52 — Elements of Core Interoperation Functions::InteroperationFunctions

Name:	InteroperationFunctions
Definition:	Interoperation is modelled as receipt of a query from an external service and broadcast of results.
Stereotype:	Interface
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

7.3.5.3 Interoperation Query module

External queries may originate from an external client application and range in syntax from natural language queries (e.g. 'Where are the gas pipelines in Western Canada located?', or 'How has the Murray-Darling Basin in Australia changed over the past 27 years?', or 'Compute the watershed area of the Kawarau Catchment in New Zealand'), to an OWS 'GetCapabilities' or similar type of query, to an SQL (or similar) statement. To support interoperability, a DGGS specification shall define methods to receive, interpret and translate an external data query (or process) request into a form that can be processed by the internal DGGS data retrieval and query functions.

Figure 18 shows the key functional elements required for DGGS to translate and execute an external query or process operations.

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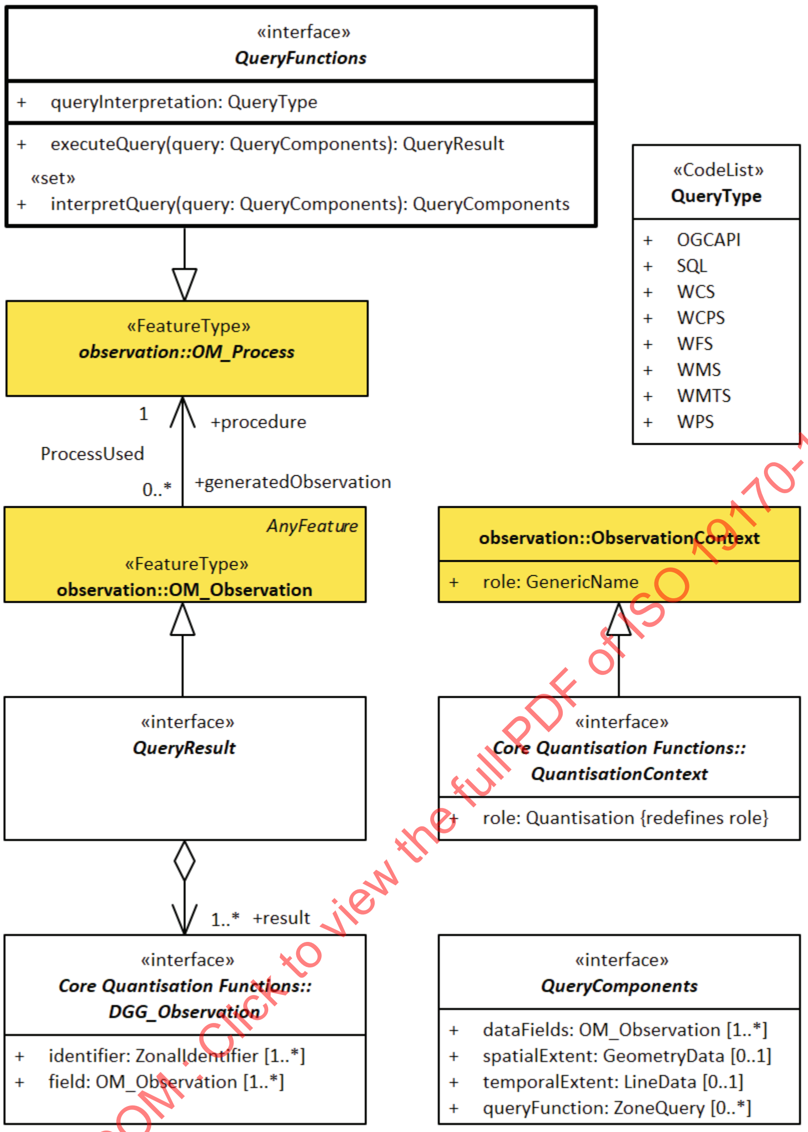
«interface»
QueryFunctions
+ queryInterpretation: QueryType
+ executeQuery(query: QueryComponents): QueryResult
«set»
+ interpretQuery(query: QueryComponents): QueryComponents
«CodeList»
QueryType
+ OGCAPI
+ SQL
+ WCS
+ WCPS
+ WFS
+ WMS
+ WMTS
+ WPS
«FeatureType»
observation::OM_Process
1
+procedure
ProcessUsed
0..*
+generatedObservation
AnyFeature
«FeatureType»
observation::OM_Observation
observation::ObservationContext
+ role: GenericName
«interface»
QueryResult
«interface»
Core Quantisation Functions::
QuantisationContext
+ role: Quantisation {redefines role}
1..* +result
«interface»
Core Quantisation Functions::
DGG_Observation
+ identifier: ZonalIdentifier [1..*]
+ field: OM_Observation [1..*]
«interface»
QueryComponents
+ dataFields: OM_Observation [1..*]
+ spatialExtent: GeometryData [0..1]
+ temporalExtent: LineData [0..1]
+ queryFunction: ZoneQuery [0..*]

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Figure 18 — Components of Interoperation Query module

7.3.5.4 Defining tables

a) Table 53 — Elements of Interoperation Query::QueryComponents

b) Table 54 — Elements of Interoperation Query::QueryFunctions

c) Table 55 — Elements of Interoperation Query::QueryResult

d) Table 56 — Elements of Interoperation Query::QueryType

Table 53 — Elements of Interoperation Query::QueryComponents

Name:	QueryComponents					
Definition:	Structure to hold parameters for a query.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	dataFields	Descriptor of the non-spatial information that is requested from the DGGS.		M	*	OM_Observation
	queryFunction	Spatio-temporal extent of the region of interest for the query, expressed as a ZonalAlgebra expression.		C	*	ZoneQuery
	spatialExtent	Spatial extent of the region of interest for the query, expressed as GeometryData.		C	1	GeometryData
	temporalExtent	Temporal extent of the region of interest for the query, expressed as temporal geometry.		C	1	LineData
Constraints:	(none)					

Table 54 — Elements of Interoperation Query::QueryFunctions

Name:	QueryFunctions					
Definition:	QueryFunctions is an interface to receive, interpret, and execute queries from external services. Queries for broadcast are modelled as OM_Process, which makes an OM_Observation of a «set» of Cells and their associated DGG_Observations to create a QueryResult. The ObservationContext:role is selected from the Quantization CodeList.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	queryInterpretation	Identifies the language type for query.		M	1	QueryType (code list)

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Table 54 *(continued)*

	Name	*Parameters: ParameterType*	*Return type*	*Definition*
Operations:	interpretQuery	(query: QueryComponents)	QueryComponents	Transform query components from an external structure to a «set» of one or more query components structured for execution by the DGGS.
	executeQuery	(query: QueryComponents)	QueryResult	Execute query to generate a result.
Constraints:	(none)			

Table 55 — Elements of Interoperation Query::QueryResult

Name:	QueryResult			
Definition:	Abstract placeholder for a query result.			
Stereotype:	Interface			
Abstract:	true			
Associations:	*Association with:*	*Obligation*	*Maximum occurrence*	*Provides:*
	DGG_Observation (feature type)	M	*	result
Public attributes:	(none)			
Constraints:	(none)			

Table 56 — Elements of Interoperation Query::QueryType

Name:	QueryType	
Definition:	CodeList for the structure of an interoperation query.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	OGCAPI	OGC API query.
	SQL	Structured Query Language query.
	WCS	Web Coverage Service query.
	WCPS	Web Coverage Processing Service query.
	WFS	Web Feature Service query.
	WMS	Web Map Processing Service query.
	WMTS	Web Map Tile Service query.
	WPS	Web Processing Service query.

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The following requirement applies:

Requirement 18: www.opengis.net/spec/DGGS/2.0/req/core/functions/interoperation/query

A DGGS specification shall implement operations to read, interpret and execute external data queries that conform to the data model in Figure 17 and Figure 18 and definitions in Table 52–Table 56.

7.3.5.5 Interoperation Broadcast module

Just as it is necessary for DGGSS to be able to interpret and execute external data queries, DGGS shall also define methods to broadcast results from data queries to external client(s) or data infrastructure(s). External clients are anticipated to be web-based client(s), software client(s) on the same ICT infrastructure as the DGGS, or other DGGSS.

Figure 19 shows basic elements required to translate the result set(s) returned from a DGGS data query into a suitable data format for transfer and broadcast the reformatted result set via one or a number of data or information transfer protocols.

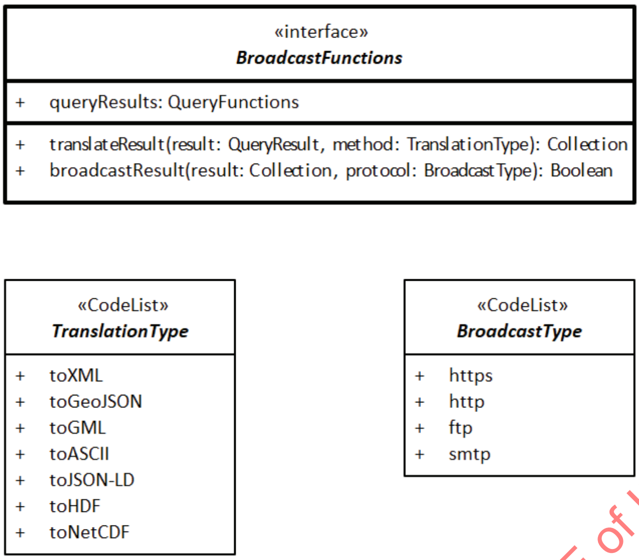
«interface»
BroadcastFunctions
+ queryResults: QueryFunctions
+ translateResult(result: QueryResult, method: TranslationType): Collection
+ broadcastResult(result: Collection, protocol: BroadcastType): Boolean
«CodeList»
TranslationType
+ toXML
+ toGeoJSON
+ toGML
+ toASCII
+ toJSON-LD
+ toHDF
+ toNetCDF
«CodeList»
BroadcastType
+ https
+ http
+ ftp
+ smtp

Figure 19 — Components of Interoperation Broadcast module

7.3.5.6 Defining tables

a) Table 57 — Elements of Interoperation Broadcast::BroadcastFunctions

b) Table 58 — Elements of Interoperation Broadcast::TranslationType

c) Table 59 — Elements of Interoperation Broadcast::TranslationType

Table 57 — Elements of Interoperation Broadcast::BroadcastFunctions

Name:	BroadcastFunctions					
Definition:	An interface to translate the results from an Interoperation Query::QueryFunctions into the requested format and return it to the client.					
Stereotype:	Interface					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	queryResults	Result received from the QueryFunctions ready for processing for export.		M	1	QueryFunctions
	resultBroadcast			M	1	BroadcastMethod
	resultTranslation			M	1	ResultTranslation-Method

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Table 57 *(continued)*

Operations:	*Name*	*Parameters: ParameterType*	*Return type*	*Definition*
	translateResult	(result:QueryResult)	Collection	Reformat query result from internal structure to requested format for broadcast.
	broadcastResult	(result:Collection)	Boolean	Broadcast reformatted result to client using designated protocol and return acknowledgement of success.
Constraints:	(none)			

Table 58 — Elements of Interoperation Broadcast::BroadcastType

Name:	BroadcastType	
Definition:	CodeList for DGGS interoperation data broadcast protocols.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	https	Broadcast over Hypertext transfer secure protocol.
	http	Broadcast over Hypertext transfer protocol.
	ftp	Broadcast over File transfer protocol.
	smtp	Broadcast over Simple mail transfer protocol.

Table 59 — Elements of Interoperation Broadcast::TranslationType

Name:	TranslationType	
Definition:	CodeList for DGGS interoperation data broadcast translation formats.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	toASCII	Translate to ASCII format.
	toGeoJSON	Translate to GeoJSON format.
	toGML	Translate to GML format.
	toHDF	Translate to HDF format.
	toJSON-LD	Translate to JSON-LD format.
	toNetCDF	Translate to NetCDF format.
	toXML	Translate to XML format.

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The following requirement applies:

Requirement 19: www.opengis.net/spec/DGGS/2.0/req/core/functions/interoperation/broadcast

A DGGS specification shall implement operations to translate data results from interoperation queries to standard data formats and broadcast the reformatted result set that conforms to the data model in Figure 17 and Figure 19, and definitions in Table 52 and Table 57–Table 59.

8 Equal-Area Earth DGGS

8.1 Equal-Area Earth DGGS package

8.1.1 Equal-Area Earth RS module

This clause specifies the Equal-Area Earth RS module.

For a DGGS RS that is conformant with the DGGS Core to be an EAERS, it shall satisfy all the requirements for the Equal-Area Earth DGGS package.

The data model supports DGGS EAERSs based on either static or dynamic datums. Care shall be taken when implementing DGGSs with static datums. Static CRSs are by their nature only intended for use on one tectonic plate. However, the definition for a DGGS always has a global domain. This apparent conundrum is resolved in two ways:

a) **Orientation:** Noting that some static CRSs have one or more points on the Earth's surface where the underlying mathematics is poorly behaved, orient the EA_BaseUnitPolyhedron so that areas, centroids, vertices, and edges can be computed; and

b) **Precision:** On the tectonic plate where the reference frame is static choose the level of DGGS precision to suit the intended use of the DGGS (typically in the range of millimetres to 10s of metres), and in areas of the Earth on plates that are moving with respect to the static reference frame choose the level of DGGS precision to reflect the larger of the constraints imposed by the mathematics and by plate tectonics (typically in the of range 10s to 100 000s of metres).

Dynamic datums present problems of a different form. The most frequently used is WGS 84, which is a datum ensemble. Care shall be taken to ensure that the error budget for EA_Cell's area is set at a value that caters to the level of approximation in the WGS 84 definition.

Figure 20, Figure 21 and Figure 22 show the data models for modules in the Equal-Area Earth DGGS package.

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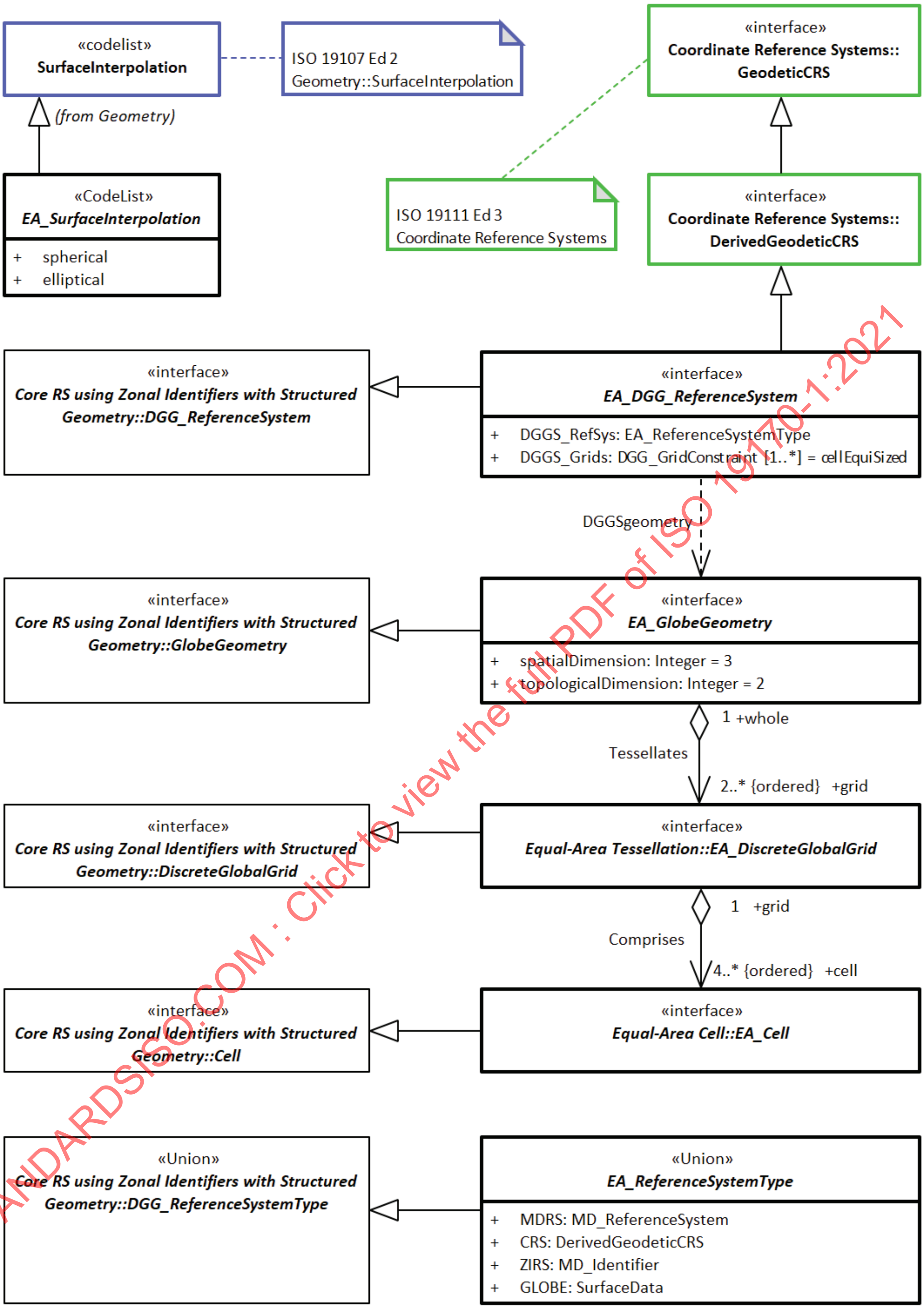
«codelist»
SurfaceInterpolation
ISO 19107 Ed 2
Geometry::SurfaceInterpolation
(from Geometry)
«CodeList»
EA_SurfaceInterpolation
+ spherical
+ elliptical
«interface»
Coordinate Reference Systems::
GeodeticCRS
ISO 19111 Ed 3
Coordinate Reference Systems
«interface»
Coordinate Reference Systems::
DerivedGeodeticCRS
«interface»
Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystem
«interface»
EA_DGG_ReferenceSystem
+ DGGS_RefSys: EA_ReferenceSystemType
+ DGGS_Grids: DGG_GridConstraint [1..*] = cellEquiSized
DGGSgeometry
«interface»
Core RS using Zonal Identifiers with Structured Geometry::GlobeGeometry
«interface»
EA_GlobeGeometry
+ spatialDimension: Integer = 3
+ topologicalDimension: Integer = 2
1 +whole
Tessellates
2..* {ordered} +grid
«interface»
Core RS using Zonal Identifiers with Structured Geometry::DiscreteGlobalGrid
«interface»
Equal-Area Tessellation::EA_DiscreteGlobalGrid
1 +grid
Comprises
4..* {ordered} +cell
«interface»
Core RS using Zonal Identifiers with Structured Geometry::Cell
«interface»
Equal-Area Cell::EA_Cell
«Union»
Core RS using Zonal Identifiers with Structured Geometry::DGG_ReferenceSystemType
«Union»
EA_ReferenceSystemType
+ MDRS: MD_ReferenceSystem
+ CRS: DerivedGeodeticCRS
+ ZIRS: MD_Identifier
+ GLOBE: SurfaceData

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🟩 ISO 19111:2019

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Figure 20 — Components of Equal-Area Earth RS module

See 8.1.2 for definitions of elements in this Figure 20.

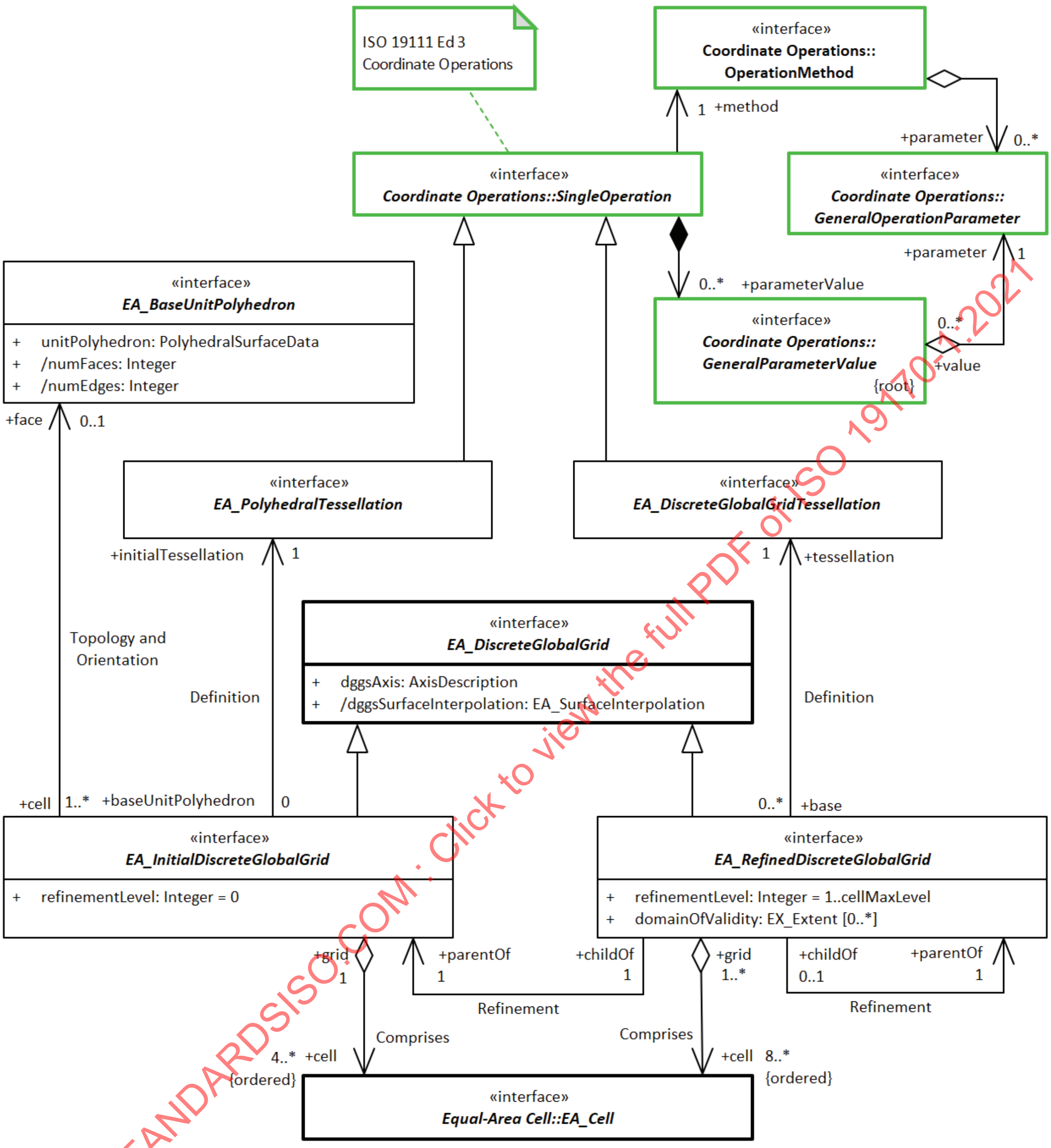

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Figure 21 — Components of Equal-Area Tessellation module

See 8.1.4.5 for definitions of elements in Figure 21.

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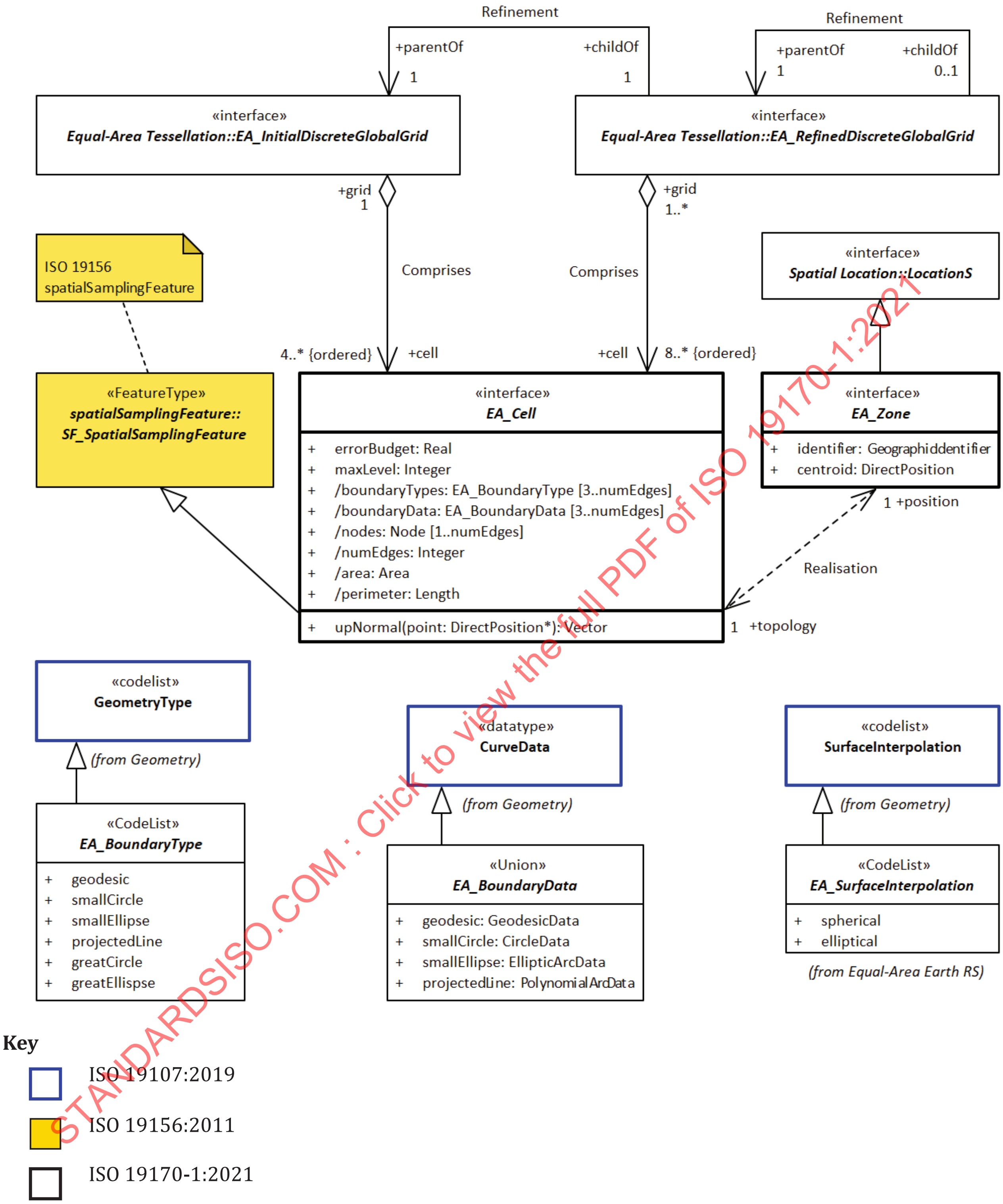

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Figure 22 — Components of Equal-Area Cell module

See 8.1.5.4 for definitions of elements in Figure 22.

8.1.2 Defining tables

a) Table 60 — Elements of Equal-Area Earth RS::EA_DGG_ReferenceSystem

b) Table 61 — Elements of Equal-Area Earth RS::EA_GlobeGeometry

c) Table 62 — Elements of Equal-Area Earth RS::EA_ReferenceSystemType

d) Table 63 — Elements of Equal-Area Earth RS::EA_SurfaceInterpolation

Table 60 — Elements of Equal-Area Earth RS::EA_DGG_ReferenceSystem

Name:	EA_DGG_ReferenceSystem					
Definition:	Defining characteristics of a RS using Zonal Identifiers with Structured Geometry for an Equal-Area Earth DGGS.					
Stereotype:	Interface					
Inheritance from:	DGG_ReferenceSystem					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	DGGS_Grids	List of characteristics that constrain the grid cells in this DGGS in decreasing order of priority. cellEquiSized shall be the first value.		M	*	DGG_GridConstraint (code list)
	DGGS_RefSys	Reference system metadata.		M	1	EA_ReferenceSystemType (union data type)
Constraints:	(none)					

Table 61 — Elements of Equal-Area Earth RS::EA_GlobeGeometry

Name:	EA_GlobeGeometry					
Definition:	Parent geometry specifying the geometry, dimensionality and domain of the globe for this DGGS. Geometry of the surface of an earth reference model.					
Stereotype:	Interface					
Inheritance from:	GlobeGeometry					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	EA_DiscreteGlobalGrid (feature type)			M	*	grid
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	spatialDimension	EA_GlobeGeometry shall have a spatialDimension of 3.		M	1	Integer
	topologicalDimension	EA_GlobeGeometry shall have a topologicalDimension of 2, corresponding to the surface of the Earth.		M	1	Integer
Constraints:	(none)					

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Table 62 — Elements of Equal-Area Earth RS::EA_ReferenceSystemType

Name:	EA_ReferenceSystemType					
Definition:	Defining metadata elements of the base CRS for a DGGS Equal-Area Earth RS					
Stereotype:	Union					
Inheritance from:	DGG_ReferenceSystemType					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	CRS	Metadata required to reference coordinates, Includes CRS ID and coordinate Epoch for dynamic CRS.		M	1	DerivedGeodeticCRS
	GLOBE	SurfaceData for the chosen EA_GlobeGeometry that specifies geometry, spatial, and topological dimensionality and domain of the globe for this DGGS.		M	1	SurfaceData
	MDRS	Reference system information describing this whole DGGS.		M	1	MD_ReferenceSystem
	ZIRS	Identifier for the spatial RSUsingZonalIdentifiers used by the DGGS.		M	1	MD_Identifier
Constraints:	(none)					

Table 63 — Elements of Equal-Area Earth RS::EA_SurfaceInterpolation

Name:	EA_SurfaceInterpolation	
Definition:	Subset of Geometry::SurfaceInterpolation (code list) providing permitted interpolation methods for EA_Cell.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	spherical	The EA_Cell surface is a section of a spherical surface. NOTE 1 For EA_Cells of sufficiently small extent, linear interpolation is sufficient to meet the `EA_Cell.errorBudget` for area.
	elliptical	The EA_Cell surface is a section of an elliptical surface. NOTE 2 For EA_Cells of sufficiently small extent, spherical interpolation is sufficient to meet the `EA_Cell.errorBudget` for area. NOTE 3 For EA_Cells of sufficiently small extent, linear interpolation is sufficient to meet the `EA_Cell.errorBudget` for area.

The following requirement applies:

Requirement 20: www.opengis.net/spec/DGGS/2.0/req/ea/ers/harmonised_model

An EAERS specification shall comply with the data model in Figure 20–Figure 22 and definitions in Table 60–Table 73.

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8.1.3 Global domain

For a DGGS RS to be an EAERS, the domain shall be defined as the entire surface of the Earth.

The following requirement applies:

Requirement 21: www.opengis.net/spec/DGGS/2.0/req/ea/ers/global_domain

EAERS global domain — the domain of an EAERS shall be the whole surface of the reference frame's Earth model and the DGG_ReferenceSystem shall specify cellEqualSized as one of the DGGS_Grids constraint values.

8.1.4 Equal-Area Tessellation module

8.1.4.1 Tessellation overview

A multiresolution hierarchical tessellation of cells is created by constructing a sequence of discrete global grids, each with successively finer cell resolutions. First an initial discrete global grid is constructed as described in subclause 8.1.4.2. The cells of this initial tessellation are then iteratively refined by application of cell refinement method(s)[34] to create finer resolution child cells. The initial tessellation, the cell shape, the refinement methods and indexing methods may all vary for different DGGSs.

8.1.4.2 Initial tessellation

The entire surface of the Earth is partitioned to a finite/discrete set of regions. Most methods initially approximate the Earth's surface using a simple base unit polyhedron which is scaled so that all vertices are located on the surface model of the Earth, and the edges are warped so they also lie on the surface model. The resulting edges may be any of the types listed in EA_CurveType. These include geodesics, small circles, small ellipses and lines that project to a straight line on a plane. These all result from intersections of a plane and an ellipsoid. The initial discrete global grid tessellation has the same form as the base unit polyhedron. Each EA_Cell of the initial tessellation represents one face of the chosen base unit polyhedron mapped to the chosen surface model of the Earth. This document refers to the initial tessellation as a "polyhedral tessellation". The most common choices for an initial base unit polyhedron are discussed in subclause C.4[34].

The following requirement applies:

Requirement 22: www.opengis.net/spec/DGGS/2.0/req/ea/ers/tessellation/initial

An EAERS specification shall include an initial tessellation that is defined by equal-area cells produced by mapping the faces of a base unit polyhedron to the surface model of the Earth.

8.1.4.3 Tessellation sequence

DGGS EAERS comprise a discrete sequence of global grids formed from recursive application of a tessellation method to refine the grid cells, so that each global grid has a progressively finer spatial resolution.

The following requirements apply:

Requirement 23: www.opengis.net/spec/DGGS/2.0/req/ea/ers/tessellation/sequence

An EAERS specification shall have tessellation operations that generate a sequence of discrete global grids with progressively smaller cells.

Requirement 24: www.opengis.net/spec/DGGS/2.0/req/ea/ers/tessellation/sequence/max

An EAERS specification shall specify a limit to the number of iterations in its sequence of discrete global grids, to ensure that the error budget for EA_Cell's area is not exceeded.

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8.1.4.4 Global area preservation

Preservation of total surface area throughout the range of hierarchical tessellations is a necessary property of DGGSs in order to represent information consistently at successive resolutions. This requirement ensures that each level of grid refinement completely covers the Earth's surface without cell overlaps.

The following requirement applies:

Requirement 25: www.opengis.net/spec/DGGS/2.0/req/ea/ers/tessellation/global_area_preservation

For each successive discrete global grid of an EAERS specification one of the following two statements shall apply:

Dynamic Datum	If the base CRS has a dynamic datum the sequence of discrete global grids shall preserve global domain completeness and position uniqueness throughout the sequence.
Static Datum	If the base CRS has a static datum the sequence of discrete global grid shall preserve domain completeness and position uniqueness throughout the sequence for all EA_Cells within their respective discrete global grids.

8.1.4.5 Defining tables

a) Table 64 — Elements of Equal-Area Tessellation::EA_BaseUnitPolyhedron

b) Table 65 — Elements of Equal-Area Tessellation::EA_DiscreteGlobalGrid

c) Table 66 — Elements of Equal-Area Tessellation::EA_DiscreteGlobalGridTessellation

d) Table 67 — Elements of Equal-Area Tessellation::EA_InitialDiscreteGlobalGrid

e) Table 68 — Elements of Equal-Area Tessellation::EA_PolyhedralTessellation

f) Table 69 — Elements of Equal-Area Tessellation::EA_RefinedDiscreteGlobalGrid

Table 64 — Elements of Equal-Area Tessellation::EA_BaseUnitPolyhedron

Name:	EA_BaseUnitPolyhedron
Definition:	EA_BaseUnitPolyhedron Polyhedron with circumsphere radius of one, specified by the number and faces and edges and the collection of boundary curves that make up each polygonal face.
Stereotype:	Interface
Abstract:	true
Associations:	(none)

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Table 64 *(continued)*

Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	numEdges	Number of edges in the EA_BaseUnitPolyhedron.	true	M	1	Integer
	numFaces	Number of faces on the EA_BaseUnitPolyhedron, corresponds to the number of EA_Cells in the EA_InitialDiscreteGlobalGrid.	true	M	1	Integer
	unitPolyhedron	PolygonData for each of the unit Polyhedron's segment Polygons, expressed in spherical coordinates (theta, phi) with unit radius.		M	1	PolyhedralSurfaceData
Constraints:	self.vertex.r = 1					

Table 65 — Elements of Equal-Area Tessellation::EA_DiscreteGlobalGrid

Name:	EA_DiscreteGlobalGrid					
Definition:	Super class for EA_InitialDiscreteGlobalGrid and EA_RefinedDiscreteGlobalGrid					
Stereotype:	Interface					
Inheritance from:	DiscreteGlobalGrid					
Generalization of:	EA_InitialDiscreteGlobalGrid, EA_RefinedDiscreteGlobalGrid					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	EA_Cell (feature type)			M	*	cell
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	dggsAxis	A dggsAxis typically follows a space-filling curve designed to recursively traverse all cells in each tesselation, Cell::identifiers are ordered along the path of the dggsAxis.		M	1	AxisDescription
	dggsSurfaceInterpolation	EA_SurfaceInterpolation corresponding to the form of the specified EA_GlobeGeometry.	true	M	1	EA_SurfaceInterpolation (code list)
Constraints:	(none)					

Table 66 — Elements of Equal-Area Tessellation::EA_DiscreteGlobalGridTessellation

Name:	EA_DiscreteGlobalGridTessellation
Definition:	The EA_DiscreteGlobalGridTessellation method implements the DGGS_Grids constraint, DGGS_Refinement strategy and DGGS_RefinementRatio, to create a child EA_RefinedDiscreteGlobalGrid from a parent EA_DiscreteGlobalGrid.

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Table 66 *(continued)*

Stereotype:	Interface
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 67 — Elements of Equal-Area Tessellation::EA_InitialDiscreteGlobalGrid

Name:	EA_InitialDiscreteGlobalGrid					
Definition:	The EA_InitialDiscreteGlobalGrid is formed by applying the EA_PolyhedralTessellation method to an EA_BaseUnitPolyhedron.					
Stereotype:	Interface					
Inheritance from:	EA_DiscreteGlobalGrid					
Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	EA_Cell (feature type)			M	*	cell
	EA_BaseUnitPolyhedron (feature type)			C	1	face
	EA_PolyhedralTessellation (feature type)			M	1	initialTessellation
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	refinementLevel	EA_InitialDiscreteGlobalGrid has a refinementlevel of 0.		M	1	Integer
Constraints:	(none)					

Table 68 — Elements of Equal-Area Tessellation::EA_PolyhedralTessellation

Name:	EA_PolyhedralTessellation
Definition:	The EA_PolyhedralTessellation method transforms the EA_BaseUnitPolyhedron in such a way that: 1) the surface area of each cell belonging to the EA_InitialDiscreteGlobalGrid is the same, 2) domain completeness is preserved by the EA_InitialDiscreteGlobalGrid, and 3) location uniqueness is preserved by the EA_InitialDiscreteGlobalGrid.
Stereotype:	Interface
Abstract:	true
Associations:	(none)
Public attributes:	(none)
Constraints:	(none)

Table 69 — Elements of Equal-Area Tessellation::EA_RefinedDiscreteGlobalGrid

Name:	EA_RefinedDiscreteGlobalGrid
Definition:	EA_DiscreteGlobalGrid formed by an EA_DiscreteGlobalGriodTessellation, is an EA_RefinedDiscreteGlobalGrid.
Stereotype:	Interface
Inheritance from:	EA_DiscreteGlobalGrid

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Table 69 *(continued)*

Abstract:	true					
Associations:	*Association with:*			*Obligation*	*Maximum occurrence*	*Provides:*
	EA_Cell (feature type)			M	*	cell
	EA_RefinedDiscreteGlobalGrid (feature type)			M	1	parentOf
	EA_InitialDiscreteGlobalGrid (feature type)			M	1	parentOf
	EA_DiscreteGlobalGridTessellation (feature type)			M	1	tessellation
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	domainOfValidity	For DGGS with a dynamic datum the domainOfValidity is always global.		C	*	EX_Extent
	refinementLevel	The child EA_Refined-DiscreteGlobalGrid has a refinementlevel of one greater than its parent.		M	1	Integer
Constraints:	(none)					

8.1.5 Equal-Area Cell module

8.1.5.1 Cells are simple polygons

EA_Cells are simple polygons formed from an ordered set of boundary curves adhering to the geometric reference surface of the Earth model. EA_Cells are defined in three-dimensional space and are topologically two-dimensional. Different cell shapes can be used, typically triangle, quadrilateral, pentagon, hexagon, and octagon. Cells formed from faces of the five (5) Platonic solids (tetrahedron-triangle, cube-quadrilateral, octahedron-triangles, dodecahedron-pentagons, icosahedron-triangles) all satisfy the requirements for simple cells. Larger numbers of faces and therefore cells at the top of the hierarchy of tessellations, increases the uniformity of the cell shape. The truncated icosahedron, with thirty-two (32) faces is often used for DGGSs. It produces mostly hexagons augmented by twelve (12) pentagons in each tessellation. Each cell shape has its own advantages and disadvantages[34] and it is usually desirable for each refined discrete global grid to have a majority of cells with the same shape[37],[41]. Triangular, quadrilateral and hexagonal cells are common choices used in DGGSs on the surface of the Earth. These shapes provide regular tiling of the plane[37], which can be mapped to a curved surface such as a spherical or ellipsoidal Earth surface model.

The cell structures in each successive level of cell refinement are constrained by the properties of the initial tessellation, but do not necessarily have the same geometry as the initial tessellation. Simple two-dimensional cells have the following properties:

a) edges meet only at the vertices;

b) exactly two edges meet at each vertex;

c) exactly the same number of edges and vertices; and,

d) enclose a region which always has a measurable area.

The following requirement applies:

Requirement 26: www.opengis.net/spec/DGGS/2.0/req/ea/ers/cell/simple/2d_polygon

For each successive discrete global grid, an EAERS specification shall define EA_Cells that are simple polygons.

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8.1.5.2 Cells referenced at their centroid

Each EA_Cell shall be referenced at its centroid. This is because the centroid is the only location that provides a representative point that behaves consistently with shape and is invariant under orientation. The representative point for an EA_Cell shall lie on the surface of the cell. For curved surfaces, the "centre of gravity" computed in three-dimensions cannot actually lie on the surface (see ISO 19107:2019, 6.4.4.8). If, however, the "centre of gravity" is computed using distances computed along geodesic arcs on the curved surface, then the centroid is constrained to lie on the surface. This is a centroid calculated as the "geodesic centre of surface area" of an EA_Cell.

The centroid enables a dual representation of a DGGS tessellation as both two-dimensional areal cell grids and as point-based lattices of cell reference locations.

The following requirement applies:

Requirement 27: www.opengis.net/spec/DGGS/2.0/req/ea/ers/cell/direct_position/centroid

An EAERS specification shall define the DirectPosition of an EA_Cell to be the centroid of the EA_cell, computed as the geodesic centre of surface area.

8.1.5.3 Cells of equal area

This document defines an EAERS based on a hierarchy of equal-area tessellations. Cells of equal area provide global grids with spatial units that (at multiple resolutions) have an equal probability of contributing to an analysis. Equal-area cells also help to minimize the confounding effects of area variations in spatial analyses where the curved surface of the earth is the fundamental reference frame.

In an EAERS the unit of measure is a unit of area, not length as in a cartesian XYZ coordinate system or angle as in an ellipsoidal coordinate system. For angular measures the degree is defined as one 360th integer fraction of a full circle, and by analogy the areal unit of measure of a DGGS coordinate reference system is an integer fraction of the surface area of the chosen ellipsoidal surface model for the earth. For DGGSs the integer fraction is the number of cells in the initial discrete global grid. Continuing the angular analogy with minutes being 1/60th of a degree and seconds being 1/60th of a minute, for DGGSs, recursive use of the refinement ratio generates a sequence of smaller areal units, one for each refined discrete global grid.

Standard units of measure are defined through a reference measure with defined precision. The meter unit of length has been redefined a number of times as technology has improved. For example:

a) **From 1793:** 1/10 000 000 of the meridian through Paris between the North Pole and the Equator ($\pm\sim 10^{-4}$ m); and

b) **From 1983:** The length of the path travelled by light in a vacuum in 1/299 792 458th of a second ($\pm 10^{-10}$ m).

To address the need for transparency of the precision in its units of area, this document uses the concept of a specified error budget. The error budget takes into account all sources of variation that are relevant to the particular DGGS, its derivation, and its expected use. For most day to day uses, most of these sources contribute errors that are significantly smaller than the precision required of the DGGS. However, as technology pushes the limits of available precision, use-cases demand combining data from highly disparate sources, and users push their expectations, it becomes increasingly important to know when limits of use are reached.

The sources considered for inclusion in the error budget can include:

a) **spatial variation:** whether the available precision of each source of error is uniform or variable across the DGGS's domain;

b) **datum:** precision of the underlying measurements for the datum;

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c) **static datum:** precision of the assertion that the coordinates are static both on the tectonic plate the datum is tied to, and away from the static plate;

d) **earth model:** differences between the chosen ellipsoidal or spherical earth model and the real earth's surface. Spheres lead to faster and more precise computations for the tessellations but have a less precise fit to the real earth's surface.

While implementation issues are beyond the scope of this document, the following sources can contribute to increases in error budgets for an implementation:

a) **spherical maths:** exact solutions are available for solving the required mathematics on the surface of a sphere;

b) **ellipsoidal maths:** solving the required mathematics on the surface of an ellipsoid requires the use of iterative numerical methods which result in approximate solutions with an uncertainty determined by both the method and the number of iterations used to perform the computation;

c) **data-type precision:** most probably use 64-bit double precision for location, anything less has a significant impact on the error budget;

d) **cell edge type:** geodesics, small circles, small ellipses, and projected lines each have different solutions with different consequences for their precision and performance. At finer resolutions it can be possible to implement a simpler edge type and still stay within the implementation error budget;

e) **error propagation:** the choice of strategy for implementing the sequence of tessellations.

The error budget puts a limit on the number of iterations in the sequence of refined discrete global grids. This is acknowledged in the requirements.

DGGSs may validly comprise more than one cell geometry. This most typically arises for systems based on truncated polyhedra such as the cuboctahedron, with both square and triangular faces, and the truncated icosahedron, with pentagonal and hexagonal faces. In these situations, equal area is interpreted to mean that all of the cells of a particular geometry are equal area, and that the ratio of the areas of the two geometries is preserved through the tessellations. For example, in the truncated icosahedron used by ISEA, the ratio of pentagonal to hexagonal areas within a tessellation level is always 5/6.

The following requirements apply:

Requirement 28: www.opengis.net/spec/DGGS/2.0/req/ea/ers/cell/equal_area/error_budget

An EAERS shall specify error budget(s) for cell area of 1 % or less that represents the maximum ratio of a cells area to the theoretical average cell area of all cells in a discrete global grid computed from the number of cells in the discrete global grid and the discrete global grid's surface area. One of the following two statements shall apply:

Dynamic Datum If the base CRS has a dynamic datum, for each successive level of grid refinement, an EAERS specification shall specify one error budget value.

Static Datum If the base CRS has a static datum, for each successive level of grid refinement, an EAERS specification shall specify at least one error budget value for the area of the globe that it is static, and at least one error budget value for the area of the globe that is not static.

Requirement 29: www.opengis.net/spec/DGGS/2.0/req/cell/equal_area

For each discrete global grid, and for each cell geometry, an EAERS specification shall define EA_Cells that are equal area within the specified error budget.

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8.1.5.4 Defining tables

a) Table 70 Elements of Equal-Area Cell::EA_BoundaryData

b) Table 71 Elements of Equal-Area Cell::EA_Cell

c) Table 72 Elements of Equal-Area Cell::EA_Zone

d) Table 73 Elements of Equal-Area Cell::EA_BoundaryType

Table 70 — Elements of Equal-Area Cell::EA_BoundaryData

Name:	EA_BoundaryData					
Definition:	Curve data for the permitted boundary types. GreatCircle and greatEllipse boundary types use the same data types as smallCircle and smallEllipse respectively.					
Stereotype:	Union					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	geodesic	Curve data for a geodesic boundary.		M	1	GeodesicData
	projectedLine	Curve data for a projected line boundary.		M	1	PolynomialArcData
	smallCircle	Curve data for a small circle boundary.		M	1	CircleData
	smallEllipse	Curve data for a small ellipse boundary.		M	1	EllipticArcData
Constraints:	(none)					

Table 71 — Elements of Equal-Area Cell::EA_Cell

Name:	EA_Cell
Definition:	Reference system unit of geometry associated with an EA_Zone. As part of EA_GlobeGeometry, it has the same spatial, temporal and topological dimensionality as GlobeGeometry. NOTE As an EA_Cell on the surface of the Earth, its topologicalDimension is 2.
Stereotype:	Interface
Inheritance from:	Cell
Abstract:	true
Associations:	(none)

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Table 71 *(continued)*

Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	area	Area of the cell's surface	true	M	1	Area
	boundaryData	List of EA_BoundaryDara that make up the cells' boundary, starting with the curve connecting node_0 to node_1, and continuing in a clockwise sequence.	true	M	1	EA_BoundaryData (union data type)
	boundaryTypes	List of EA_CurveTypes that make up the cells' boundary, starting with the curve connecting node_0 to node_1, and continuing in clockwise sequence.	true	M	1	EA_BoundaryType (code list)
	errorBudget	For DGGSs referencing a dynamic datum, cellEqualAreaPrecision is typically a single value for each tessellation, and therefore most efficiently realized as an attribute of each RefinedDiscreteGlobalGrid.		M	1	Real
	maxLevel	For DGGSs referencing a dynamic datum, cellMaxLevel is typically a single value for each tessellation, and therefore most efficiently realized as an attribute of each RefinedDiscreteGlobalGrid. For DGGSs referencing a static datum, cellMaxLevel has different values in different locations, primarily dependent on whether the location is on or off the tectonic plate the datum is tied to. Under these circumstances the cellMaxLevel can be realized as an attribute of a parent cell one or more refinement levels above the cell.		M	1	Integer
	nodes	Ordered sequence of vertices, clockwise round the cell's boundary.	true	M	1	Node
	numEdges	Number of edges that make up the cell's boundary.	true	M	1	Integer
	perimeter	Length of the cell's boundary.	true	M	1	Length
Constraints:	(none)					

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Table 72 — Elements of Equal-Area Cell::EA_Zone

Name:	EA_Zone					
Definition:	An EA_Cell's location is an EA_Zone					
Stereotype:	Interface					
Inheritance from:	LocationS					
Abstract:	true					
Associations:	(none)					
Public attributes:	*Name*	*Definition*	*Derived*	*Obligation*	*Maximum occurrence*	*Data type*
	centroid	Cell's representative position calculated as the cell's geodesic centre of surface area, held by the cell's LocationS.		M	1	DirectPosition
	identifier	EA_Zone's unique GeographicIdentifier.		M	1	GeographicIdentifier
Constraints:	(none)					

Table 73 — Elements of Equal-Area Cell::EA_BoundaryType

Name:	EA_BoundaryType	
Definition:	CodeList for permitted curve types as constructors of an EA_Cell boundary. NOTE All EA_BoundaryType curves can be constructed as an intersection of a plane and an ellipsoid. So, each of these curve types is a straight line on a designated plane.	
Stereotype:	CodeList	
Abstract:	true	
Associations:	(none)	
Values:	*Name*	*Definition*
	geodesic	Shortest path between two points on the spherical or ellipsoidal DGGS's Earth reference model. Geodesic curves are defined using the GeodesicData constructor.
	smallCircle	Curves that are the intersection of a plane and an ellipsoid, where the plane is perpendicular to the axis of rotation of an ellipsoid, are small circles. See greatCircle. Lines of latitude are small circles.
	greatCircle	The great circle is a special case of small circle where the two focal points of the ellipse are also on the defining plane. On a non-spherical ellipsoid this is the only circle that is also a geodesic.
	smallEllipse	Curves that are the intersection of a plane and an ellipsoid, where the plane is parallel to the axis of rotation of the ellipsoid, are small ellipses. See greatEllipse.
	greatEllipse	A greatEllipse is a special case of smallEllipse where the axis of rotation is on the defining plane. GreatEllipses are geodesics. Lines of longitude are greatEllipses.
	projectedLine	A curve on the surface of an ellipsoid, whose equal-area projection on the projection's reference plane is a straight line.

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Annex A
(normative)

Abstract test suite

A.1 General

This annex specifies an Abstract test suite for the conformance categories in this document. The requirement tests associated with each conformance category are listed in Table A.1–Table A.3. Tests identifiers below are relative to http://www.opengis.net/spec/DGGS/2.0/

A.2 Common Spatio-temporal Classes package conformance categories

The requirement tests that apply to each conformance category in the Common Spatio-temporal Classes package are listed in Table A.1.

Table A.1 — Categories of conformance

Category	Requirements
Temporal geometry and topology	Requirement Test A.1
Temporal reference systems using period identifiers	Requirement Test A.4
Spatial zone geometry and topology	Requirement Test A.2
Spatial reference systems using zonal identifiers	Requirement Test A.3, and Requirement Test A.5
Spatio-temporal zone geometry and topology	Requirement Test A.1, and Requirement Test A.2
Spatio-temporal reference systems using zonal identifiers	Requirement Test A.3, Requirement Test A.4, and Requirement Test A.5

Requirement Test A.1: Common Spatio-temporal Classes — Temporal — Geometry

Abbreviation:	conf/cc/temporal/geometry
Type:	Basic
Requirement:	6.2.1.2, Requirement 1: http://www.opengis.net/spec/DGGS/2.0/req/cc/temporal/geometry
Reference sub-clause:	6.2.1
Test purpose:	To verify the common classes for temporal geometry and topology conform to the data model in Figure 3 and Figure 4 and defining tables in Table 2–Table 13.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.2: Common Spatio-temporal Classes — Zone — Geometry

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Abbreviation:	conf/cc/zone/geometry
Type:	Basic
Requirement:	6.2.2.2, Requirement 2: http://www.opengis.net/spec/DGGS/2.0/req/cc/zone/geometry
Reference subclause:	6.2.2
Test purpose:	To verify the common classes for zonal geometry and topology conform to the data model in Figure 5 and defining tables in Table 14–Table 19.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.3: Common Spatio-temporal Classes — Spatial — Location

Abbreviation:	conf/cc/spatial/location
Type:	Basic
Requirement:	6.3.1.2, Requirement 3: http://www.opengis.net/spec/DGGS/2.0/req/cc/spatial/location
Reference subclause:	6.3.1
Test purpose:	To verify the common classes for spatial location conform to the data model in Figure 6 and defining tables in Table 20.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.4: Common Spatio-temporal Classes — Temporal — Reference system using period identifiers

Abbreviation:	conf/cc/temporal/rsupi
Type:	Basic
Requirement:	6.3.2.2, Requirement 4: http://www.opengis.net/spec/DGGS/2.0/req/cc/temporal/rsupi
Reference subclause:	6.3.2
Test purpose:	To verify the common classes for reference systems using period identifiers conform to the data model in Figure 6 and defining tables in Table 21–Table 24.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.5: Common Spatio-temporal Classes — Zone — Reference system using zonal identifiers

Abbreviation:	conf/cc/zone/rsuzi
Type:	Basic
Requirement:	6.3.3.2, Requirement 5: http://www.opengis.net/spec/DGGS/2.0/req/cc/zone/rsuzi

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Reference subclause: 6.3.3

Test purpose: To verify the common classes for reference systems using zonal identifiers conform to the data model in Figure 8-Figure 11 and defining tables in Table 25–Table 36.

Test method: Inspect documentation of the DGGS specification.

A.3 DGGS Core package conformance categories

A.3.1 Categories of conformance

Table A.2 shows the requirement tests that apply to each conformance category in the DGGS Core package.

Table A.2 — Categories of conformance

Category	Requirements
Spatial DGGS Core	Requirement Test A.2, Requirement Test A.3, Requirement Test A.5, and all Core requirement tests in Requirement Test A.6–Requirement Test A.19.
Spatio-temporal DGGS Core	Requirement Test A.1, Requirement Test A.2, Requirement Test A.3, Requirement Test A.4, Requirement Test A.5, and all Core requirement tests in Requirement Test A.6–Requirement Test A.19.

A.3.2 Core — Reference system

Requirement Test A.6: Core — Reference system — Harmonized model

Abbreviation: conf/core/rs/harmonized_model

Type: Basic

Requirement: 7.2.2, Requirement 6: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/harmonized_model

Reference subclause: 7.2

Test purpose: To verify that all reference system classes conform with classes in the Core reference system data model in Figure 13 and definitions in Table 37–Table 43.

Test method: Inspect documentation of the DGGS specification.

Requirement Test A.7: Core — Reference system — CRS

Abbreviation: conf/core/rs/crs

Type: Basic

Requirement: 7.2.2, Requirement 7: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/crs

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Reference sub-clause: 7.2

Test purpose: To verify that the DGGS RS defines a CRS and conforms with coordinate epoch requirements as specified for MD_ReferenceSystem.

Test method: Inspect documentation of the DGGS specification.

Requirement Test A.8: Core — Reference system — Global domain

Abbreviation: conf/core/rs/global_domain

Type: Basic

Requirement: 7.2.3, Requirement 8: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain

Reference sub-clause: 7.2.3

Test purpose: To verify a reference system specifies a global domain, and its spatial, temporal and topological dimensionality.

Test method: Inspect documentation of the DGGS specification.

Requirement Test A.9: Core — Reference system — Global domain — Complete

Abbreviation: conf/core/rs/global_domain/complete

Type: Basic

Requirement: 7.2.3, Requirement 9: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain/complete

Reference sub-clause: 7.2.3

Test purpose: To verify reference system domain completeness, with the level zero discrete global grid covering the entire global domain.

Test method: Inspect documentation of the DGGS specification.

Requirement Test A.10: Core — Reference system — Global domain — Unique

Abbreviation: conf/core/rs/global_domain/unique

Type: Basic

Requirement: 7.2.3, Requirement 10: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/global_domain/unique

Reference sub-clause: 7.2.3

Test purpose: To verify reference system domain uniqueness, with every location in the domain of the DGGS located in exactly one cell of the level zero discrete global grid.

Test method: Inspect documentation of the DGGS specification.

Requirement Test A.11: Core — Reference system — Cell — Simple

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Abbreviation:	conf/core/rs/cell/simple
Type:	Basic
Requirement:	7.2.4.1, Requirement 11: http://www.opengis.net/spec/DGGS/2.0/req/core/cell/simple
Reference sub-clause:	7.2.4.1
Test purpose:	To verify that all the cells of a DGGS specification have shapes that are simple geometry, where the geometry of the cell: does not self-intersect; is topologically the same as the equivalent shape of a circle with the cell's dimensionality; and encloses a region that is measurable in the cell's metric.
Test method	Inspect documentation of the DGGS specification.

Requirement Test A.12: Core — Reference system — Cell — Direct position

Abbreviation:	conf/core/rs/cell/direct_position
Type:	Basic
Requirement:	7.2.4.2, Requirement 12: http://www.opengis.net/spec/DGGS/2.0/req/core/cell/direct_position
Reference sub-lcause:	7.2.4.2
Test purpose:	To verify that all zones in each discrete global grid are assigned a direct position that is within the zone's boundary.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.13: Core — Reference system — Cell — Address

Abbreviation:	conf/core/rs/cell/address
Type:	Basic
Requirement:	7.2.4.3, Requirement 13: http://www.opengis.net/spec/DGGS/2.0/req/core/cell/address
Reference sub-clause:	7.2.4.3
Test purpose:	To verify that all zones in all discrete global grids have a globally unique zonal identifier (or cell index) that provides a spatio-temporal reference.
Test method:	Inspect documentation of the DGGS specification.

Requirement Test A.14: Core — Reference system — Discrete global grid

Abbreviation:	conf/core/rs/discrete_global_grid
Type:	Basic
Requirement:	7.2.5, Requirement 14: http://www.opengis.net/spec/DGGS/2.0/req/core/rs/discrete_global_grid

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