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The OpenGIS® Abstract Specification

Topic 2: Spatial Referencing by Coordinates

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Contents

i. Preface

This document describes modelling requirements for spatial referencing by coordinates. Coordinate Reference System data is metadata about spatial data whose positions are described by coordinates. Without the Coordinate Reference System data, interpretation of coordinates is ambiguous.

This document supplements and corrects ISO 19111: Geographic Information – Spatial Referencing by Coordinates. It makes use of contents and formatting of the ISO document where possible, providing additional modelling detail and textual clarification only where it was felt to be required. The differences with ISO DIS 19111 are summarized in an annex.

This document replaces OGC document 99-102r1 – The OpenGIS™ Abstract Specification, Topic 2: Spatial Reference Systems.

ii. Revision history

Date	Release	Author	Paragraph modified	Description
7 Sept 2001	01-063	RN	New document	First draft for internal OGC feedback
12 Nov 2001	01-063r1 (v 1.0.1)	RN	Various editorial comments and a modification of the UML model	Initial feedback from CT Working Group implemented
8 Jan 2002	01-063r2 v 1.0.2	RN	Various editorial comments and modifications of the UML model	Final feedback implemented from the CT Working Group

Foreword

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

This document replaces OGC Document 99-102r1, titled "The OpenGIS® Abstract Specification – Topic 2: Spatial Reference Systems". The reasons for complete replacement rather than a revision are:

a) The publication of ISO 19111, which covers largely the same ground as OGC Document 99-102r1 and the alignment with that document.

b) Alignment with published Implementation Specification "OpenGIS® Coordinate Transformation Services Implementation Specification" and OpenGIS® Recommendation Paper: "Recommended Definition Data for Coordinate Reference Systems and Coordinate Transformations". The abstract model that underlies both of these documents has progressed considerably from that described in OGC Document 99-102r1 and is more in line with ISO 19111.

Although this document is to a very large extent based on ISO 19111, it deviates on a number of points and adds a degree of detail. A list of these variations is provided in Annex B. Rather than publishing a list of variations with ISO 19111 and forcing the reader to continually make cross-references, it was decided to provide the reader with a coherent document that reproduces parts of ISO 19111 verbatim, interlaced with the additions and variations mentioned. It is felt that this enhances readability and will facilitate understanding this specialist subject matter.

Introduction

Position on or near the Earth's surface can be described by systems of spatial referencing. These are of two basic types:

– those using coordinates;

– those based on geographic identifiers (for example postal addresses, administrative areas).

Spatial referencing by geographic identifiers is defined in ISO 19112, *Geographic information - Spatial referencing by geographic identifier*s. The subject matter of this document is confined to spatial referencing by coordinates.

Coordinates are unambiguous only when the coordinate reference system to which those coordinates are related has been fully defined. A coordinate reference system is a coordinate system that has a reference to the Earth.

This document describes the elements that are necessary to fully define various types of coordinate systems and coordinate reference system applicable to geographic information. The subset of elements required is partially dependent upon the type of coordinates. The document also includes optional fields to allow for the inclusion of non-essential coordinate reference system information. The elements are intended to allow implementations to be designed that permit both machine and human interpretation of the data. A set of coordinates on the same coordinate reference system requires one coordinate reference system description.

In addition to describing a coordinate reference system, this document provides for the description of a coordinate transformation or coordinate conversion between two different coordinate reference systems. With such information, geographic data referred to different coordinate reference systems can be merged together for integrated manipulation. Alternatively an audit trail of coordinate reference system manipulations can be maintained.

OGC Abstract Specification – Topic 2: Spatial Referencing by Coordinates

1 Scope

This part of the OGC Abstract Specification defines the conceptual schema for the description of spatial referencing by coordinates, optionally extended by temporal referencing. It describes the minimum data required to define 1-, 2- and 3-dimensional coordinate reference systems with an extension to merged spatial-temporal coordinate reference systems. It allows additional descriptive information to be provided. It also describes the information required to change coordinate values from one coordinate reference system to another. It is applicable to producers and users of geographic information. Although it is applicable to digital geographic data, its principles can be extended to many other forms of geographic data such as maps, charts, and text documents.

2 Conformance

This document does not currently specify requirements for conformance to this specification, of OGC Implementation Specifications and other OGC documents. Such conformance requirements will be added to future versions of this document, as considered needed. Requirements for conformance to OGC Implementation Specifications or other documents based on the OGC Abstract Specification are specified in those documents.

3 Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

ISO 19103, *Geographic Information – Conceptual Schema Language*

ISO 19108, *Geographic Information – Temporal Schema*

ISO 19111, *Geographic Information – Spatial Referencing by Coordinates*

ISO 19114*, Geographic information – Quality Evaluation Procedures*

ISO19115, *Geographic Information – Metadata*

Guidelines for Successful OGC Interface Specifications, OGC document 00-014r1.

Normative reference to ISO 19115 is restricted as follows. ISO 19115 contains descriptions of elements of coordinate reference systems and coordinate operations, which are described in these Abstract Specifications as well as in ISO 19111. These elements are described as optional in ISO 19115, and are excluded as normative references for these Abstract Specifications.

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply. Some definitions deviate from ISO/DIS 19111, where more universally valid definitions are provided.

4.1
Cartesian coordinate system
coordinate system which gives the position of points relative to *N* mutually-perpendicular straight axes

NOTE In the context of geospatial coordinates the maximum value of N is three.

4.2
compound coordinate reference system
coordinate system describing the position of points through two or more independent coordinate reference systems

EXAMPLE One coordinate reference system can be a two-dimensional horizontal coordinate system, and the other coordinate reference system can be a vertical gravity-related height system.

4.3
concatenated transformation
sequential application of multiple transformations

4.4
coordinate
one of a sequence of *N* numbers designating the position of a point in *N*-dimensional space

NOTE In a coordinate reference system, the coordinate numbers must be qualified by units.

4.5
coordinate conversion
change of coordinates, based on a one-to-one relationship, from one coordinate reference system to another based on the same datum

EXAMPLE Between geodetic and Cartesian coordinate systems or between geodetic coordinates and projected coordinates, or change of units such as from radians to degrees or feet to metres.

NOTE A conversion uses parameters which have specified values, not empirically determined values.

4.6
coordinate reference system
coordinate system which is related to the real world by a datum

NOTE For geodetic and vertical datums, it will be related to the Earth.

4.7
coordinate system
set of (mathematical) rules for specifying how coordinates are to be assigned to points

NOTE 1 One coordinate system may be used in many coordinate reference systems.

NOTE 2 The geometric properties of a coordinate space determine how distances and angles between points are calculated from the coordinates. For example, in an ellipsoidal (2D) space distances are defined as curves on the surface of the ellipsoid, whereas in a Euclidean plane as used for projected CRS distance is the length of a straight line between two points. The mathematical rules that determine distances and angles are calculated from coordinates and vice versa are comprised in the concept of coordinate system.

4.8
coordinate transformation
computational process of converting a position given in one coordinate reference system into the corresponding position in another coordinate reference system

NOTE 1 A coordinate transformation can require and use the parameters of the ellipsoids associated with the source and target coordinate reference systems, in addition to the parameters explicitly associated with the transformation.

NOTE 2 The term 'transformation' is used only when the parameter values associated with the transformation have been determined empirically from a measurement / calculation process. This is typically the case when a change of datum is involved.

4.9
covariance matrix
matrix of elements (or cells) that contain the expected average values of the product of the error in the matrix row coordinate times the simultaneous error in the matrix column coordinate

NOTE 1 A covariance matrix is a form of detailed error estimate data. Covariance matrices are sometimes called variance-covariance matrices.

NOTE 2 All complete covariance matrices are symmetrical, meaning that the same element values appear on both sides of the diagonal elements.

NOTE 3 Covariance matrices contain information about the absolute and/or relative accuracy of the data elements (e.g. coordinates). The absolute accuracy information is contained in the diagonal matrix elements. Relative accuracy is a function of multiple diagonal and off-diagonal elements. A complete covariance matrix for N specific points in 3D space would contain 3N rows by 3N columns

EXAMPLE For three coordinates, a covariance matrix is a 3 by 3 matrix, with the matrix rows and columns each corresponding to the three coordinates. For just two horizontal coordinates, a covariance matrix is a 2 by 2 matrix, with the matrix rows and columns each corresponding to the two horizontal coordinates. Similarly, for two image coordinates, a covariance matrix is a 2 by 2 matrix, with the matrix rows and columns each corresponding to the two image coordinates.

4.10
cylindrical coordinates
3-dimensional coordinates with two distance and one angular coordinate

4.11
datum
parameter or set of parameters that determine the location of the origin, the orientation and the scale of a coordinate reference system

4.12
depth
distance of a point below a chosen reference surface usually measured along the local vertical (gravity vector).

NOTE 1 Depth is sometimes measured along a line that does not follow the vector of gravity locally. An example is depth in an oil or gas well. These are generally measured along the wellbore path, which may vary significantly from the local vertical. Some sections of a wellbore path may even run horizontally or slope upwards. Nevertheless the distance along the wellbore path is referred to as 'depth'.

NOTE 2 See elevation, ellipsoidal height, and gravity-related height.

4.13
dimension
number of ordinates needed to describe a position in a coordinate system

4.14
elevation
distance of a point from a chosen reference surface along the direction of the gravity vector from the point to that surface.

NOTE 1 See ellipsoidal height and gravity-related height. It should be noted that ellipsoidal height is defined w.r.t. an ellipsoidal model of the shape of the earth. Ellipsoidal height is measured from the point along the line perpendicular to the ellipsoid's surface.

NOTE 2 Height of a point outside the surface treated as positive; negative height is also named as depth.

4.15
ellipsoid
surface formed by the rotation of an ellipse about an axis

NOTE 1 In this document the axis of rotation is always the minor axis.

NOTE 2 Sometimes the alternative word 'spheroid' is used in geodetic or survey practice to express the same concept. Although mathematically speaking incorrect the more common term in geodetic or survey practice is 'ellipsoid'.

NOTE 3 An alternative term used in geodetic practice is 'reference ellipsoid'

4.16
ellipsoidal coordinate system
geodetic coordinate system
coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three-dimensional case) ellipsoidal height, associated with one or more geographic coordinate reference systems.

4.17
ellipsoidal height
geodetic height
distance of a point from the ellipsoid measured along the perpendicular from the ellipsoid to this point, positive if upwards or outside of the ellipsoid

NOTE Only used as part of a three-dimensional geodetic coordinate system and never on its own.

4.18
engineering coordinate reference system
a coordinate reference system that is defined for and usually used in a contextually local sense, which may be an area, significantly less than the complete surface of the earth or a moving platform and its vicinity

EXAMPLE Local engineering and architectural coordinates, grids, and drawings; also: vessel navigation systems and CRS's associated with orbiting spacecraft

NOTE 1 A transformation of engineering coordinates to geodetic coordinates may or may not be possible depending on whether such operation parameters have been determined (or defined).

NOTE 2 An Engineering CRS may be defined to describe geometry that is local to the context of a moving platform, such as a car, a ship, an aircraft or a spacecraft. Transformation of such engineering coordinates to geodetic coordinates involves time dependent operation parameters and, when repeated at (regular) time-intervals, will result in a record of the 'track' of the moving platform. Additionally such a transformation may be used for real-time navigation of the platform. The term 'vicinity of the moving platform' may constitute an area varying from the immediate surroundings of the platform to the entire earth, the latter being the case in a number of space applications.

4.19
flattening
ratio of the difference between the semi-major (a) and semi-minor axis (b) of an ellipsoid to the semi-major axis; $f = (a-b)/a$

NOTE Sometimes inverse flattening $1/f = a/(a-b)$ is given instead of flattening; $1/f$ is also known as reciprocal flattening.

4.20
geocentric coordinate reference system
3-dimensional coordinate reference system with its origin at the (approximate) centre of the Earth.

4.21
geodetic coordinates
coordinates defined in a geocentric, geographic (2D or 3D) or projected coordinate reference system.

4.22
geodetic datum
datum describing the relationship of a 3D or 2D coordinate system to the Earth

NOTE In most cases, the geodetic datum includes an ellipsoid definition.

4.23
geographic coordinate reference system
coordinate reference system using an ellipsoidal coordinate system and based on an ellipsoid that approximates the shape of the Earth

NOTE 1 A geographic coordinate system can be 2D or 3D. In a 3D geographic coordinate system, the third dimension is height above the ellipsoid surface

4.24
geographic dataset
dataset with a spatial content

4.25
geoid
level surface which best fits mean sea level either locally or globally

NOTE "Level surface" means an equipotential surface of the Earth's gravity field that is everywhere perpendicular to the direction of gravity.

4.26
gravity-related height
height dependent on the Earth's gravity field

NOTE In particular, orthometric height or normal height, which are both approximations of the distance of a point above the geoid.

4.27
Gregorian calendar
calendar in general use first introduced in 1582 to correct an error in the Julian calendar

NOTE In the Gregorian calendar, common years have 365 days and leap years 366 days divided into 12 sequential months .

4.28
Greenwich meridian
prime meridian passing through Greenwich, United Kingdom

NOTE Most geodetic datums use the Greenwich meridian as the prime meridian.

4.29
ground coordinates
earth referenced coordinates
terrestrial coordinates
coordinates of points expressed in a non-image, earth-fixed coordinate reference system

NOTE The term ground coordinates is used herein to distinguish such coordinates from image coordinates. Even when an image is collected by a near vertical camera, image coordinates are different from ground coordinates.

4.30
image
record of the likeness of any features, objects, and activities

NOTE An image can be acquired through the sensing of visual or any other segment of the electromagnetic spectrum by sensors, such as thermal infrared, and high resolution radar.

4.31
image coordinates
definition of position within an image, expressed in image row and column coordinates

4.32
image geometry model
mathematical model that specifies the mapping (or projection) from 3D ground position coordinates to the corresponding 2D image position coordinates

NOTE 1 An image geometry model is alternately called an image sensor model, sensor model, imaging model, or image mathematical model. The term “sensor” is often used when the image is generated by a digital camera and is thus originally digital. The word “camera” is usually used when the image is recorded in analogue form, normally on film. Of course, film images can be later scanned or digitised and are then “digital”.

NOTE 2 An image geometry model can also be used to determine the correct ground position for an image position, if used with additional data. When a single (or monoscopic) image is used, this additional data normally defines the shape and position of the visible ground (or object) surface. For example, this additional data is often a single elevation or is grid elevation data, sometimes called a Digital Terrain Model (DTM). Alternately, two stereoscopic images or multiple overlapping images can be used, that show the same ground point viewed from different directions. In this case, the two (or more) image geometry mathematical models can also be used, with the point coordinates in each individual image, to determine the corresponding 3D ground position.

4.33
image version
new image produced by sub-setting and/or re-sampling the pixels in an original image

4.34
interface
named set of operations that characterise the behaviour of an element

NOTE An interface standard specifies the services in terms of the functional characteristics and behaviour observed at the interface. The standard is a contract in the sense that it documents a mutual obligation between the service user and provider and assures stable definition of that obligation.

4.35
latitude
geodetic latitude
ellipsoidal latitude
angle from the equatorial plane to the perpendicular to the ellipsoid through a given point, northwards treated as positive

4.36
local datum
engineering datum
datum with a local reference, used as a basis for an engineering coordinate reference system

NOTE Engineering datum excludes both geodetic and vertical datums.

4.37
longitude
geodetic longitude
ellipsoidal longitude
angle from the prime meridian plane to the meridian plane of the given point, eastward treated as positive

4.38
map projection
conversion from a geodetic coordinate system to a planar surface

4.39
mean sea level
average level of the surface of the sea over all stages of tide

NOTE Mean sea level in a local context normally means mean sea level for the region as measured by tide gauge measurements at one or more points over a given period of time. Mean sea level in a global context differs from a global geoid by not more than 2 metres.

4.40
meridian
intersection of an ellipsoid by a plane containing the semi-minor axis of the ellipsoid

NOTE This term is often used for the pole-to-pole arc rather than the complete closed figure.

4.41
oblique Cartesian coordinate system
coordinate system with straight axes that are not necessarily mutually perpendicular

4.42
pixel
two-dimensional picture element that is the smallest non-divisible element of a digital image. In image processing, the smallest element of a digital image that can be assigned a grey level.

NOTE This term originated as a contraction for “picture element”.

4.43
polar coordinates
2-dimensional coordinates in which position is specified by distance to the origin and the direction angle

NOTE ISO/DIS 19111 does not specify the number of dimensions and therefore implicitly permits a 3-dimensional polar coordinate system to exist. The equivalent of the latter is termed "spherical coordinate system" in this document.

4.44
position
spatial reference of a point or an object

4.45
prime meridian
zero meridian
meridian from which the longitudes of other meridians are quantified

4.46
projected coordinate reference system
two-dimensional coordinate system resulting from a map projection.

NOTE A projected coordinate reference system is derived from a 2D geographic coordinate reference system by applying a parameterised coordinate transformation known as a ‘map projection’.

NOTE A projected coordinate reference system commonly uses a Cartesian coordinate system.

4.47
reference ellipsoid
ellipsoid used as the best local or global approximation of the surface of the geoid.

4.48
semi-major axis
semi-diameter of the longest axis of a reference ellipsoid.

NOTE This equates to the semi-diameter of the reference ellipsoid measured in its equatorial plane

4.49
semi-minor axis
semi-diameter of the shortest axis of a reference ellipsoid

NOTE The shortest axis coincides with the rotation axis of the reference ellipsoid and therefore contains both poles.

4.50
spherical coordinate system
3-dimensional coordinate system with one distance, measured from the origin and two angular coordinates, commonly associated with a geocentric coordinate reference system

NOTE Not to be confused with an ellipsoidal coordinate system based on an ellipsoid ‘degenerated’ into a sphere.

4.51
temporal coordinate
distance from the origin of the interval time scale used as the basis for a temporal reference system

4.52
temporal coordinate reference system
reference system against which time is measured

4.53
transformation
change of coordinates from one coordinate reference system to another coordinate reference system based on a different datum through a one-to-one relationship

NOTE A transformation uses parameter values which may have to be derived empirically by a set of points common to both coordinate reference systems. See coordinate conversion and coordinate transformation.

4.54
unit
unit of measure
defined quantity in which dimensioned parameters are expressed

NOTE In this document, the subtypes of units are length units, angular units, time units, scale units and pixel spacing units .

4.55
UTC
coordinated Universal Time
time scale maintained by the Bureau International des Poids et Mesures (International Bureau of Weights and Measures) and the International Earth Rotation Service (IERS) that forms the basis of a coordinated dissemination of standard frequencies and time signals

4.56
vertical coordinate system
1-dimensional coordinate reference system used for elevation, height, or depth measurements

4.57
vertical datum
datum describing the relation of gravity-related heights to the Earth

NOTE In most cases the vertical datum will be related to sea level. Ellipsoidal heights are treated as related to a three-dimensional ellipsoidal coordinate system referenced to a geodetic datum. Vertical datums include sounding datums (used for hydrographic purposes), in which case the heights may be negative heights or depths.

4.58
well-known
shared
data that has been completely specified and published by some recognised authority, and is accessible through use of an identifier

5 Conventions

5.1 Symbols (and abbreviated terms)

a	semi-major axis
a	addition parameter numerator in unit of measure conversion formula
b	semi-minor axis
b	multiplication parameter numerator in unit of measure conversion formula
c	addition parameter denominator in unit of measure conversion formula
d	multiplication parameter denominator in unit of measure conversion formula
C	conditional
CC	Change Coordinates (package abbreviation in UML model)
CD	Coordinate datum (package abbreviation in UML model)
CCRS	Compound coordinate reference system
CI	Citation
CRS	Coordinate reference system
CS	Coordinate system (also package abbreviation in UML model)
DQ	Data quality (package abbreviation in UML model)
E	Easting
f	flattening
h	ellipsoidal height
H	gravity-related height
ISO	International Organization for Standardization

M	mandatory
MC	Metadata Coordinates (package abbreviation in UML model)
N	Northing
O	optional
OGC	Open GIS Consortium
SC	Spatial referencing by Coordinates (package abbreviation in UML model)
SI	Le Système International d'Unités
UML	Unified Modeling Language
XML	eXtensible Markup Language
1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
λ	geodetic longitude
φ	geodetic latitude
X, Y, Z	Cartesian coordinates in a geocentric coordinate reference system
i, j, k	Cartesian coordinates in an engineering coordinate reference system, (integer or real)

5.2 UML Notation

The diagrams that appear in this standard are presented using the Unified Modeling Language (UML) static structure diagram. The UML notations used in this standard are described in Figure 1 below.

In this standard, the following stereotypes of UML classes are used:

a) <<DataType>> A descriptor of a set of values that lack identity (independent existence and the possibility of side effects). A DataType is a class with no operations whose primary purpose is to hold the information.

b) <<CodeList>> A flexible enumeration that uses string values for expressing a list of potential values.

c) <<Enumeration>> A fixed enumeration that uses string values for expressing a list of potential values.

d) <<Abstract>> A class that cannot be directly instantiated.

In this standard, the following standard data types are used:

a) CharacterString – A sequence of characters

b) Integer – An integer number

c) Real – A signed real (floating point) number consisting of a mantissa and an exponent, the length of a real is encapsulation and usage dependent.

d) DateTime – A character string, as specified by ISO/DIS 19108, that comprises year, month, day and time of the day to the appropriate level of precision.

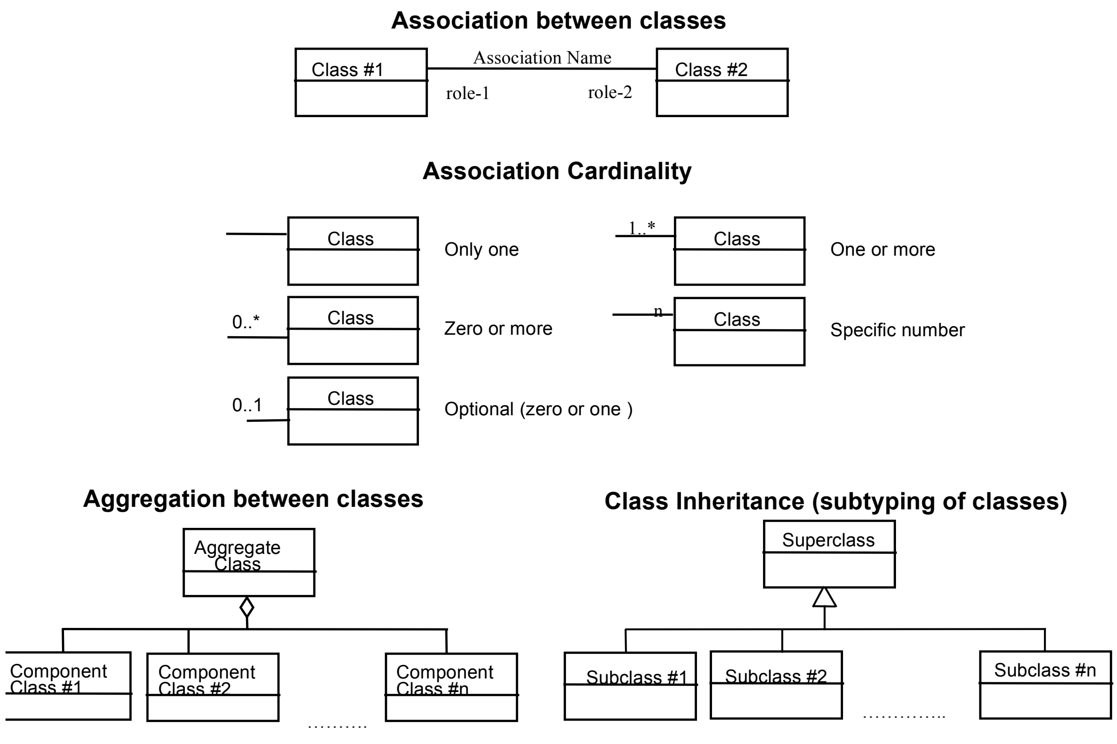

Figure 1 — UML notation

5.3 Attribute status

In the clauses below attributes are given a requirement status:

requirement	definition	comment
M	mandatory	this attribute shall be supplied.
C	conditional	this attribute shall be supplied if the condition (given in the attribute description) is true. It may be supplied if the condition is false.
O	optional	this attribute may be supplied

The Occurrence column indicates the maximum number of occurrences of attribute values that are permissible, with N indicating no upper limit. The conceptual schema for describing coordinate reference systems is modelled with the Unified Modelling Language (UML) in annex B. In case of inconsistency between the metadata textual description and the UML model (re: annex B), the textual description shall prevail. The basic data types are defined in ISO 19103.

6 Coordinates and coordinate reference systems

6.1 Coordinates

The position(s) of a feature can be described by (a set of) coordinates. Coordinates are unambiguous only when the associated coordinate reference system has been fully defined.

The geometry of spatial features might also be expressed in terms of invariant geometric quantities, viz. shapes and relative positions/orientations (strictly speaking only distance ratios and angles are invariant quantities). However, this would be unworkable: performing calculations on spatial data would become a major effort. The expression of the position of a point by coordinates introduces simplicity in terms of overview and calculus. However, there is a price to be paid for this convenience. To describe a simple shape such as a triangle in a plane six (plane) coordinates are required, whereas only a single distance ratio and an angle would suffice.

The inherent degrees of freedom (four in 2D, seven in 3D) have to be satisfied by choosing the origin of the coordinate axes, their unit of measure and the orientations of the axes. This choice underlines the fact that coordinates are human-defined quantities and not natural phenomena. Although this may seem self-evident, it is often overlooked and has consequences for the interpretation of coordinates and their error characteristics.

The choice of values for the parameters that constitute the degrees of freedom of the coordinate space is captured in the concept of *coordinate reference system*. Without the full specification of the coordinate reference system, coordinates are ambiguous at best and meaningless at worst. The fact that such a choice *must* be made, either arbitrarily or by adopting values from survey measurements, leads for example to the large number of coordinate reference systems in use around the world. It also the cause of the little understood fact that the latitude and longitude of a point are not unique.

In the context of this specification the term “coordinates” indicates the tuple of ordered scalar values that defines the position of a single point in a coordinate reference system.

The tuple is composed of one, two or three "ordinates". The ordinates must be mutually independent and their number must be equal to the dimension of the coordinate space; for example a tuple of coordinates may not contain two heights.

In this specification the term "set of coordinates" is used to indicate the coordinates of multiple points. However, it must be pointed out that usage in practice of the term "coordinates" is subject to some ambiguity. Sometimes the term "coordinate" is used to indicate the tuple; the plural "coordinates" in that case describes the coordinates of multiple points. Others use the term "set of coordinates" to describe the coordinates of a single point. In that case the term "coordinate" is sometimes used instead of "ordinate". The reader is advised to carefully infer the intended meaning from the context.

The concept of coordinates may be expanded from a strictly spatial context to include time. Time is then added as another ordinate to the coordinate tuple. It is even possible to add two time-coordinates, provided the two coordinates describe different independent quantities. An example of the latter is the time/space position of a subsurface point of which the vertical ordinate is expressed as the two-way travel time of a sound signal in milliseconds, as is common in seismic imaging. A second time-ordinate indicates the time of observation, usually expressed in whole years.

In summary: each tuple of coordinates describing the position of a point shall be related to a coordinate reference system.

Instead of supplying the definition of the coordinate reference system with every single point, coordinates may be supplied in datasets in which all coordinates shall belong to the same coordinate reference system. Each dataset shall then include one coordinate reference system description that applies to all coordinates in that dataset.

6.2 Some geodetic concepts

Geodesy is the applied science that aims to determine the size and shape of the earth. In a more practical and local sense, this may be understood to mean the determination of the relative positions of points on or near the earth's surface. Survey measurements and techniques are the means to achieve this aim.

The most accurate reference shape approximating the earth is the geoid, the surface that is defined as the locus of all points with equal gravity at mean sea level. This shape excludes topography and the effects of tides, currents and weather on the oceans and seas. Topographic heights are typically expressed relative to the geoid. The gravity vector at mean sea level is everywhere perpendicular to this surface. Due to the irregular mass distribution in the earth's interior the geoid has an irregular shape. This makes it unfortunately unsuitable to use in calculations on spatial data. Unfortunate because the familiar concept of height derives from the geoid and the geoid therefore implicitly plays an important role in all engineering and mapmaking activities. The direction of gravity also plays an important role in the mentioned survey techniques.

The geoid is approximated by the nearest regular body, an oblate spheroid, of which the oblateness corresponds to the flattening of the physical earth (and thus the geoid) at the poles due to the earth's rotation. In survey practice this spheroid is often referred to as an ellipsoid. Although mathematically the term “spheroid” is a more precise description than “ellipsoid”, the latter term will be used in this specification in preference to “spheroid”, in accordance with ISO 19111. The ellipsoid is a reasonably accurate approximation of the geoid, the latter undulating around the ellipsoid’s surface with variations only in the order of several tens of metres.

The advantage of the ellipsoid is that it is much easier to work with mathematically than the geoid. It forms the basis of the best-known type of coordinate reference systems: the Geographic CRS. The position of a point relative to the ellipsoid is then expressed by means of geographic coordinates: geodetic latitude (φ) and geodetic longitude (λ). The height (h) above the ellipsoid is of not much practical use because everyday heights are related to the geoid (gravity-related heights, indicated by H). Ellipsoidal height is an inseparable element of a 3D coordinate tuple and originates either directly from a 3D survey technique (e.g. GPS) or from the transformation of horizontal coordinates extended with a gravity-related height. See Subclause 6.5 below for this concept.

Unfortunately there is not just one ellipsoid. An ellipsoid is a matter of choice and therefore many choices are possible. The size and shape of the ellipsoid are traditionally chosen such that the surface of the geoid is matched as closely as possible locally, e.g. in a country, although a number global of best-fits are available. Each association of an ellipsoid with earth surface geometry results in the implicit choice of parameters to satisfy the degrees of freedom problem described in Subclause 6.1 above. In this case, the choice results in the definition of the origin, orientation, size, and shape of the ellipsoid. Collectively this choice is captured by the concept of “geodetic datum”.

A Geographic CRS is not suitable for mapmaking, because it describes geometry on a curved surface. It is impossible to represent such geometry in a Euclidean plane without introducing distortions. The need to control these distortions has given rise to the development of the science of map projections. Although some map projections can be represented as a geometric process, in general a map projection is a set of formulae that converts geodetic latitude and longitude to plane (map) coordinates. Height plays no role in this process, which is entirely two-dimensional.

Heights are traditionally determined separate from horizontal position in separate height networks, which is due to the different survey techniques used for the determination of horizontal and vertical geometry. Most practical heights are defined in close relationship with the gravity vector. Geodetic science distinguishes several different types of gravity-related heights. The differences between those are considered irrelevant for the purposes of this specification.

6.3 Coordinate reference system

6.3.1 Introduction

A coordinate reference system consists of a coordinate system and a datum.

The coordinate system is composed of a set of coordinate axes with specified units of measure. The concept implies the mathematical rules that define how coordinate values are calculated from distances, angles and other geometric elements and vice versa.

The datum defines the origin, orientation, and scale of the coordinate system and ties it to the earth, ensuring that the abstract mathematical concept "coordinate system" can be applied to the practical problem of describing positions of features on or near the earth's surface by means of coordinates. The datum implicitly (occasionally explicitly) contains the values chosen for the set parameters that represent the degrees of freedom of the coordinate system, as described in Subclause 6.1 above.

The high level abstract model for spatial referencing by coordinates is therefore as shown in Figure 2 below.

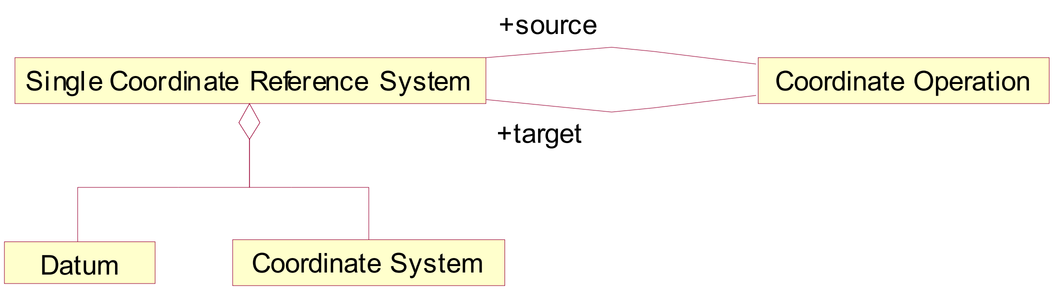

Figure 2 — High-level model for spatial referencing by coordinates

6.3.2 Kind of coordinate reference system

A coordinate reference system may be either single or compound. Single coordinate reference system is defined in 6.3.3 and compound coordinate reference system is defined in 6.3.4. The requirements for identifying the kind of the coordinate reference system shall be in accordance with Table 1.

Table 1 — Requirements for describing the kind of coordinate reference system

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Coordinate reference system kind code	kindCode	SC_KindCode	M	1	Code denoting the kind of coordinate reference system 1 — a single coordinate reference system 2 — a compound coordinate reference system
Coordinate reference system remarks	remarks	CharacterString	O	1	Comments on the coordinate reference system including source information

6.3.3 Single coordinate reference system

A coordinate reference system consists of a set of coordinate system axes that is related to the earth through a datum. A coordinate reference system is realised by a set of coordinates. The realisation is sometimes known as a reference frame.

A coordinate reference system shall be defined by one datum and by one coordinate system, see Figure 2.

For the purposes of this specification a coordinate reference system shall not change with time, with the exception of engineering coordinate reference systems defined on moving platforms such as cars, ships, aircraft and spacecraft. The intention is to exclude the option to describe the time variability of geodetic coordinate reference systems as a result of e.g. tectonic motion. This variability is part of the subject matter of geophysical and geodetic science. The model for spatial referencing by coordinates described in this specification is in principle not suitable for such zero-order geodetic problems. Such time-variability of coordinate reference systems shall be covered in the spatial referencing model described in this document by creating different coordinate reference systems, each with a different datum, for (consecutive) epochs. The date of realisation of the datum shall then be included in its definition. It is further recommended to include the date of realisation in the names of those datums and coordinate reference systems.

The requirements for describing a coordinate reference system shall be in accordance with Table 2.

Table 2 — Requirements for describing a coordinate reference system

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur -rence	Description
Coordinate reference system identifier	SRSID	RS_identifier	O	1	Identifier of the spatial (i.e. coordinate) reference system
Coordinate reference system name	CRSname	CharacterString	M	1	The name by which this coordinate system is uniquely identified
Coordinate reference system alias	alias	MC_Alias	O	N	Alternative name or identifier by which this coordinate reference system is known
Coordinate reference system type	CRSType	SC_Coordinate ReferenceSystem Type	M	1	The type of coordinate reference system.
Coordinate reference system valid area	domainOf Validity	Ex_Extent	O	1	Area for which the coordinate reference system is valid
Coordinate reference system scope	scope	CharacterString	O	1	Application for which the coordinate reference system is valid
Coordinate reference system remarks	remarks	CharacterString	O	1	Comments on or information about this coordinate reference system, including data source information

Coordinate reference systems are usually divided into sub-types. ISO 19111 does not provide any sub-typing of coordinate reference systems. This specification does provide sub-typing, because it is commonly used in geodetic survey practice and serves a clear purpose.

The common classification criterion for sub-typing of coordinate reference systems can be described as the way in which they deal with earth curvature. This has a direct effect on the portion of the earth's surface that can be covered by that type of CRS with an acceptable degree of error.

Table 3 lists the subtypes for coordinate reference system with a description how it satisfies the classification criterion. The exceptions to the rule is the subtype "Temporal", which has been added by analogy and those Engineering CRS's that are used on moving platforms such as road vehicles, vessels, aircraft and spacecraft.

Table 3 — Single coordinate reference system subtypes

CRS subtype	**Description**
Geocentric	CRS that deals with the earth's curvature by taking the 3D spatial view, which obviates the need to model the earth's curvature. The origin of a geocentric CRS is at the approximate centre of mass of the earth.
Geographic	CRS based on an ellipsoidal approximation of the geoid; this provides an accurate representation of the geometry of geographic features for a large portion of the earth's surface.
Projected	The shape of the earth's surface is approximated by a plane, but in such a way that the distortion that is inherent to the approximation is carefully controlled and known. Distortion correction is commonly applied to calculated bearings and distances to produce values that are a close match to actual field values.
Engineering	Contextually local CRS; which can be divided into two broad categories: - earth-fixed systems, applied to engineering activities on or near the surface of the earth; - CRSs on moving platforms such as road vehicles, vessels, aircraft or spacecraft. Earth-fixed Engineering CRSs are commonly based on a simple flat-earth approximation of the earth's surface, and the effect of earth curvature on feature geometry is ignored: calculations on coordinates use simple plane arithmetic without any corrections for earth curvature. The application of such Engineering CRSs to relatively small areas and "contextually local" is in this case equivalent to "spatially local". Engineering CRSs used on moving platforms are usually intermediate CRSs that are computationally required to calculate geodetic coordinates. These CRSs are subject to all the motions of the platform with which they are associated. In this case "contextually local" means that the associated coordinates are meaningful only relative to the moving platform. In the spatial sense their applicability may extend from the immediate vicinity of the platform (e.g. a moving seismic ship) to the entire earth (e.g. in space applications). The determining factor is the mathematical model deployed in the positioning calculations. Transformation of coordinates from these moving Engineering CRSs to an earth-referenced CRSs involves time-dependent coordinate operation parameters, which can be accommodated by the abstract model described in this document.
Image	Engineering coordinate reference systems applied to images. Image SRSs warrant treatment as a separate sub-type because a separate user community exists for images with its own vocabulary.
Vertical	Used for the recording of heights or depths. Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but its relationship with gravity may not be straightforward. By implication ellipsoidal heights (*h*) cannot be captured in a vertical coordinate reference system. Ellipsoidal heights cannot exist independently, but only as inseparable part of a 3D coordinate tuple defined in a geographic 3D coordinate reference system.
Temporal	Used for the recording of time.

6.3.4 Compound coordinate reference system

The traditional separation of horizontal and vertical position has resulted in coordinate reference systems that are horizontal (2D) in nature and vertical (1D). It is established practice to combine the horizontal coordinates of a point with a height or depth from a different coordinate reference system.

The coordinate reference system to which these 3D coordinates are referenced is composed of the separate horizontal and vertical coordinate reference systems of the horizontal and vertical coordinates. Such a coordinate system is called a compound coordinate reference system (CCRS). It consists of an ordered sequence of the two or more single coordinate reference systems. An example is provided in Figure 3.

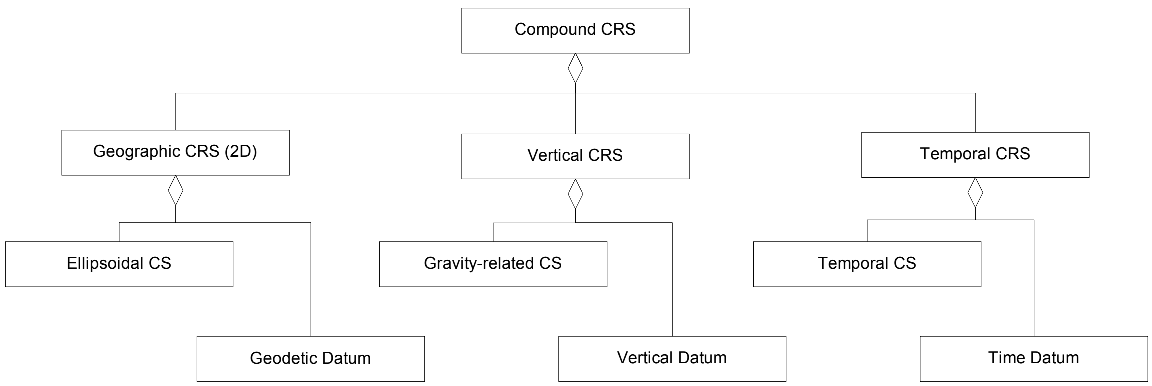

Figure 3 — Example of a compound coordinate reference system

A compound coordinate reference system is thus a coordinate reference system that combines two or more coordinate reference systems, none of which can themselves be compound. In general, a compound coordinate reference system may contain any number of axes.

For spatial coordinates, a number of constraints exist for the construction of compound coordinate reference systems. For example, the coordinate reference systems that are combined should not contain any duplicate or redundant axes. Valid combinations include:

– Geographic 2D + Vertical

– Geographic 2D + Engineering 1D (near vertical)

– Projected + Vertical

– Projected + Engineering 1D (near vertical)

– Engineering (horizontal 2D or 1D linear) + Vertical

Any coordinate reference system, or any of the above listed combinations of coordinate reference systems, can have a temporal coordinate reference system added. More than one temporal coordinate reference system may be added if these axes represent different time quantities. For example, the oil industry sometimes uses “4D seismic”, by which is meant seismic data with the vertical axis expressed in milliseconds (signal travel time). A second time axis indicates how it changes with time (years), e.g. as a reservoir is gradually exhausted of its recoverable oil or gas).

The requirements for describing a compound coordinate reference system shall be in accordance with Table 4.

Table 4 — Requirements for describing a compound coordinate reference system

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Compound coordinate reference system identifier	SRSID	RS_identifier	O	1	Identifier of the compound coordinate reference system.
Compound coordinate reference system name	CRSName	CharacterString	M	1	The name by which this compound coordinate reference system is identified
Compound coordinate reference system alias	alias	MC_Alias	O	N	Alternative name or identifier by which this compound coordinate reference system is known
Compound coordinate reference system valid area	domainOf Validity	Ex_Extent	O	1	Area for which the compound coordinate reference system is valid
Compound coordinate reference system scope	scope	CharacterString	O	1	Application for which the compound coordinate reference system is valid
Compound coordinate reference system remarks	remarks	CharacterString	O	1	Comments on or information about this compound coordinate reference system, including data source information

Each of the two coordinate reference systems shall be described in accordance with requirements in Table 2 above.

6.4 Coordinate system

Each of the two coordinate reference systems shall be described in accordance with requirements in Table 2 above.

6.4 Coordinate system

The coordinates of points are recorded in a coordinate system. A coordinate system is the set of coordinate system axes that spans the coordinate space. This concept implies the set of mathematical rules that determine how coordinates are associated with invariant quantities such as angles and distances[1]. In other words: a coordinate system implies how

1) The word ‘distances’ is used loosely in this description. Strictly speaking distances are not invariant quantities, as they are expressed in the unit of measure defined for the coordinate system; ratios of distances are invariant.

coordinates are calculated from geometric elements such as distances and angles and vice versa. The calculus required to derive angles and distances from point coordinates and vice versa is in a map plane is simple Euclidean 2D arithmetic. To do the same on the surface of an ellipsoid (curved 2D space) involves more complex ellipsoidal calculus. These rules cannot be specified in detail, but are implied in the geometric the properties of the coordinate space.

One coordinate system may be used by multiple coordinate reference systems. Its axes can be spatial, temporal, or mixed.

The dimension of the coordinate space, the names, the units of measure, the directions and sequence of the axes are recorded in 'Coordinate system'. Coordinates in coordinate tuples must be listed according to the defined axes sequence. The number of coordinates in a tuple and the number of axes in a coordinate system shall be equal to the specified dimension of the coordinate system.

Coordinate systems are divided in subtypes by the geometric properties of the coordinate space spanned and the geometric properties of the axes themselves (straight or curved; perpendicular or not). Certain subtypes of coordinate system can only be used with specific subtypes of coordinate reference system. A description of coordinate system subtypes is provided in Table 5. The constraints on their usage are also shown in Figure 4.

Table 5 — Subtypes of coordinate system and constraints in its relationship with coordinate reference system

CS subtype	Description	Used with CRS type
Cartesian	1-, 2-, or 3-dimensional coordinate system. It gives the position of points relative to orthogonal straight axes in the 2- and 3-dimensional cases. In the 1-dimensional case, it contains a single straight coordinate axis. In the multi-dimensional case, all axes shall have the same unit of measure.	Geocentric Projected Engineering Image
oblique Cartesian	Coordinate system with straight axes that are not necessarily orthogonal	Engineering Image
ellipsoidal	2- or 3-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three-dimensional case) ellipsoidal height, associated with one or more geographic coordinate reference systems.	Geographic Engineering
spherical	3-dimensional coordinate system with one distance, measured from the origin, and two angular coordinates. Not to be confused with an ellipsoidal coordinate system based on an ellipsoid ‘degenerated’ into a sphere	Geocentric Engineering
cylindrical	3-dimensional coordinate system consisting of a polar coordinate system extended by a straight coordinate axis perpendicular to the plane spanned by the polar coordinate system.	Engineering
polar	2-dimensional coordinate system in which position is specified by distance to the origin and the angle between the line from origin to point and a reference direction. Note: ISO 19111 does not specify the number of dimensions and therefore implicitly permits a 3-dimensional polar coordinate system to exist. The equivalent of the latter is termed "spherical coordinate system" in this Abstract Specification.	Engineering

CS subtype	Description	Used with CRS type
gravity-related	1-dimensional coordinate system used to record the heights (or depths) of points dependent on the Earth's gravity field. An exact definition is deliberately not provided as the complexities of the subject fall outside the scope of this specification.	Vertical Engineering
multi-linear	Coordinate system containing one or more coordinate system axes that may have any shape that has no intersections with itself. This/these axes may be supplemented by one or two straight axes to complete a 2 or 3 dimensional coordinate system. The non-straight axes are typically incrementally straight or curved. In the one-dimensional case only the position of points that lie on this axis can be described. The associated ordinate is the distance from the specified origin to the point along the axis. Example: usage of the line feature representing a road to describe points on or along that road. In the multidimensional case it must be specified how the axes intersect and how the position of a point is defined. An example is a 2-dimensional coordinate system that can be used to describe points along a river, based on one linear axis following the river centre line. A point in 2d space can be defined by the distance along the river centre line from the origin and the perpendicular offset from the centre line. The positive direction needs to be specified as with other multi-dimensional coordinate systems.	Engineering
temporal	1-dimensional coordinate system containing a single time axis and used to describe the temporal position of a point in the specified time units from a specified time origin.	Temporal

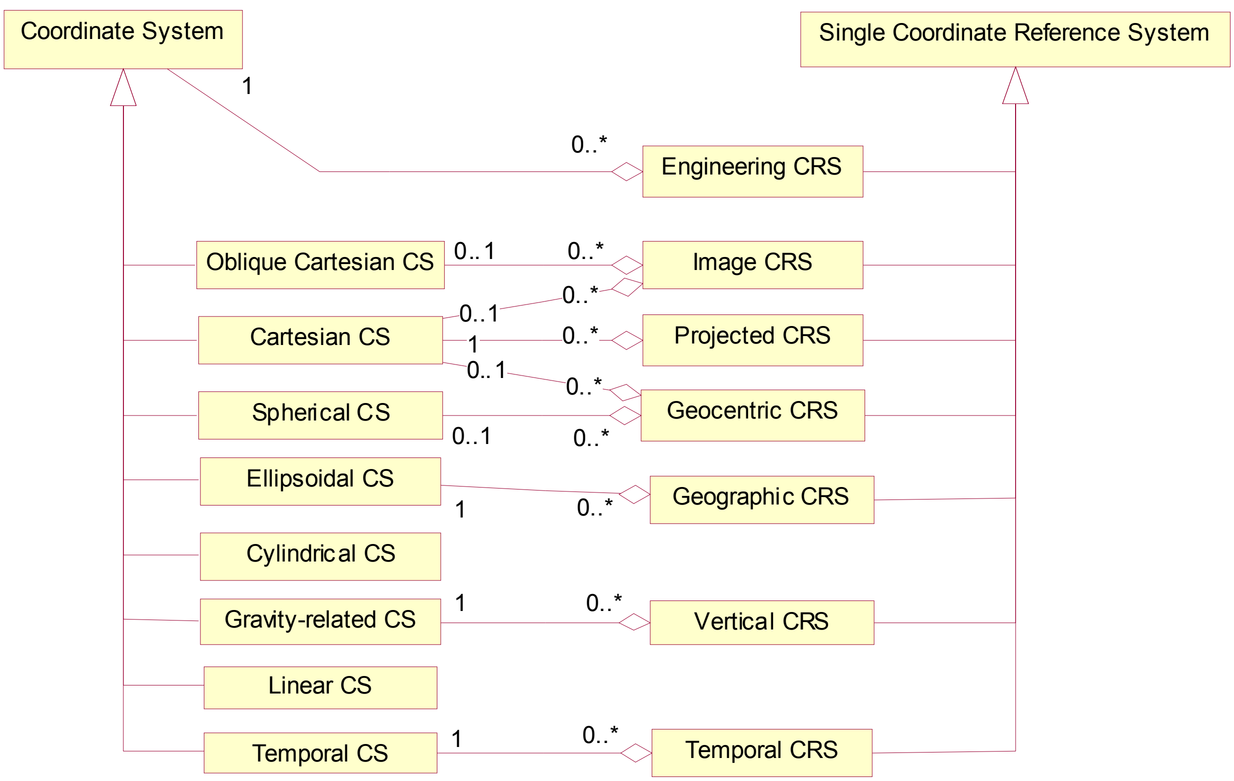

Figure 4 — Relationship constraints between coordinate reference system and coordinate system

The requirements for describing a coordinate system shall be in accordance with Tables 6 and 7.

Table 6 — Requirements for describing a coordinate system

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur -rence	Description
Coordinate system identifier	CSID	RS_identifier	O	1	Identifier of the coordinate system.
Coordinate system name	CSname	CharacterString	M	1	The name by which this coordinate system is identified
Coordinate system type	type	SC_Coordinate SystemType	M	1	Type of the coordinate system, identifying the coordinate axes and coordinate space geometry.
Coordinate system dimension	dimension	Integer	M	1	Number of coordinates {3,2,1} in the coordinate tuple
Coordinate system remarks	remarks	CharacterString	O	1	Comments on or information about the coordinate system, including data source information

6.5 Coordinate system axis

Each coordinate system axis[2)] shall be described, the order of each axis description following the order of the coordinates in the dataset. The elements for each coordinate system axis, as described in Table 7, shall be kept together (as in a data block), and the number of data blocks shall be equal to the value provided for coordinate system dimension in Table 6.

Usage of coordinate system axis names is constrained by geodetic custom in a number of cases, depending mainly on the coordinate reference system type. These constraints are shown in Table 8 below. This constraint works in two directions; for example the names ‘geodetic latitude’ and ‘geodetic longitude’ shall be used to designate the coordinate axis names associated with a geographic coordinate reference system. Conversely, these names shall not be used in any other context.

Image and engineering coordinate reference systems may make use of names specific to the local context or custom and are therefore not included as constraints in the above list.

---

2) The concept 'coordinate system axis' as a constituting part of a coordinate system should be interpreted to mean the definition of the relevant coordinate. That definition can be associated with an axis only with Cartesian coordinate systems. The *x*-axis in an arbitrary *x,y,z* coordinate system is defined as the locus of points with *y*=*z*=0. In the case of coordinate systems that make use of angular coordinates this concept may lead to confusion. An ellipsoidal coordinate system is said to be composed of a Latitude axis and a Longitude axis. By definition the Latitude axis would be the locus of points for which Longitude = 0, in other words the Prime Meridian!

A coordinate system shall contain the number of coordinate system axes defined by its dimension attribute. Each of its axes is completely characterised by a unique combination of axis name, axis abbreviation, axis direction and axis unit of measure.

Example: The combination {Latitude, Lat, north, degree} would lead to one instance of the object class 'coordinate system axis'; the combination {Latitude, φ, north, degree} to another instance, the axis abbreviation being different.

Table 7 — Requirements for describing a coordinate system axis

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur -rence	Description
Coordinate system axis identifier	axisID	RS_identifier	O	1	Identifier of the coordinate system axis.
Coordinate system axis name	axisName	CharacterString	M	1	Name of the coordinate system axis.
Coordinate system axis direction	axisDirection	CharacterString	M	1	Direction of the coordinate system axis (or, in the case of Cartesian or projected coordinates, the direction of the coordinate system axis at the origin) Example: north or south, east or west, up or down Within any set of coordinate system axis, only one of each pair of terms can be used.
Coordinate system axis unit identifier	axisUnitID	UnitOf Measure	M	1	Identifier of the unit for the coordinate system axis
Coordinate system axis abbreviation	axisAbbrev	CharacterString	M	1	The abbreviation used for this coordinate system axes; this abbreviation is also used to identify the ordinates in coordinate tuple. Examples are X and Y.

Table 8 — Some naming constraints for coordinate system axis

CS	CRS	Permitted coordinate system axis names
Cartesian	Geocentric	Geocentric X, Geocentric Y, Geocentric Z
Spherical	Geocentric	Spherical Latitude, Spherical Longitude, Geocentric Radius
Ellipsoidal	Geographic	Geodetic Latitude, Geodetic Longitude, Ellipsoidal height (if 3D)
Gravity-related	Vertical	Gravity-related height
Gravity-related	Vertical	Depth
Cartesian	Projected	Easting, Northing
Cartesian	Projected	Westing, Southing

6.6 Datum

6.6.1 Types of datums

A datum specifies the relationship of a coordinate system to the earth, thus creating a coordinate reference system, and can be used as the basis for two- or three-dimensional systems. Five subtypes of datum are specified: geodetic, vertical, engineering, image and temporal.

Each datum subtype can be associated only with specific types of coordinate reference systems. A geodetic datum is used with three-dimensional or horizontal (two-dimensional) coordinate reference systems, and normally requires an ellipsoid definition and a prime meridian definition. A vertical datum can only be associated with a vertical coordinate reference system. Image datum and engineering datum are both used in a local context only: to describe the origin of an image and the origin of an engineering (or local) coordinate reference system.

6.6.2 Datum description

If a coordinate reference system citation is not supplied, then a datum description in accordance with Table 9, Table 10 or Table 11 shall be supplied.

Table 9 — Requirements for describing a geodetic and engineering datum

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Datum identifier	datumID	RS_identifier	O	1	Identifier of the datum
Datum name	datumName	CharacterString	M	1	The name by which this datum is identified
Datum alias	alias	MC_Alias	O	N	Alternative name or names by which this datum is known
Datum anchor point	anchorPoint	CharacterString	O	1	Description, possibly including coordinates, of the point or points used to anchor the datum to the Earth. Also known as Fundamental Point in case of a geodetic datum
Datum realization epoch	realization Epoch	Date	O	1	Epoch of realization of the datum
Datum valid area	validArea	Ex_Extent	O	1	Area for which the datum is valid
Datum scope	scope	CharacterString	O	1	Application for which the datum is valid
Datum remarks	remarks	CharacterString	O	1	Comments on the datum including data source information

Table 10 — Requirements for describing a vertical datum

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Datum identifier	datumID	RS_identifier	O	1	Identifier of the datum
Datum name	datumName	CharacterString	M	1	The name by which this datum is identified
Vertical datum type	vertDatum Type	CharacterString	M	1	Type of vertical datum. Permitted values are: - geoidal (default) - depth - barometric
Datum alias	alias	MC_Alias	O	N	Alternative name or names by which this datum is known
Datum anchor point	anchorPoint	CharacterString	O	1	Description, possibly including coordinates, of the point or points used to anchor the datum to the Earth.
Datum realization epoch	realization Epoch	Date	O	1	Epoch of realization of the datum
Datum valid area	validArea	Ex_Extent	O	1	Area for which the datum is valid
Datum scope	scope	CharacterString	O	1	Application for which the datum is valid
Datum remarks	remarks	CharacterString	O	1	Comments on the datum including source information

Geoidal: The zero value of the associated (vertical) coordinate system axis is defined to approximate a constant potential surface, usually the geoid. Such a reference surface is usually determined by a national or scientific authority and is then a well-known, named datum.

Depth: The zero point of the vertical axis is defined by a surface that has meaning for the purpose the associated vertical measurements are used for. For hydrographic charts, this is often a predicted nominal sea surface (i.e. without waves or other wind and current effects) that occurs at low tide. Examples are Lowest Astronomical Tide and Lowest Low Water Spring. A different example is a sloping and undulating River Datum defined as the nominal river water surface occurring at a quantified river discharge.

Barometric: A vertical datum is of type "barometric" if atmospheric pressure is the basis for the definition of the origin.

> Atmospheric pressure may be used as the intermediary to determine height (barometric height determination) or it may be used directly as the vertical ordinate, against which other parameters are measured. The latter case is applied routinely in meteorology.
>
> Barometric height determination is routinely used in aircraft. The altimeter (barometer) on board is set to the altitude of the airfield at the time of take-off, which corrects simultaneously for instantaneous air pressure and altitude of the airfield. The measured height value is commonly named "altitude".
>
> In some land surveying applications height differences between points are measured with barometers. To obtain absolute heights the measured height differences are added to the known heights of control points. In that case the vertical datum type is not barometric, but is the same as that of the vertical control network used to obtain the heights of the new points and its vertical datum type.
>
> The accuracy of this technique is limited, as it is affected strongly by the spatial and temporal variability of atmospheric pressure. This accuracy limitation impacts the precision of the associated vertical datum definition. The datum is usually the surface of constant atmospheric pressure approximately equating to mean sea level (MSL). The origin or anchor point is usually a point of known MSL height. The instruments are calibrated at this point by correcting for the instantaneous atmospheric pressure at sea level and the height of the point above MSL.
>
> In meteorology, atmospheric pressure routinely takes the role as vertical ordinate in a CRS that is used as a spatial reference frame for meteorological parameters in the upper atmosphere. The origin of the datum is in that case the (hypothetical) zero atmospheric pressure and the positive vertical axis points down (to increasing pressure).

Other surface: In some cases, e.g. oil exploration and production, geological features, i.e. the top or bottom of a geologically identifiable and meaningful subsurface layer, are sometimes used as a vertical datum. Other variations to the above three vertical datum types may exist and are all bracketed in this category.

The requirements for describing a temporal datum shall be in accordance with Table 11.

Table 11 — Requirements for describing an image datum

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Datum identifier	datumID	RS_identifier	O	1	Identifier of the datum
Datum name	datumName	CharacterString	M	1	The name by which this datum is identified
Datum alias	alias	MC_Alias	O	N	Alternative name or names by which this datum is known
Datum anchor point	point	CharacterString	M	1	Position of the origin (0,0) of the image coordinates. Permitted values are: - Image centre - Image corner
Pixel in cell	PixelinCell	CharacterString	M	1	Specification of the way the image grid is associated with the image data attributes. Permitted values are: - Cell centre - Cell corner
Datum realization epoch	realizationEpoch	Date	O	1	Epoch of realization of the datum
Datum valid area	validArea	Ex_Extent	O	1	Area for which the datum is valid
Datum scope	scope	CharacterString	O	1	Application for which the datum is valid
Datum remarks	remarks	CharacterString	O	1	Comments on the datum including source information

The image grid is defined as the set of lines of constant integer ordinate values. The term “image grid” is often used in other standards to describe the concept of Image CRS. However, care must be taken to correctly interpret this term in the context in which it is used. The term “grid cell” is often used as a substitute for the term “pixel”.

The grid lines of the image may be associated in two ways with the data attributes of the pixel or grid cell (ISO CD 19123). The data attributes of the image usually represent an average or integrated value that is associated with the entire pixel.

An image grid can be associated with this data in such a way that the grid lines run through the centres of the pixels. The cell centres will thus have integer coordinate values. In that case the attribute “pixel in cell” will have the value “cell centre”.

Alternatively the image grid may be defined such that the grid lines associate with the cell or pixel corners rather than the cell centres. The cell centres will thus have non-integer coordinate values, the fractional parts always being 0.5. ISO CD 19123 calls the grid points in this latter case “posts” and associated image data: “matrix data”. The attribute “pixel in cell” will now have the value “cell corner”.

This difference in perspective has no effect on the image interpretation, but is important for coordinate transformations involving this defined image.

The requirements for describing a temporal datum shall be in accordance with Table 12.

Table 12 — Requirements for describing a temporal datum

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Datum identifier	datumID	RS_identifier	O	1	Identifier of the datum
Datum name	datumName	CharacterString	M	1	The name by which this datum is identified
Datum alias	alias	MC_Alias	O	N	Alternative name or names by which this datum is known
Datum anchor point	anchorPoint	CharacterString	O	1	Description, possibly including coordinates, of the point or points used to anchor the datum to the Earth.
Time origin	Origin	DateTime	M	1	The year, month, day and time of day used as the origin of the temporal CRS with which this datum is associated
Datum realization epoch	realizationEpoch	Date	O	1	Epoch of realization of the datum
Datum valid area	validArea	Ex_Extent	O	1	Area for which the datum is valid
Datum scope	scope	CharacterString	O	1	Application for which the datum is valid
Datum remarks	remarks	CharacterString	O	1	Comments on the datum including source information

6.7 Prime meridian

A prime meridian defines the origin from which longitude values are specified. Most geodetic datums use Greenwich as their prime meridian. A prime meridian description is not needed if the datum type other than geodetic, or if the datum type is geodetic and the prime meridian is Greenwich.

The prime meridian description shall be mandatory if the datum type is geodetic and its prime meridian is not Greenwich and if neither coordinate reference system citation nor datum citation is supplied.

The requirements for describing a prime meridian shall be in accordance with Table 13.

Table 13 — Requirements for describing a prime meridian

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Prime meridian identifier	meridianID	RS_identifier	O	1	Identifier of the prime meridian.
Prime meridian name	meridianName	CharacterString	M	1	The name by which this prime meridian is identified
Prime meridian Greenwich longitude	Greenwich Longitude	MC_Angle	C	1	Longitude of the prime meridian measured from the Greenwich meridian, positive eastward. If the datum type is geodetic and the prime meridian name is not supplied then the prime meridian name is taken to be "Greenwich" and the prime meridian Greenwich longitude is taken to be "0°".
Prime meridian remarks	remarks	CharacterString	O	1	Comments on the prime meridian including data source information

6.8 Ellipsoid

An ellipsoid specification shall not be provided if the datum type is vertical or engineering and neither coordinate reference system citation nor datum citation is supplied. The requirements for describing an ellipsoid shall be in accordance with Table 14.

Table 14 — Requirements for describing an ellipsoid

Element name	UML identifier	Data type	Obliga-tion	Maximum Occurrence	Description
Ellipsoid identifier	ellipsoidID	RS_identifier	O	1	Identifier of the ellipsoid for the datum.
Ellipsoid name	ellipsoidName	CharacterString	M	1	The name by which this ellipsoid is identified
Ellipsoid alias	alias	MC_Alias	O	N	Alternative name or names of the ellipsoid
Ellipsoid semi-major axis	semiMajorAxis	MC_Length	M	1	Length of the semi-major axis of the ellipsoid. Condition described below
Ellipsoid remarks	remarks	CharacterString	O	1	Comments on or information about the ellipsoid including data source information

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Ellipsoid semi-minor axis	semiMinorAxis	MC_Length	C	1	Length of the semi-major axis of the ellipsoid. Condition described below
Ellipsoid inverse flattening	inverseFlattening	MC_Scale	C	1	Inverse flattening of the ellipsoid. Condition described below
Ellipsoid shape	isSphere	CharacterString	C	1	This attribute has a fixed value of "sphere". Condition described below
Condition: Only one of the three elements marked by a conditional obligation in Table 13 should be supplied. For an ellipsoid, the second defining parameter is either the inverse flattening or the semi-minor axis. The element Ellipsoid shape has a fixed value of "sphere', indicating, when used, that a sphere rather than an ellipsoid is used as reference surface. The sphere is completely defined by the semi-major axis, which in that case will be equal to the radius of the sphere.					

7. Coordinate operation

7.1 General

Coordinates are unambiguous only when the coordinate reference system to which those coordinates are related has been fully defined.

If the relationship between any two coordinate reference systems is known, coordinates can be transformed or converted to another coordinate reference system. The abstract model therefore specifies a source and target coordinate reference system for such operations[3]. For that reason a coordinate operation is often popularly said to operate between coordinate reference systems. Although this may be good enough for conversation, it should be realised that coordinate operations do not operate on coordinate reference systems, but on coordinates. This is important for the design of implementation specifications because it implies that coordinate reference systems cannot be 'created' from another coordinate reference system by a coordinate operation. Neither can a coordinate operation be used to modify the definition of a coordinate reference system, e.g. by converting the units of measure of the coordinates.

Coordinate operations are divided into two subtypes:

Coordinate conversion – mathematical operation on coordinates that does not include any change of Datum. The best-known example of a coordinate conversion is a map projection. The parameters describing coordinate conversions are defined rather than empirically derived. Note that some conversions have no parameters.

Coordinate transformation – mathematical operation on coordinates that usually includes a change of Datum. The parameters of a coordinate transformation are empirically

[3] There is an exception to this rule, viz. "defining coordinate conversions". This exception is described in Subcaluse 7.2 below.

derived from data containing the coordinates of a series of points in both coordinate reference systems. This computational process is usually 'over-determined', allowing derivation of error (or accuracy) estimates for the transformation. Also, the stochastic nature of the parameters may result in multiple (different) versions of the same coordinate transformation.

The requirements for describing a coordinate operation shall be in accordance with Table 15.

Table 15 — Requirements for describing a coordinate operation

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Coordinate operation identifier	coordinateOperationID	RS_identifier	O	1	Identifier of the coordinate operation
Coordinate operation name	coordinateOperationName	CharacterString	M	1	The name by which this coordinate operation is identified.
Coordinate operation alias	alias	MC_Alias	O	N	Alternative name or names of the coordinate operation
Coordinate operation valid area	validArea	Ex_Extent	O	1	Area for which the coordinate operation is valid
Coordinate operation version	version	CharacterString	C	1	Version of the coordinate transformation (i.e. instantiation due to the stochastic nature of the parameters). Condition: Mandatory only when describing a coordinate transformation.
Coordinate operation scope	scope	CharacterString	O	1	Application for which the coordinate operation is valid
Coordinate operation remarks	remarks	CharacterString	O	1	Comments on the coordinate operation including source information
Source dimensions	sourceDimensions	Integer	M	1	Required dimension for the source CRS
Target dimensions	targetDimensions	Integer	M	1	Required dimension for the target CRS
Position error estimates	positionErrorEstimates	DQ_PositionalAccuracy	O	1	Estimate of the impact of this operation on point accuracy

7.2 Coordinate conversions

Coordinate conversions are coordinate operations that make use of exact, defined (rather than measured or computed), and therefore error-free parameter values. The relationship between the two coordinate reference systems, related through a coordinate conversion is therefore fixed, whereby one of the two systems cannot exist without the coordinate conversion and the 'source' coordinate reference system being defined. Projected coordinate reference systems are the best-known example, being based on a source geographic coordinate reference system. The associated map projection effectively defines the projected coordinate reference system from the geographic coordinate system.

This concept is modelled in Figure B.3 as a direct link between coordinate reference system and coordinate conversion.

Please note that this does not contradict the statement in the second paragraph above that a coordinate operation cannot be used to create or modify a coordinate reference system in a software implementation. The text above describes a static source-result relationship between two coordinate reference systems. For such defining coordinate conversions, no source and target coordinate reference system are defined. The usage of such a coordinate conversion is in the coordinate reference system, which will point to that conversion and to its source coordinate reference system.

7.3 Concatenated coordinate operation

A concatenated coordinate operation is an ordered series of coordinate operations. The sequence of operations is constrained by the requirement that the source coordinate reference system of step ($n+1$) must be the same as the target coordinate reference system of step (n).

The source coordinate reference system of the first step and the target coordinate reference system of the last step are the source and target coordinate reference system associated with the concatenated operation.

The above constraint should not be interpreted as implying that only those coordinate operations can be used in a concatenated operation that have their source and a target coordinate reference system specified through the association pair between CC_CoordinateOperation and SC_CRS (see Figure A.3 in Annex A). This would exclude coordinate conversions. Concatenated coordinate operations may contain coordinate transformations and/or coordinate conversions.

The source and target coordinate reference system of a coordinate conversion are defined by the self-reference association of the SC_CoordinateReferenceSystem class. When used in a concatenated operation, the conversion's source and target coordinate reference system are equally subject to the above constraint as the source and target of a transformation although they are specified in a different manner.

The concatenated coordinate operation class is primarily intended to provide a mechanism that forces application software to use a preferred path to go from source to target coordinate reference system if a direct transformation between the two is not available.

7.4 The derivation of coordinate operations from other coordinate operations

Coordinate transformation services should be able to automatically derive coordinate operations that are not stored explicitly in any permanent data store, in other words determine their own concatenated operations. The reason is that is practically impossible to store all possible pairs of coordinate reference systems in an explicitly defined coordinate operation. The key to a successful software implementation is the ability to apply meaningful constraints and validations to this process. For example: it may be mathematically possible to derive a concatenated coordinate operation that will transform North American Datum 1983 coordinates to Australian National Datum; in a practical sense that operation would be meaningless. The key validation that would flag such an operation as invalid would be a comparison of the two areas of validity.

Coordinate transformation services should also be able to derive or infer the inverse of any coordinate operation (from 'B' to 'A') from its complementary forward operation ('A' to 'B'). Most permanent data stores for coordinate reference parameter data will record only one of the two operations that may exist between any two coordinate reference systems. The inverse operation is then inferred by the application software logic from the stored operation.

In some cases the algorithm for the inverse operation is the same as the forward algorithm and only the signs of the parameter values need to be reversed for the inverse operation to be fully defined. An example is the 7-parameter Helmert transformation (both position vector and coordinate frame rotation convention).

Some polynomial coordinate operations require the signs of only most, but not all, parameter values to be reversed. Other coordinate operation methods (see 7.5 below) imply two algorithms, one for the forward and one for the inverse operation. The parameters are generally the same in that case. The latter situation generally applies to map projections.

Finally the same algorithm may be used for the inverse operation, with entirely different parameter values. This is the case with some polynomial and affine operations. In those cases the inverse operation cannot be inferred from the forward operation but must be explicitly defined.

The logic to derive the inverse transformation should be built into the application software, be it server or client, that performs the coordinate operation.

The requirements for describing a concatenated operation shall be in accordance with Table 16 below.

Table 16 — Requirements for describing a concatenated coordinate operation

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Concatenated coord. operation identifier	coordinateOperationID	RS_identifier	O	1	Identifier of the concatenated operation
Concatenated coord operation name	coordinateOperationName	CharacterString	M	1	The name by which this concatenated operation is identified.
Coordinate operation alias	alias	MC_Alias	O	N	Alternative name or names of the concatenated operation
Concatenated coordinate operation valid area	validArea	Ex_Extent	O	1	Area for which the concatenated operation is valid
Concatenated coordinate operation version	version	CharacterString	C	1	Version of the concatenated operation (i.e. instantiation due to the stochastic nature of the parameters). Condition: Mandatory if one or more coordinate transformations are included in this concatenated operation.
Concatenated coordinate operation scope	scope	CharacterString	O	1	Application for which the concatenated operation is valid
Concatenated coordinate operation remarks	remarks	CharacterString	O	1	Comments on the concatenated operation including source information
Source dimensions	sourceDimensions	Integer	M	1	Required dimension for the source CRS
Target dimensions	targetDimensions	Integer	M	1	Required dimension for the target CRS
Position error estimates	positionErrorEstimates	DQ_PositionalAccuracy	O	1	Estimate of the impact of this operation on point accuracy

7.5 Pass-through coordinate operation

Coordinate operations require input coordinate tuples of certain dimensions and produce output tuples of certain dimensions. The dimensions of these coordinate tuples and the dimensions of the coordinate reference system they are defined in must be the same.

The ability to define compound coordinate reference systems from two or more other coordinate reference systems, not themselves compound, introduces a difficulty. It may be required to transform only the horizontal or only the vertical component of a compound coordinate reference system, which will put them at odds with coordinate operations specified for either horizontal or vertical coordinates only. To the human mind this is a trivial problem, but not so for coordinate transformation software that ought to be capable of automatic operation, without human intervention: the software logic would be confronted with the problem of having to apply a 2-dimensional coordinate operation to 3-dimensional coordinate tuples.

This problem can be solved by defining a pass-through operation. This specifies what subset of a coordinate tuple is subject to a requested transformation. It takes the form of a sequence of numbers defining the positions in the coordinate tuple of the coordinates affected by the transformation. The order of the coordinates in a coordinate tuple should agree with the order of the coordinate system axes as defined for the associated coordinate system.

The requirements for describing a pass-through operation shall be in accordance with Table 17 below.

Table 17 — Requirements for describing a pass-through operation

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur -rence	Description
Pass-through operation identifier	coordinateOperationID	RS_identifier	O	1	Identifier of the pass-through coordinate operation
Pass-through operation name	coordinateOperationName	CharacterString	M	1	The name by which this pass-through operation is identified.
Pass-through operation alias	alias	MC_Alias	O	N	Alternative name or names of the pass-through coordinate operation
Pass-through operation valid area	validArea	Ex_Extent	O	1	Area for which the coordinate operation is valid
Pass-through operation version	version	CharacterString	C	1	Version of the coordinate transformation (i.e. instantiation due to the stochastic nature of the parameters). Condition: Mandatory when describing a coordinate transformation only.
Pass-through operation scope	scope	CharacterString	O	1	Application for which the coordinate operation is valid
Pass-through operation remarks	remarks	CharacterString	O	1	Comments on the coordinate operation, including source information
Source dimensions	sourceDimensions	Integer	M	1	Required dimension for the source CRS. This includes the ordinates that are not modified.
Target dimensions	targetDimensions	Integer	M	1	Required dimension for the target CRS. This includes the ordinates that are not modified.
Modified coordinates	modifiedCoordinates	Sequence<Integer>	M	1	The sequence of coordinates in the coordinate tuple affected by the transformation. This sequence (i.e. order) must match the definition of the coordinate system of the source CRS.
Position error estimates	positionErrorEstimates	DQ_PositionalAccuracy	O	1	Estimate of the impact of this operation on point accuracy
Note: The Coordinate operation alias, Coordinate operation valid area, and Coordinate operation version (inherited) elements are optional or conditional, but will normally not be populated for a pass-through transformation. This information applies to the referenced coordinate operation and would be supplied with that object.					

7.6 Coordinate operation method and parameters

The algorithm used to execute the coordinate operation is defined in the coordinate operation method. Concatenated operations and pass-through operations do not require a coordinate operation to be specified. Each coordinate operation method uses a number of parameters (although some coordinate conversions use none), and each coordinate operation assigns value to these parameters.

Most values are numeric, but for a number of operation methods, notably those implementing a grid interpolation algorithm, the parameter value could be a file name and location (this may be a URI). An example is the coordinate transformation from NAD 27 to NAD 83 in the USA; depending on the locations of the points to be transformed one of a series of grid files should be used.

As this class comes close to the heart of any coordinate transformation software, it is recommended to make extensive use of identifiers, referencing well-known datasets wherever possible. There is as yet no standard way of spelling or even naming the various coordinate operation methods. Client software requesting a coordinate operation to be executed by a coordinate transformation server implementation may therefore ask for an operation method this server doesn't recognise, although a perfectly valid method may be available. The same holds for coordinate operation parameters used by any coordinate operation method.

To facilitate recognition and validation it is recommended to include the operation formulae in the relevant object and if possible a worked example.

The requirements for describing a coordinate operation method shall be in accordance with Table 18 below.

Table 18 — Requirements for describing a coordinate operation method

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Coordinate operation method identifier	methodID	RS_identifier	O	1	Identifier of the coordinate operation method
Operation method name	methodName	CharacterString	M	1	The name by which this operation method is identified.
Coordinate operation method alias	alias	MC_Alias	O	N	Alternative name or names of the coordinate operation method
Coordinate operation method formula	formula	CharacterString	M	1	Formula(s) used by the coordinate operation method. This may be a reference to a publication.
Coordinate operation method remarks	remarks	CharacterString	O	1	Comments on the coordinate operation method including source information

The requirements for describing a coordinate operation parameter shall be in accordance with Table 19 below.

Table 19 — Requirements for describing a coordinate operation parameter

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Operation parameter identifier	parameterID	RS_identifier	O	1	Identifier of the coordinate operation parameter
Operation parameter name	parameterName	CharacterString	M	1	The name by which this parameter is identified.
Operation parameter alias	alias	MC_Alias	O	N	Alternative name or names of the coordinate operation parameter
Operation parameter remarks	remarks	CharacterString	O	1	Comments on the coordinate operation parameter including source information

The requirements for describing a coordinate operation parameter value shall be in accordance with Table 20 below.

Table 20 — Requirements for describing an operation parameter value

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Operation parameter value	value	MC_Measure	C	1	Numeric value of the coordinate operation parameter with its associated unit of measure
Operation parameter file reference	valueFile	CharacterString	C	1	Alphanumeric string providing reference to a file containing the parameter values. May be a URI.
Condition: The two attributes are mutually exclusive. The provision of one of the two is mandatory.					

8. Metadata for spatial referencing

8.1 RS_Identifier

The description of an object's attributes can be done explicitly, in direct description, or by identifier, a reference to a recognised source that contains a full description of the object. The RS_Identifier class is defined in ISO 19115 as a specialisation of the MD_Identifier class. The requirements for describing the RS_Identifier are given in Table 20. This definition of the RS_Identifier class is slightly different from the definition provided in ISO 19111. See Annex C for details.

The CI_Citation can be used optionally within RS_Identifier to provide information, e.g. by means of a URI, where the referenced information, as specified by the accompanying RS_Identifier element, can be found.

Implementers are warned that there may be issues associated with the specification of elements through an identifier referring to a well-known dataset. The version or edition of a dataset may not be sufficient to uniquely define the referenced element. In any well-known dataset, errors in the data may be corrected in accordance with a strategy specific to that dataset. If the referenced element contained an error in the past, that error could have been corrected in one of several ways: the erroneous data may be simply be overwritten or it have marked as incorrect with the corrected data supplemented in e.g. a new record or set of records. The strategy for dealing with erroneous data in well-known datasets as implemented by the responsible authority needs to be known to implementers in order to be able to find the data that is required by their application; merely the most up-to-date information or the erroneous information from the past, because that was used to transform spatial data that is still in use.

The requirements for describing an identifier shall be in accordance with Table 21 below.

Table 21 — Requirements for describing an identifier

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Code	code	CharacterString	M	1	Code or identifier of the object referenced
Code Space	codeSpace	CharacterString	O	1	Namespace in which the code is valid and which identifies the dataset referenced.
Version	version	CharacterString	O	1	Version of the Code Space or Code. This optional version identifier applies to either the Code Space or the Code as defined by the Code Space authority. When appropriate, the version is identified by the effective date, coded using ISO 8601 date format.
Authority	authority	CI_Citation	O	1	Citation; definition by reference to a well-known source

The CI_Citation class and the EX_Extent class are defined in ISO 19115.

8.2 Names and aliases

Most objects have one or more aliases. These may be alternative names, the name as the object is known in other authoritative sources, or abbreviations.

Aliases and abbreviations are covered by the UML class MC_Alias. The requirements for describing Alias are given in Table 22.

Table 22 — Requirements for describing an Alias

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Alias	alias	CharacterString	M	1	The alias of the referenced object.
Alias Type	aliasType	MC_AliasType	O	1	Object class this alias describes
Alias namespace	aliasNameSpace	CharacterString	O	1	Namespace the alias is defined in; e.g. 'ISO 2-char country code' or 'EPSG abbreviation'
Alias remarks	remarks	CharacterString	O	1	Remarks relating to this alias

8.3 Unit of Measure

The UML class diagram of the Unit of Measure specification in ISO 19103 is shown in Figure 4. This specification has been extended by additional attributes: an RS_Identifier attribute (pointer to class RS_Identifier) to permit referencing units of measure from well-known datasets and multiple aliases have been included to allow name, alias and abbreviation specification.

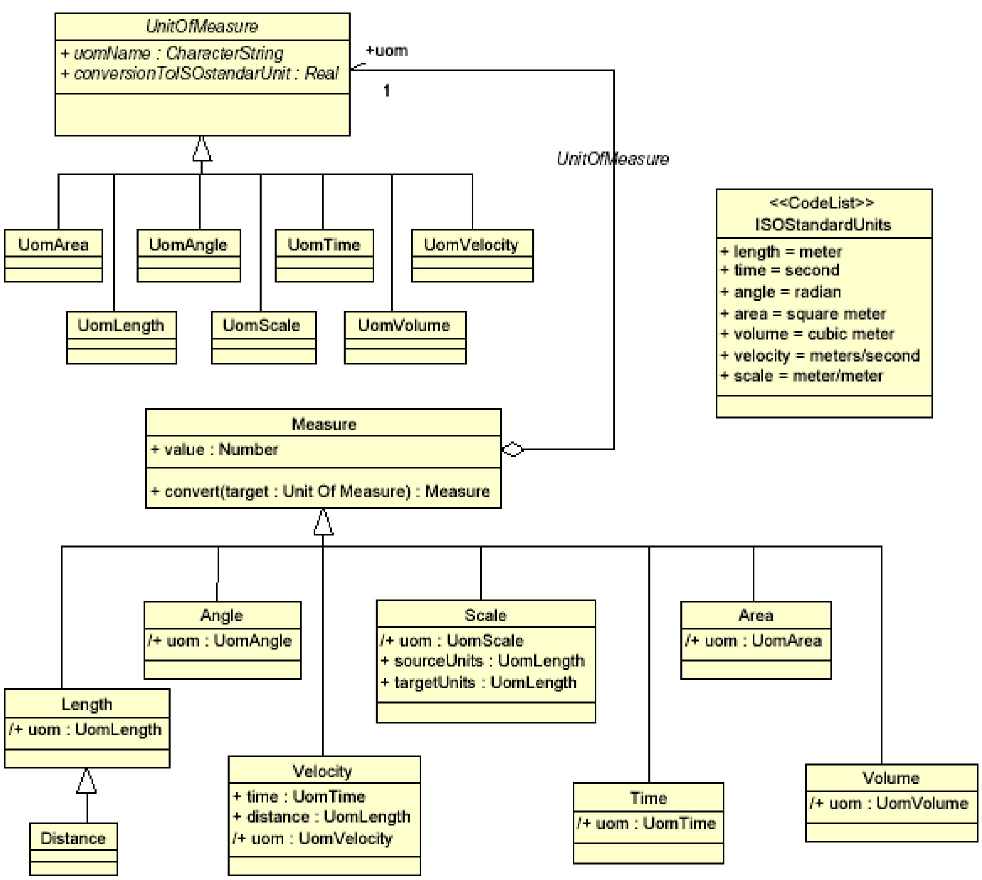

Figure 4 — Unit of Measure as modelled in ISO 19103

Furthermore a more general formula has been specified, permitting a quantity to be converted to a value expressed in a standard Unit of Measure. This has been modelled by adding a pointer to a target Unit of Measure. The target Units of Measure are constrained to the standard unit for the relevant Unit of Measure type. The derived data types "Angle" and "Length", as defined in ISO 19103 have been used where it was feasible to specify a value/unit pair. In cases where this was not possible the value has been specified as a real number with an explicit reference to a Unit of Measure.

The requirements for describing a unit of measure shall be in accordance with Table 23 below.

Table 23 — Requirements for describing a Unit of Measure

Element name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Unit of Measure Identifier	uomID	RS_Identifier	O	1	Identifier of Unit of Measure
Unit of Measure Name	uomName	CharacterString	M	1	The name by which this Unit of Measure is identified.
Unit of Measure alias	alias	MC_Alias	O	N	Alternative name or names of the Unit of Measure
Target Unit of Measure	targetUom	MC_UnitOfMeasure	M	1	The standard unit of measure to which a quantity expressed in the subject unit of measure can be converted. For length: International Metre For angle: radian For scale: unity
Numerator addition 'a'	a	Real	M	1	A quantity 'x' in the subject unit of measure can be converted to a quantity 'y' in the standard unit of measure of the same type according to the following formula: $y = (a + b.x)/(c + d.x)$ For the units of measure of length, angle and scale the addition constants 'a' and 'd' are zero.
Numerator factor 'b'	b	Real	M	1	
Denominator addition 'c'	c	Real	M	1	
Denominator factor 'd'	d	Real	M	1	
Unit of Measure remarks	remarks	CharacterString	O	1	Comments on the coordinate operation method including source information

8.4 Accuracy

Information about the accuracy or precision of coordinates, or coordinate operations and of coordinate operation parameters is quality information and shall be reported where possible in conformance with ISO 19115 and ISO 19114.

As discussed in Subclause 6.1, the parameters that define a coordinate reference system are chosen rather than measured to satisfy the degrees-of-freedom problem in the changeover from observation to coordinate quantities. Coordinate reference systems are therefore by definition error-free (i.e. non-stochastic). A coordinate reference system is realised through a network of control points. The coordinates of those control points, derived from surface and/or from satellite observations, are stochastic. Their accuracy can be expressed in a covariance matrix, which, due to the degrees-of-freedom problem will have a rank deficiency, described in geodetic literature.

Coordinate transformations between coordinate reference systems usually have parameter values derived from two sets of point coordinates, one set in system 1, the other set in system 2. As these coordinates are stochastic (i.e. have random-error characteristics) the derived transformation parameter values will also be stochastic. Their covariance matrix can be calculated.

Coordinates that have not been 'naturally' determined in coordinate reference system 2, but have been determined in coordinate system 1 and then transformed to system 2, have the random error effects of the transformation superimposed on their original error characteristics. It may be possible in well-controlled cases to calculate the covariance matrices of the point coordinates before and after the transformation, and thus isolate the effect of the transformation, but in practice a user will only be interested in the accuracy of the final transformed coordinates.

Nevertheless the option is offered to specify the covariance matrix of point coordinates resulting exclusively from the transformation. It is outside the scope of this document to describe how that covariance matrix should be used. The requirements for reporting data quality by means of a covariance matrix are described in tables Table 24 and Table 25.

For some transformations, this accuracy information is compacted in some assessment of an average impact on horizontal position and vertical position, allowing specification of average absolute accuracy and, when relevant and available, average relative accuracy.

Hence one or two quality measures may be specified for horizontal and for vertical position. Table 26 describes the requirements for reporting this kind of information.

The requirements for describing a unit of measure shall be in accordance with Tables 24 and 25, or, alternatively, Table 26.

Table 24 — Requirements for describing a covariance matrix for a coordinate transformation

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Covariance matrix description	matrixDescription	CharacterString	O	1	A description of the covariance matrix that allows meaningful interpretation of this data
Covariance units of measure	unitsOf Measure	Sequence<MC_UnitOfMeasure>	M	1	Ordered sequence of units of measure, corresponding with the row/column index numbers of the covariance matrix, starting with row/column 1 and ending with row/column N. Each unit of measure represents the ordinate reflected in the relevant row/column of the covariance matrix

Each covariance element of the lower or upper diagonal sub-matrix shall be specified in accordance with Table 26. Because the covariance matrix is symmetrical, only the upper or lower diagonal part (including the main diagonal) needs to be specified.

Table 25 — Requirements for describing a covariance matrix element

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Row Identifier	rowIndex	Integer	M	1	The row number of the covariance
Column Identifier	columnIndex	Integer	M	1	The column number of the covariance
Covariance	covariance	Real	M	1	The covariance value

Alternatively accuracy estimates may be provided describing the impact of the coordinate transformation on horizontal and/or vertical position. These may consist of estimates for absolute accuracy alone or absolute plus relative accuracy. A description of these measures should be provided.

Table 26 — Requirements for describing estimated accuracy parameters for a coordinate transformation

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Accuracy parameter description	measureDescription	CharacterString	O	1	A description of the accuracy parameter(s) provided
Horizontal accuracy estimate	result	MC_Measure	C	1	Estimate of the impact of the transformation on horizontal position accuracy, including its unit of measure. Mandatory if Vertical accuracy estimate is not provided
Vertical accuracy estimate	result	MC_Measure	C	1	Estimate of the impact of the transformation on vertical position accuracy, including its unit of measure. Mandatory if Horizontal accuracy estimate is not provided

Annex A – UML Schemas (normative)

A.1 UML Schema for Coordinate Reference System, Coordinate System and Datum packages

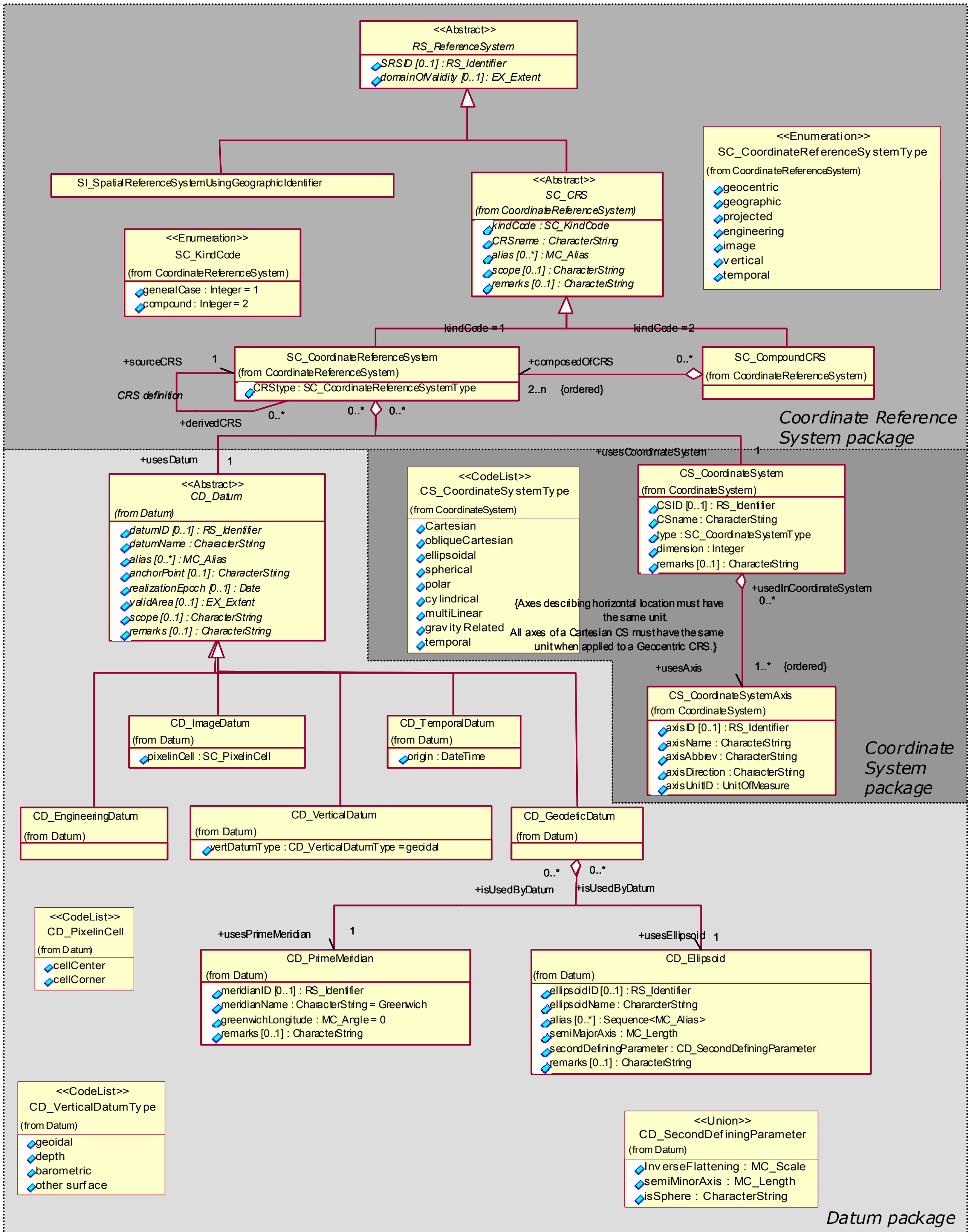

Figure A.1 — UML Schema for Coordinate Reference System, Coordinate System and Datum packages

A.2 UML Schema for Coordinate Operation package

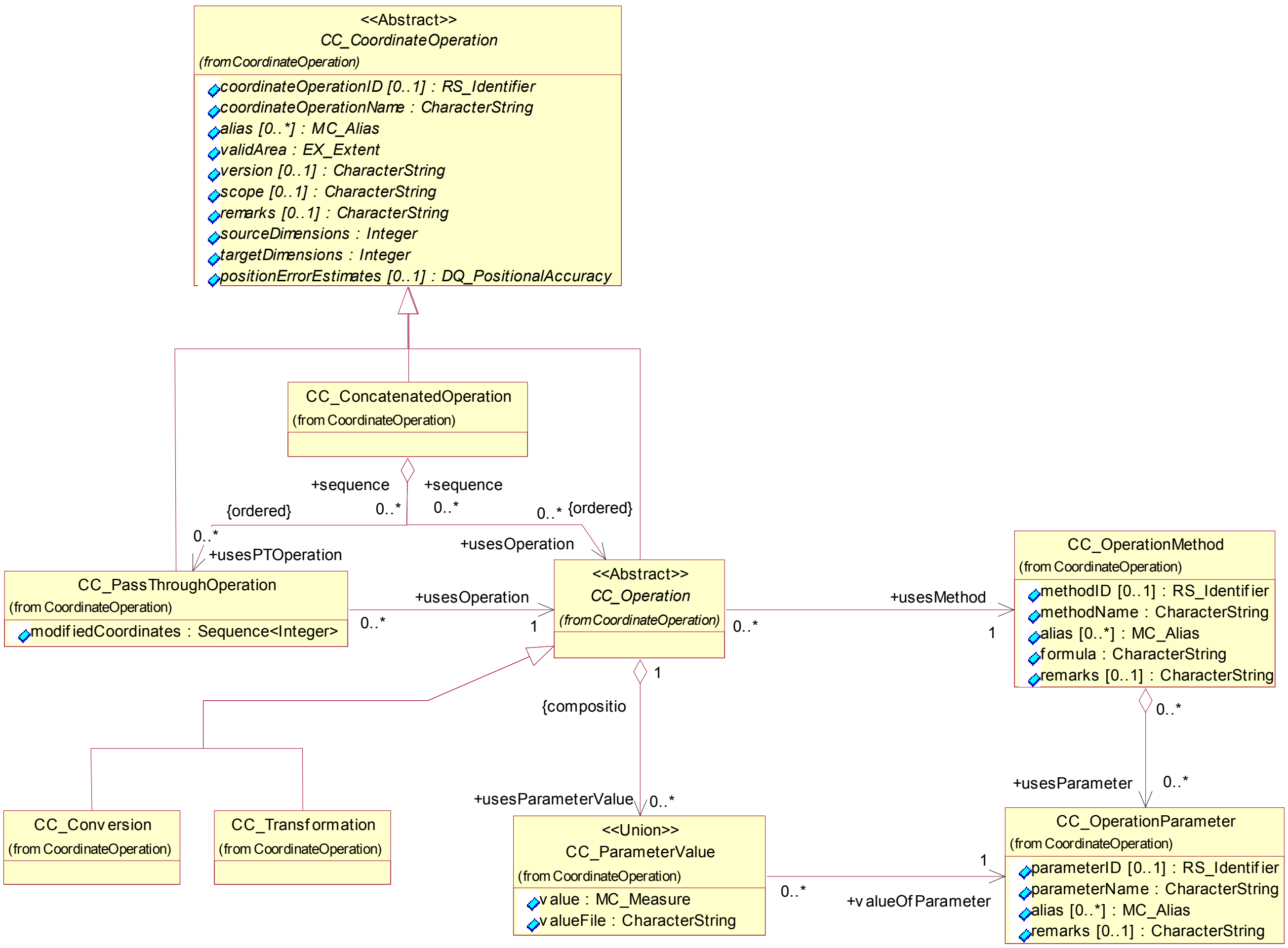

Figure A.2 — UML Schema for Coordinate Operation package

A.3 UML Schema showing relationships between Coordinate Reference System package and Coordinate Operation package

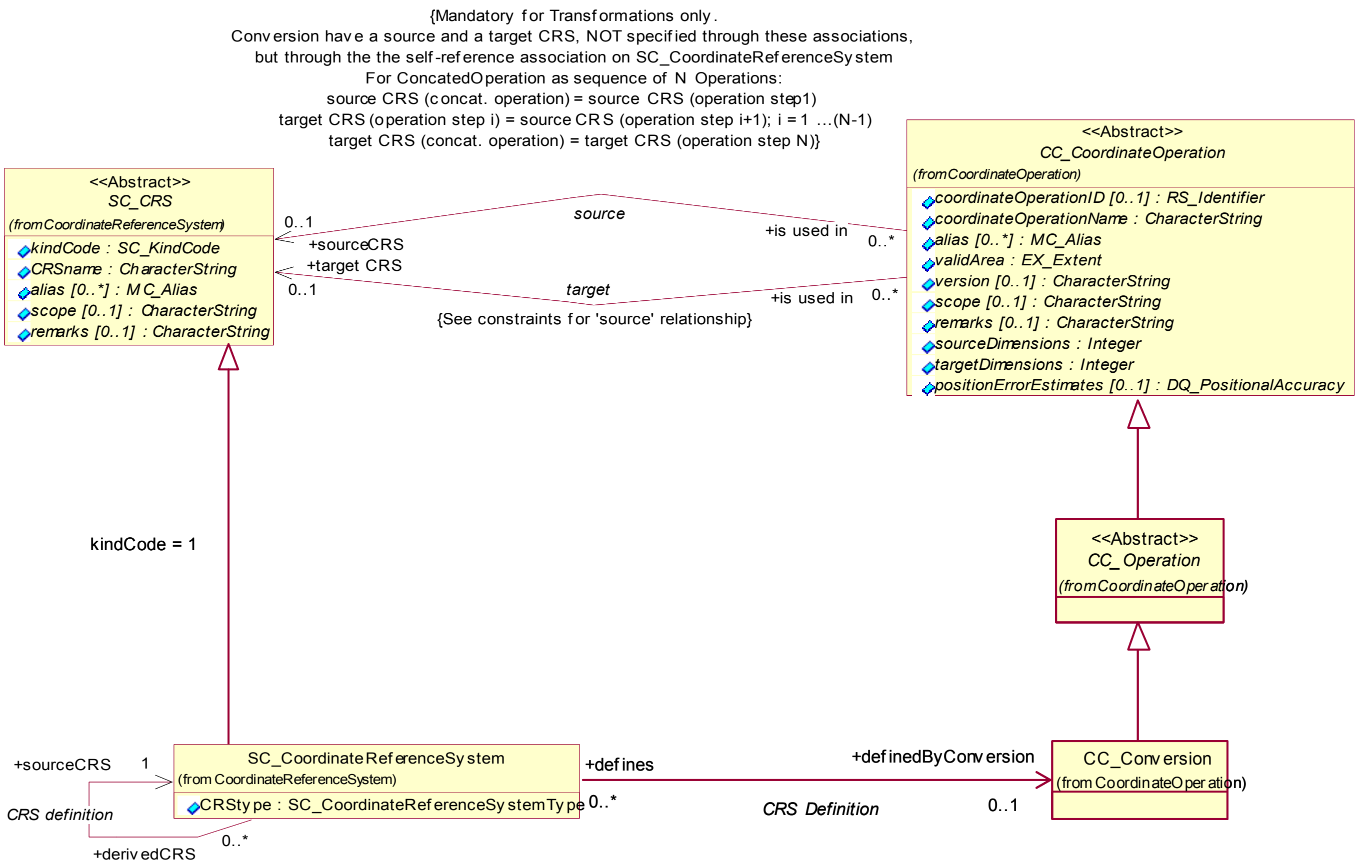

Figure A.3 — UML Schema showing relationships between Coordinate Reference System package and Coordinate Operation package

A.4 UML Schema for Coordinate Quality package

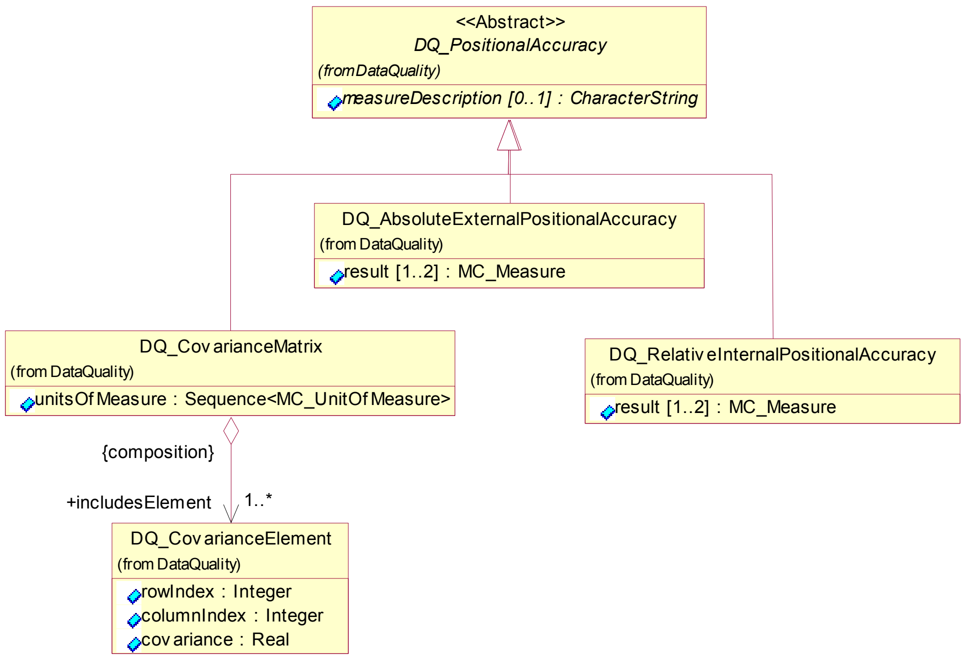

Figure A.4 — UML Schema for Coordinate Quality package

A.5 UML Schema for Metadata Coordinates package

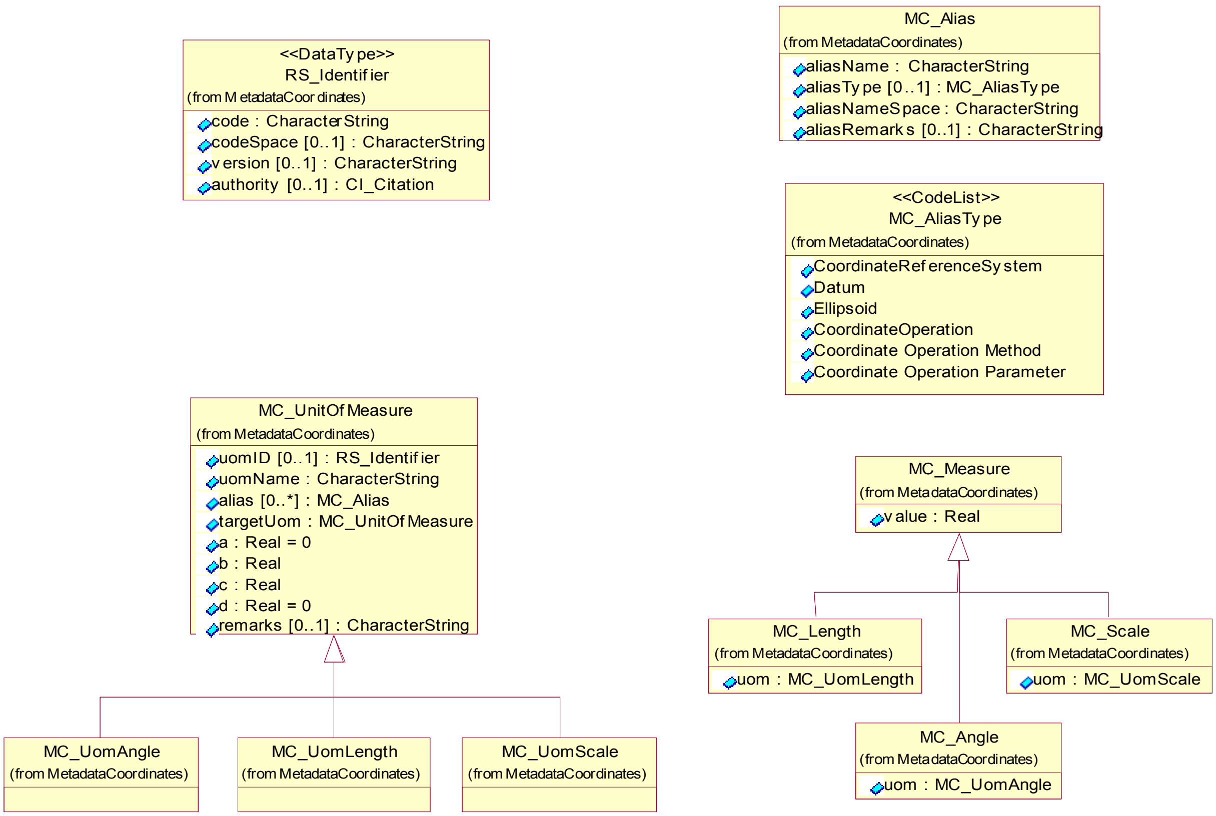

Figure A.5 — UML Schema for Metadata Coordinates package

Annex B – Differences from ISO 19111

B.1 UML modeling

Inheritance of attributes is not dealt with consistently in ISO 19111. In the OGC model, all common attributes and referenced objects have been placed in the highest level (abstract) superclass. This eliminates separate identifiers for SC_CoordinateReferenceSystem, SC_CompoundCRS, CC_Operation and CC_ConcatenatedOperation.

Also the attribute 'validArea' in entities SC_CoordinateReferenceSystem, SC_CompoundCRS, SC_Datum has been omitted, because they would duplicate the attribute: 'domainOfValidity', inherited from the abstract class RS_ReferenceSystem.

An abstract superclass CC_CoordinateOperation has been added to allow easier modelling of shared attributes and relationship of CC_Operation and CC_ConcatenatedOperation. This Abstract Specification therefore requires a source and a target CRS to be defined for CC_ConcatenatedOperation. The ISO 19111 model does not allow that, but would require implemented software to work out the source and the target CRS from the concatenation of CRS's implied in the definition of the concatenated operation. The reason for the de-normalization in this Abstract Specification is implementation ease.

In some cases ISO 19111 requires attributes where these attributes are already implied in the UML relationships; in other words these attributes contain redundant information. This affects the following attributes:

CC_ConcatenatedOperation: numberOfSteps

CC_ConcatenatedOperation: stepID

Some entities have been modelled slightly differently from ISO 19111, although the intention has been honoured and the OGC version and ISO version would result in identical implementations. Essential in assessing any modelling differences is the premise that no information should be lost. An example is the way aliases have been modelled.

ISO 19111 contains inconsistency between the two (normative) UML diagrams that cannot be resolved without making assumptions. This is further discussed in section B.4 below.

Conflict with ISO 19111?

None. It would not result in any conflict at the implementation level. Only apparent differences exist with the ISO 19111 UML model.

B.2 Coordinate Reference System subtypes

ISO 19111 does not model subtypes of this class. OGC believes it crucial that this is done, as this subtyping has been part of geodetic practice for many years. The taxonomy is based mainly on the way the effects of earth curvature are dealt with. This has a direct impact on the size of the area for which the coordinate reference system is suited. The main types are:

a) *geocentric*, describing point locations in 3D space; suited to cover the entire earth

b) *geographic*, describing point locations on or relative to a reference ellipsoid, approximating the geoid over a significant region of the earth.

c) *projected*, treating the earth's geometry as a flat plane, but carefully controlled distortion; typically suited for (parts of) countries.

d) *engineering*, treating the earth's surface as flat, disregarding earth curvature; suited for small areas

The sub-typing has been implemented in this document as an attribute with enumerated values. It might alternatively be implemented by sub-classing, which would result in a more complex but tighter model. Notable additions to the list not mentioned in ISO 19111 are the subtype 'Temporal CRS' and "Image CRS"

Conflict with ISO 19111?

Yes, but the preferred interpretation is to see this subtyping as additional detail to the minimum requirements described in ISO 19111.

B.3 Coordinate System subtypes

ISO 19111 introduces sub typing at this level, showing however a mixed taxonomy. "Projected" is the outlier here. "Projected" refers to the way earth curvature is dealt with (see 2 above), whereas the remainder of the subtypes in ISO 19111 is classified by the geometry of the coordinate axes. This Abstract Specification document retains that taxonomy with the removal of "projected" (now a treated as a CRS subtype) and it adds some subtypes.

The ISO 19111 subtype "linear" is by definition a one-dimensional coordinate system (e.g. a system used for road chainage). However, OGC recognizes the need for an extension to two or three dimensions, whereby a location along a linear feature is determined by the length along that feature (from its defined origin) and e.g. the perpendicular offset from the linear feature. Because of the implication of one-dimensionality in ISO 19111 in the definition of a "linear CS", the type "multi-linear CS" has replaced this type in this Abstract Specification

Conflict with ISO 19111?

Yes. The new types may be seen as a permitted extension of the ISO 19111 minimum requirements, but the migration of the type "projected" to the CRS types is a deviation, as well as the implication of multi-dimensionality in the type "multi-linear" .

B.4 Coordinate conversions and their role in defining Coordinate Reference Systems

This document adds a concept that is not modelled, or is unsatisfactorily modelled, in ISO 19111, viz. 'Derived CRS'. The ISO 19111 URL schema of figure B.1 in ISO 19111 documents a relationship between SC_CoordinateSystem and SC_Ellipsoid that is not described in the text. The same diagram shows a relationship between SC_CoordinateSystem and CC_Operation, also not documented in the text, whereas figure B.2 shows a (double) relationship between SC_Coordinate*Reference*System and CC_Operation. It is assumed that this is an attempt to model projected and other derived CRSs.

Some CRSs cannot exist without the relationship with a source CRS having been defined. The best example is a projected CRS; this requires a geographic CRS to exist, as well as a coordinate operation that defines the projected CRS. The implication of this relationship is, that the coordinate operation must be a coordinate conversion, as defined in ISO 19111. That is, it must have *defined,* i.e. not empirically determined, parameters. Because of this fixed relationship, the derived CRS "inherits" the source CRS's datum. This will always be the case when a coordinate conversion is used to link two coordinate reference systems. For that reason this is a significant difference between a coordinate conversion and a coordinate transformation, which would lead to different modelling of those two concepts. However, the only instance where this distinction between conversion and transformation leads to differences in modelling in ISO 19111 is described above.

The intention to distinguish between a conversion and a transformation is furthermore inferred from the relationship in ISO 19111 between SC_CoordinateSystem and CC_CoordinateOperation. Since a coordinate conversion requires the datum to remain unchanged, the reasoning in ISO 19111 appears to be that the datum information is then not needed and can be bypassed. So, whereas coordinate transformations operate between two coordinate *reference* systems it appears to be assumed that coordinate conversions can then operate between coordinate systems. However, this creates the following problem: map projections, which are conversions, need the ellipsoid parameters and those are part of the Datum definition. This appears to be the reason that an additional relationship has been created in ISO 19111 between SC_CoordinateSystem and SC_Ellipsoid.

The consequence of this extra relationship is that instances of SC_CoordinateSystem become dependent on instances of SC_Ellipsoid. In non-UML language: it would necessitate the definition of a coordinate system of a given type for every ellipsoid, e.g. an ellipsoidal coordinate system for every ellipsoid defined. Furthermore, the coordinate conversion relates two coordinate systems, a source and a target, which in the ISO model would mean that the association of coordinate system is made for both coordinate systems. The ISO 19111 UML model introduces dependency between SC_CoordinateSystem and SC_ Ellipsoid and would at the implementation level introduce data duplication with the potential for data conflicts. To eliminate these undesirable effects the OGC model is necessarily rather different from the ISO 19111 model.

In order to align with the OGC model, the ISO 19111 model requires the following changes:

- a self-reference relationship in SC_CoordinateReferenceSystem, permitting a source CRS to be defined for a target CRS, defined by a coordinate conversion;

- a relationship between SC_CoordinateReferenceSystem and CC_Conversion, permitting the defining coordinate conversion to be specified.

- making the two relationships from CC_CoordinateOperation to SC_CRS optional, to permit the source and target CRS to not be specified in the case of a Coordinate Conversion. Leaving these relationships mandatory would lead to a potential data conflict, as the information about source and target CRS would be duplicated.

Conflict with ISO 19111?

Yes

B.5 Coordinate operations

Modelling detail has been added in the area of coordinate operations. A new superclass CC_CoordinateOperation has been created to capture the shared attributes and relationships of the CC_Operation and CC_ConcatenatedOperation classes. In addition three more new classes have been created:

- CC_OperationMethod

- CC_OperationParameter

- CC_ParameterValue

One of the two reasons was normalisation, to avoid repetition of attribute values in instantiated objects.

The more important reason was to create a structure that permits being prescriptive about what operation parameters are used by what method. It permits being prescriptive about the operation methods themselves. This part of the model comes close to the heart of coordinate transformation software. The prevalence of distributed computing necessitates standardisation in the data: a coordinate operation may be requested specifying an operation method that is not recognised by the server software. If it does recognise the method, it may not recognise the operation parameters quoted. Is the parameter called 'scale factor at central meridian', 'scale factor at natural origin', 'false magnification', etc? The modelling construct proposed is derived from the EPSG data model that has proven to be able to resolve this issue.

Conflict with ISO 19111?

Yes, but it is quite possible to interpret the extra classes as additional detail implementing the more general ISO 19111 model.

B.6 RS_Identifier

ISO 19111 specifies the various Identifiers of the main classes as mandatory and of data type RS_Identifier.

The concept of identifier appears to be applied inconsistently in ISO 19111, because in the examples provided in Annex E, although not normative, the identifiers are text strings (the name of the data entity) rather than referring to an object.

The RS_Identifier concept enables data to be defined by reference to a source that contains the full definition. ISO 19111 calls this "description by citation". As such the identifier can never be mandatory, because it would imply that only data from well-known datasets could be used. This is clearly not the intention of ISO 19111, as is evidenced by the text in Section 6.6 "Citations". This implies that all identifiers should be optional, not mandatory.

OGC believes this is an inconsistency in ISO 19111 itself. This deviation is therefore not considered to be in conflict with ISO 19111.

A more serious problem was identified because RS_Identifier, defined in *ISO 19115*, was felt to be inadequate for the purpose it would be used for in 99% of the cases. RS_Identifier makes use of the CI_Citation class to provided details about the definition of the well-known dataset that is referenced. CI_Citation is heavily focussed on paper publications, whereas the usage foreseen by OGC would be dominated by well-known data made available over the Web.

For that reason OGC added two attributes to RS_Identifier, namely "codeSpace" and "version". These two attributes cover 99% or more of the usage anticipated, in which case no C_Citation class object would need to be instantiated.

Conflict with ISO 19111?

No, the optional nature of OGC's identifier does not constitute a conflict. The two additional attributes in RS_Identifier do conflict with the definition in ISO 19115, where the issue will have to be resolved.

B.7 Name attribute added

As stated in the previous point the Identifier attribute is not used consistently in ISO 19111. It is used alternatively as name of the entity and as RS_Identifier object. It has already been argued that that is incorrect. The consequence of this is that a name for the entity in question is missing, unless one would want to model that as an alias, which appears to be artificial.

Conflict with ISO 19111?

No. It appears to have been intention of ISO 19111 to model an attribute with this meaning. The modelling appears to be incorrect as the ISO 19111 "XXX Identifier" attributes looks like it is a mixture of name and reference to a well-known dataset.

B.8 Modelling of ellipsoid parameters

The modelling of the defining parameters of an ellipsoid in ISO 19111 is felt to be somewhat inadequate. An ellipsoid is defined by two independent parameters. Either of the following two options are in use:

- semi-major axis and inverse flattening;
- semi-major axis and semi-minor axis

ISO/19111 only permits the first; the OGC model permits both. The latter is necessary, because some well-known data sets (e.g. EPSG) register the original definition of the ellipsoid, which may be according to either method.

Conflict with ISO 19111?

Yes. ISO 19111 specifically precludes the definition of an ellipsoid by its two semi-axes.

B.9 Unit of measure

ISO 19111 does not specify the way units of measure are to be modelled. The OGC model uses a variation on the modelling construct in ISO CD 19103, the main difference being that the conversion formula from a unit to its standard unit of the same type uses a more complex formula.

Conflict with ISO 19111?

No.

B.10 Accuracy

ISO 19111 briefly mentions accuracy, but does not specify how to model it. The OGC model deals with accuracy only in the sense of accuracy impact of coordinate transformations (coordinate conversions have exact, hence error-free parameters).

ISO 19115 does model data accuracy, but its approach does not properly allow for covariance matrices: its splits accuracy in absolute and relative accuracy. A covariance matrix contains both. The implementation in the OGC model therefore varies somewhat from ISO 19115.

Conflict with ISO 19111?

No.

Bibliography

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[2] IEC 60027 (all parts), *Letter symbols to be used in electrical technology*.

[3] ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*.

[4] ISO DIS 19112, *Geographic information - Spatial referencing by geographic identifier*s

[5] ISO DIS 19113, *Geographic information – Quality Principles*

[6] ISO CD 19123, *Geographic Information – Schema for Coverage Geometry and Functions*

[7] OGC Document 99-102r1*, The OpenGIS® Abstract Specification – Topic 2: Spatial Reference Systems.*

