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The OpenGIS® Abstract Specification

Topic 2: Spatial referencing by coordinates

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Contents

i. Preface

This document specifies modelling requirements for spatial referencing by coordinates. Coordinate Reference System definition data is metadata about spatial data whose positions are described by coordinates. Without the Coordinate Reference System data, interpretation of coordinates is ambiguous. The file 03-073a.zip attached to this document contains the described UML model in Rational Rose 4.5 format.

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 19111 are summarized in an annex.

This document replaces OGC document 02-102 – The OpenGIS™ Abstract Specification, Topic 2: Spatial Referencing By Coordinates. (That same document was earlier numbered as document 01-063r2.) It describes the same subject matter in a tighter UML model. Some minor changes have been added to consolidate the experiences obtained while converting the model to XML Schema.

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
15 Oct 2003	v 2.0.0	RN/AW JH/DC	Revision of UML model and accompanying text	The degree of detail of the UML model has been increased to facilitate conversion to XML Schema. The previous model was supplemented by textual constraints. These constraints have now been expressed in the UML model. The changes to version 1.0.2 were separately described in OGC document 03-009r6. This version 2.0.0 is therefore a consolidation of that document and version 1.0.2 of this document.

iii. Future work

Improvements of this document appear needed to:

a) Improve handling of inertial and moving coordinate reference systems.

b) Improve discussion of time-varying coordinate operations.

c) Resolve questions if adequately handle coordinate reference systems that use a LinearCS.

d) Check consistency with ISO 19108 of SC_TemporalCRS, CD_TemporalDatum, and CS_TemporalCS.

e) Consider defining <<CodeList>> class for axisDirection and some other CharacterString attributes.

f) Provide many fragments of examples and complete examples, to aid in understanding this model, within this document and/or in separate related documents.

Foreword

This document replaces OGC Document 02-102, titled “The OpenGIS® Abstract Specification – Topic 2: Spatial Referencing by Coordinates Systems”, which, in turn, replaced OGC Document 99-102r1 titled OpenGIS® Abstract Specification – Topic 2: Spatial Reference Systems.

The reasons for replacement of OGC Document 99-102r1 were:

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.

The reasons for revision of the resulting OGC Document 02-102 are:

a) To facilitate the development of an XML Schema implementation of the described Abstract Model. the associated UML model was required to be more specific. Where in Document 01-063r2 certain relationships were described in a generic manner in the UML model, with further constraints described in the text of the document, these constraints have now been included in the UML model.

b) Experience in the development of an XML Schema implementation was captured in some minor improvements to the model, described in the current document,

Although this document is to a very large extent based on ISO 19111, it deviates on a number of points and adds a considerable degree of detail, consistent with OGC’s need to provide specifications ready for implementation in the geospatial market place. 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.

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.

Introduction

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

a) those using coordinates;

b) 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 systems applicable to geographic information and their relationships. The subset of elements required is partially dependent upon the type of coordinates. This 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 definition.

In addition to describing a coordinate reference system, this document provides for the description of a coordinate transformation or coordinate conversion between coordinates given in two different coordinate reference systems. With such information, geographic data using different coordinate reference systems can be merged together for integrated manipulation. Also, 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*

ISO 19115, *Geographic Information – Metadata*

Normative reference to ISO 19111 is restricted. This document describes proposed corrections to ISO 19111; in doing so it cannot completely follow ISO 19111.

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 specified 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 CRSs 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 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.

5 Conventions

5.1 Symbols (and abbreviated terms)

a	semi-major axis
b	semi-minor axis
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
N	Northing
O	optional
OGC	Open GIS Consortium
RS	Reference System (package abbreviation in UML model)
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

Most 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.

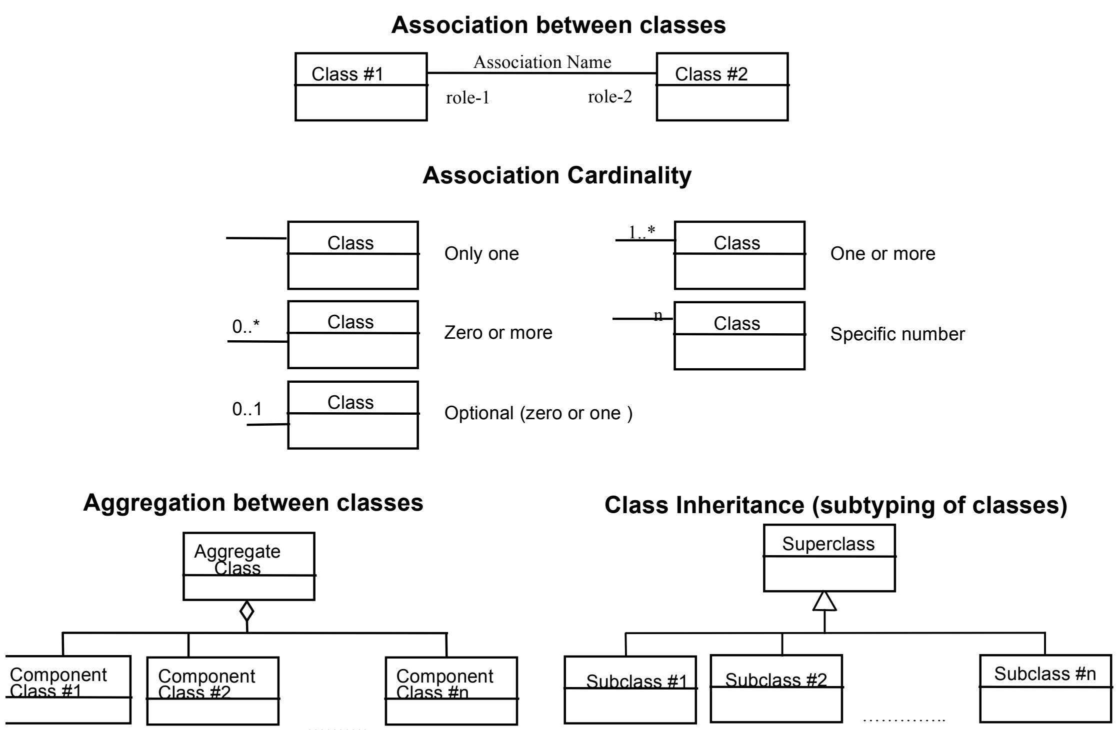

Figure 1 — UML notation

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) <<Union>> Contains a list of attributes where only one of those attributes can be present at any time.

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

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

a) CharacterString – A sequence of characters

b) Integer – An integer number

c) Double – A double precision floating point number

d) Boolean – A value specifying TRUE or FALSE

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

In addition, a Sequence type of collection is used, which contains an ordered list of values with the specified data type. The format used is “Sequence<DataType>”.

5.3 Attribute status

In the clauses below, attributes are given a requirement status:

Requirement	Definition	Meaning
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, the textual description shall prevail. The basic data types are defined in ISO 19103.

6 The geodetic context of spatial referencing by coordinates

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 <u>not</u> 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 a *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 is 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 order of the elements of the tuple and their unit(s) of measure are parts of the coordinate reference system definition. 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 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 belong to the same coordinate reference system. Each dataset shall then include one coordinate reference system description or reference, 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 10.2 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 on a planar surface, 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.

7 The UML model for spatial referencing by coordinates – overview

The Abstract Specification for spatial referencing by coordinates is defined in this document in the form of a UML model with supplementary text. The UML model contains six primary UML packages, as shown in Figure 2 below, which also shows the dependencies among these packages. Each box represents a package, and contains the package name and a listing of all classes in that package. Each dashed arrow shows the dependency of one package on another package (at the head of the arrow).

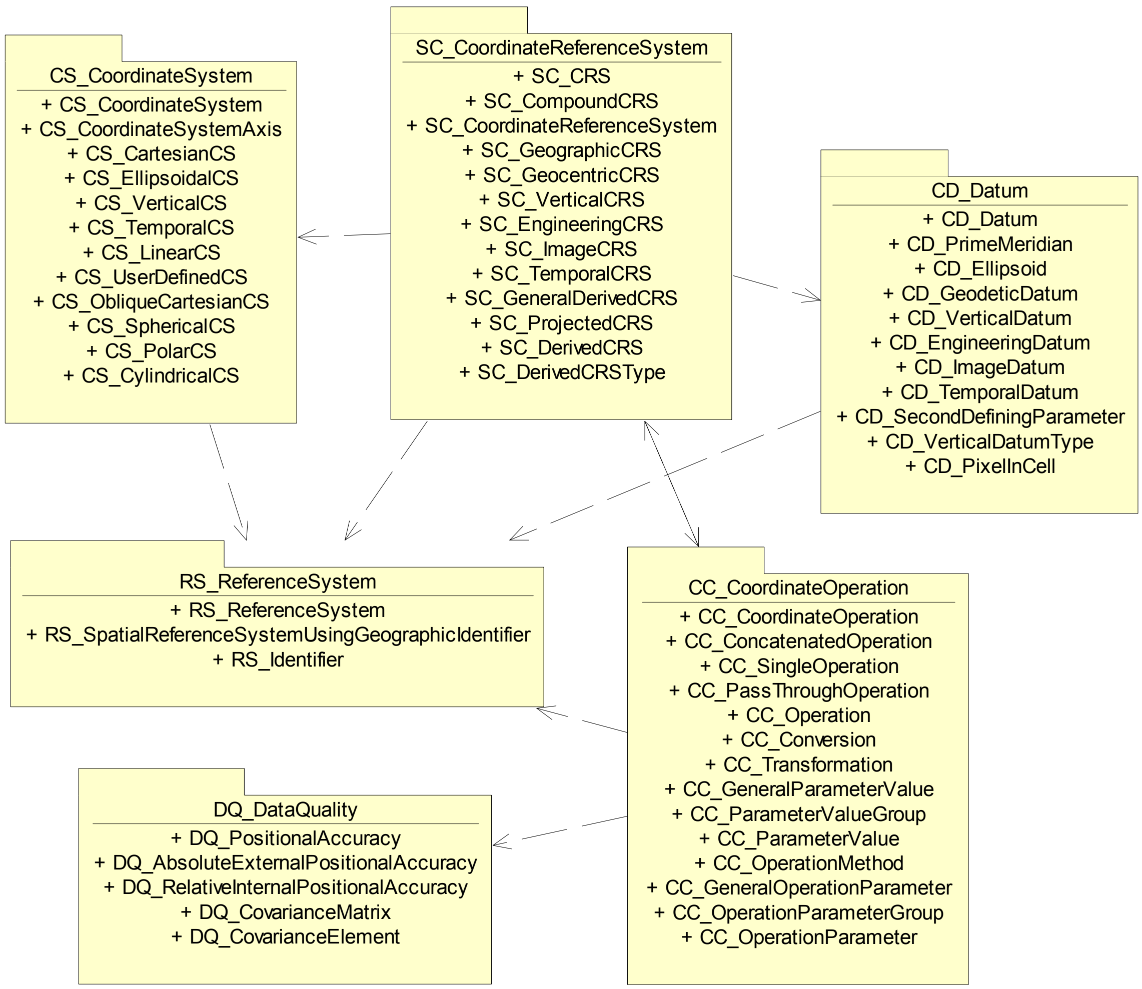

Figure 2 — UML model packages and dependencies

The six UML packages are more completely specified in the following clauses.

8 Reference System package

8.1 General aspects (informative)

A reference system contains the metadata required to interpret spatial location information unambiguously. Two methods to describe spatial location are distinguished:

a) Spatial referencing by geographic identifier. Geographic identifiers are location descriptors such as addresses and grid indexes. Such systems fall outside the scope of this document and the associated model. The requirements for spatial referencing by geographic identifier are described in ISO 19112.

b) Spatial referencing by coordinates. The scope of this document and the associated UML model is confined to the description of spatial location by coordinates.

The RS_Identifier class originates from ISO 19115, and is defined there as a specialisation of the MD_Identifier class. It has been modified in this document to improve definition of objects by identifier. The description of an object's attributes can be done explicitly, by providing all defining parameters, or by identifier, a reference to a recognised source that contains a full description of the object. Furthermore the RS_Identifier can be used to specify alternative names or aliases of the object defined.

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

NOTE: Implementers are warned that there may be issues associated with the specification of elements by identifier, referring to a publicly available dataset. The version or edition of a dataset may not be sufficient to uniquely define the referenced element. In any publicly available dataset, errors in the data may be corrected in accordance with rules specific to that dataset and defined by the responsible authority. The rules for dealing with erroneous data 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.

8.2 UML schema of RS Reference System package (normative)

Figure 3 below shows the UML class diagram of the RS Reference System package. The definition of the object classes of package RS Reference System are provided in Tables 1, 2 and 3.

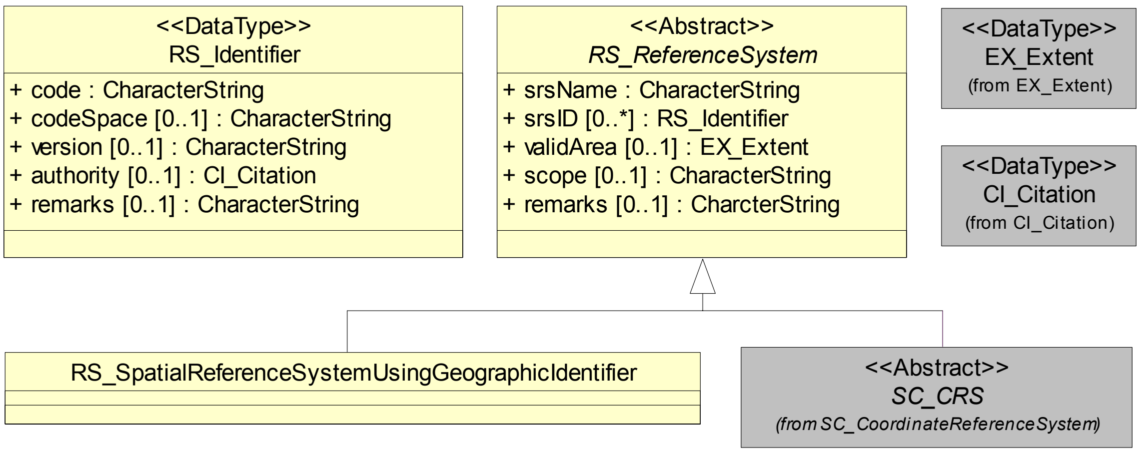

Figure 3 — RS Reference System package

Table 1 — Defining elements of RS_ReferenceSystem class

Description:	Description of a spatial and temporal reference system used by a dataset
Stereotype:	Abstract
Derived from	(none)
Association roles:	(none)
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occur-rence	Attribute description
Reference system name	srsName	CharacterString	M	1	The name by which this reference system is uniquely identified.
Coordinate reference system identifier	srsID	RS_Identifier	O	N	Set of alternative identifications of this reference system. The first srsID, if any, is normally the primary identification code, and any others are aliases.
Coordinate reference system valid area	validArea	EX_Extent	O	1	Area for which the (coordinate) reference system is valid.
Coordinate reference system scope	scope	CharacterString	O	1	Description of domain of usage, or limitations of usage, for which this CRS object is valid.
Coordinate reference system remarks	remarks	CharacterString	O	1	Comments on or information about this (coordinate) reference system, including data source information.

Table 2 — Defining elements of RS_SpatialReferenceSystemUsingGeographicIdentifier class

Description:	Spatial reference system using geographic identifier, a reference to a feature with a known spatial location. Spatial reference systems using geographic identifiers are not based on coordinates.
Stereotype:	(none)
Derived from	RS_ReferenceSystem
Association roles:	(none)
Used by:	(none)
Public attributes:	(none)

Table 3 — Defining elements of RS_Identifier class

Description:	An identification of a CRS object. The first use of an RS_Identifier for an object, if any, is normally the primary identification code, and any others are aliases.
Stereotype:	DataType
Derived from	(none)
Association roles:	(none)
Used by:	CC_CoordinateOperation CC_OperationMethod CC_OperationParmeter CC_OperationParameterGroup CD_Datum CD_Ellipsoid CD_PrimeMeridian CS_CoordinateSystem CS_CoordinateSystemAxis RS_ReferenceSystem
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Code	code	CharacterString	M	1	Identifier code or name, optionally from a controlled list or pattern defined by a code space.
Code Space	codeSpace	CharacterString	O	1	Identifier of a code space within which one or more codes are defined. This code space is optional but is normally included. This code space is often defined by some authority organization, where one organization may define multiple code spaces. The range and format of each Code Space identifier is defined by that code space authority.
Version	version	CharacterString	O	1	Identifier of the version of the associated codeSpace or code, as specified by the codeSpace or code authority. This version is included only when the "code" or "codeSpace" uses versions. When appropriate, the edition is identified by the effective date, coded using ISO 8601 date format.
Authority	authority	CI_Citation	O	1	Organization or party responsible for definition and maintenance of the code space or code.
Remarks	remarks	CharacterString	O	1	Comment on, or information about, this object code.

9 Coordinate reference system package

9.1 General (informative)

A coordinate reference system consists of one coordinate system that is related to the earth through one datum.

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

A datum specifies the relationship of a coordinate system to the earth, thus 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 resulting combination of coordinate system and datum is a coordinate reference system. Each datum subtype can be associated with only specific types of coordinate systems. 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. A datum therefore implies a choice regarding the approximate origin and orientation of the coordinate system

The high level abstract model for spatial referencing by coordinates is therefore as shown in Figure 4 below.

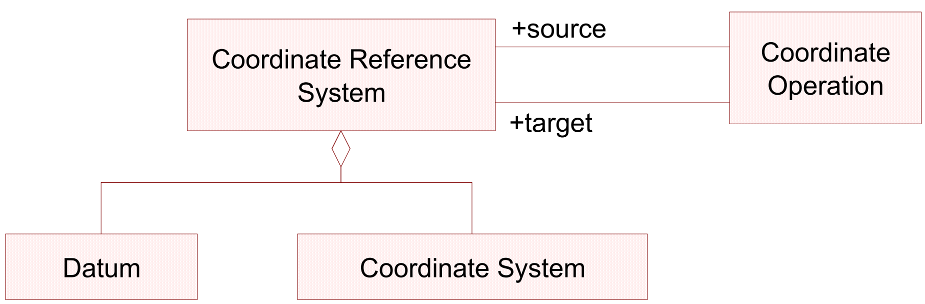

Figure 4 — High-level conceptual model for spatial referencing by coordinates

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.

9.2 Principal sub-types of coordinate reference system (informative)

Geodetic survey practice usually divides coordinate reference systems into a number of sub-types. 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.

Thus the following principal sub-types of coordinate reference system are distinguished:

a) **Geocentric**. Type of coordinate reference system 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.

b) **Geographic**. Type of coordinate reference system 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. Geographic coordinate reference systems can be 2D or 3D. A 2D Geographic CRS is used when positions of features are described on the surface of the reference ellipsoid; a 3D Geographic CRS is used when positions are described on, above or below the reference ellipsoid.

c) **Projected**. Type of coordinate reference system that is based on an approximation of the shape of the earth's surface by a plane. 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.

d) **Engineering**. Type of coordinate reference system that is that is used only in a contextually local sense. This sub-type is used to model two broad categories of local coordinate reference systems:

   - earth-fixed systems, applied to engineering activities on or near the surface of the earth;
   - coordinates 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 coordinate reference systems that are computationally required to calculate geodetic coordinates. These coordinate reference systems 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. Earth curvature is usually irrelevant and is therefore ignored. 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 earth-referenced coordinate reference systems involves time-dependent coordinate operation parameters, which can be modelled by the structures provided in this UML model.

e) **Image**. An Image CRS is an Engineering CRS applied to images. Image CRSs are treated as a separate sub-type because a separate user community exists for images with its own vocabulary. The definition of the associated Image Datum contains two data attributes not relevant for other datums and coordinate reference systems.

f) **Vertical**. Type of coordinate reference system 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.

g) **Temporal**. Used for the recording of time in association with any of the listed spatial coordinate reference systems only.

EDITOR'S NOTE The CRS WG of the OGC has agreed to expand the types of CRS described above to also allow defining Earth Cantered Inertial CRSs, which do not rotate with the Earth. However, the changes needed to do this have not yet been determined.

9.3 Additional sub-types of coordinate reference system (informative)

9.3.1 Introduction

In addition to the principal sub-types, so called because they represent concepts generally known in geodetic practice, two more sub-types have been defined to permit modelling of certain relationships and constraints that exist between the principal sub-types.

These additional sub-types are:

a) Compound coordinate reference system

b) Derived coordinate reference system

9.3.2 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 combines 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 (Compound CRS). It consists of an ordered sequence of the two or more single coordinate reference systems.

A Compound CRS is thus a coordinate reference system that combines two or more coordinate reference systems, none of which can itself be compound. In general, a Compound CRS may contain any number of axes. The Compound CRS contains an ordered set of coordinate reference systems and the tuple order of a compound coordinate set shall follow that order, while the subsets of the tuple, described by each of the composing coordinate reference systems, follow the tuple order valid for their respective coordinate reference systems.

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

a) Geographic 2D + Vertical

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

c) Projected + Vertical

d) Projected + Engineering 1D (near vertical)

e) 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 CRS added. More than one Temporal CRS 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).

Figure 5 below shows an example of the possible composition of a compound coordinate reference system.

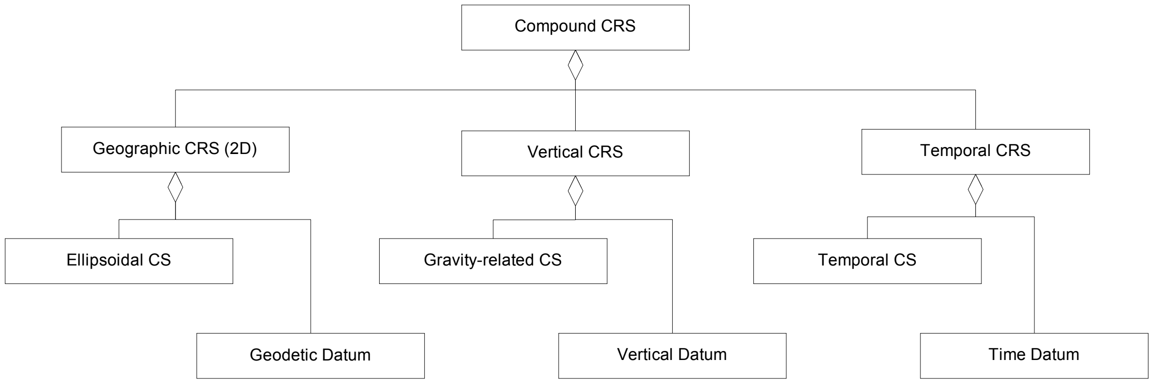

Figure 5 — Example of a compound coordinate reference system

9.3.3 Derived coordinate reference system

Some coordinate reference systems are defined by applying a coordinate conversion to another coordinate reference system. Such a coordinate reference system is called a Derived CRS and the coordinate reference system it was derived from by applying the conversion is called the Source or Base CRS. A coordinate conversion is an arithmetic operation with zero or more parameters that have defined values. The Source CRS and Derived CRS have the same Datum. The best-known example of a Derived CRS is a Projected CRS, which is always derived from a source Geographic CRS by applying the coordinate conversion known as a map projection.

In principle, all sub-types of coordinate reference system may take on the role of either Source or Derived CRS with the exception of a Geocentric CRS and a Projected CRS. The latter is modelled as an object class under its own name, rather than as a general Derived CRS of type "projected". This has been done to honour common practice, which acknowledges Projected CRSs as one of the best known types of coordinate reference systems.

An example of a Derived CRS of *derivedCRStype*: "geographic" is one of which the unit of measure has been modified with respect to an earlier defined Geographic CRS, which then takes the role of Source CRS.

9.4 UML schema of Coordinate Reference System package (normative)

Figure 6 below shows the UML class diagram of the Coordinate Reference System package. The definition of the object classes of package RS_CoordinateReferenceSystem are provided in Tables 4 through 16.

Please notice that SC_ProjectedCRS is modelled separately from SC_DerivedCRS to permit modelling of its more specific characteristics.

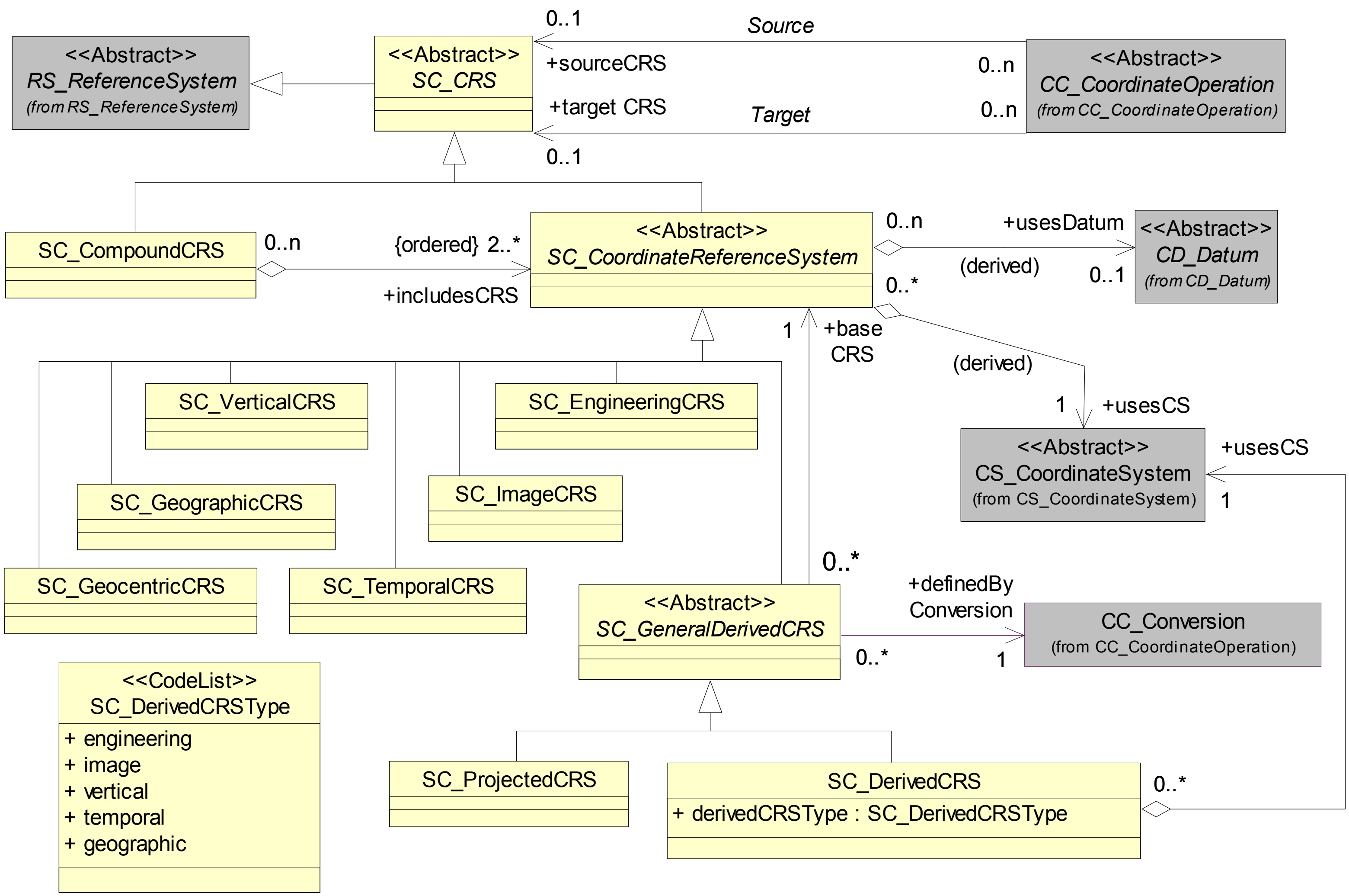

Figure 6 — SC Coordinate Reference System package

Table 4 — Defining elements of SC_CRS class

Description:	Abstract coordinate reference system, usually defined by a coordinate system and a datum.
Stereotype:	Abstract
Derived from	RS_ReferenceSystem
Association roles	sourceCRS from CC_CoordinateOperation [0..1] targetCRS from CC_CoordinateOperation [0..1]
Public attributes:	(none)

Table 5 — Defining elements of SC_CoordinateReferenceSystem class

Description:	Abstract coordinate reference system, consisting of a single Coordinate System and a single Datum (as opposed to Compound CRS)
Stereotype:	Abstract
Derived from	SC_CRS
Association roles:	(derived) usesDatum to CD_Datum [0..1] (derived) usesCS to CS_CoordinateSystem [1] sourceCRS from SC_GeneralDerivedCRS [1] (associations inherited from SC_CRS)
Public attributes:	(none)

Table 6 — Defining elements of SC_CompoundCRS class

Description:	A coordinate reference system describing the position of points through two or more independent coordinate reference systems. Thus it is associated with two or more Coordinate Systems and Datums by defining the compound CRS as an ordered set of two or more instances of SC_CoordinateReferenceSystem
Stereotype:	(none)
Derived from	SC_CRS
Association roles:	includesCRS to SC_CoordinateReferenceSystem [2..*] {ordered}
Public attributes:	(none)

Table 7 — Defining elements of SC_GeneralDerivedCRS class

Description:	A coordinate reference system that is defined by its coordinate conversion from another coordinate reference system (not by a datum).
Stereotype:	Abstract
Derived from	SC_CoordinateReferenceSystem
Association roles:	baseCRS to SC_CoordinateReferenceSystem [1] definedByConversion to CC_Conversion [1] (associations inherited from SC_CoordinateReferenceSystem)
Public attributes:	(none)

Table 8 — Defining elements of SC_DerivedCRS class

Description:	A coordinate reference system that is defined by its coordinate conversion from another coordinate reference system but is not a projected coordinate reference system. This category includes coordinate reference systems derived from a projected coordinate reference system.				
Stereotype:	(none)				
Derived from	SC_GeneralDerivedCRS				
Association roles:	usesCS to CS_CoordinateSystem [1] (associations inherited from SC_ GeneralDerivedCRS)				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Derived CRS type	derivedCRStype	SC_DerivedCRSType	M	1	Type of this derived CRS.

Table 9 — Defining elements of SC_DerivedCRSType class

Description:	The type of the derived CRS, according to the classification of principal CRS types.				
Stereotype:	CodeList				
Derived from	(none)				
Association roles:	(none)				
Used by:	SC_DerivedCRS				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Geographic CRS	geographic	CharacterString	C	1	A coordinate reference system based on an ellipsoidal approximation of the geoid; provides an accurate representation of the geometry of geographic features for a large portion of the earth's surface.
Vertical CRS	vertical	CharacterString	C	1	A coordinate reference system used for recording of heights or depths. Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but the relationship with gravity may not be straightforward
Engineering CRS	engineering	CharacterString	C	1	A contextually local coordinate reference system; 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.
Image CRS	image	CharacterString	C	1	An engineering coordinate reference system applied to locations in images.
Temporal CRS	temporal	CharacterString	C	1	A coordinate reference system used for the recording of time.
Condition: One and only one of the listed attributes can be supplied and is then mandatory					

Table 10 — Defining elements of SC_ProjectedCRS class

Description:	A 2D coordinate reference system used to approximate the shape of the earth on a planar surface, 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.
Stereotype:	(none)
Derived from	SC_GeneralDerivedCRS
Association roles:	usesCS to CS_CartesianCS [1] (associations inherited from SC_GeneralDerivedCRS)
Public Attributes:	(none)

Table 11 — Defining elements of SC_GeocentricCRS class

Description:	A 3D coordinate reference system with the origin at the approximate centre of mass of the earth. A geocentric CRS deals with the earth's curvature by taking a 3D spatial view, which obviates the need to model the earth's curvature.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum to CD_GeodeticDatum [1] usesCartesianCS to CS_CartesianCS [0..1] usesSphericalCS to CS_SphericalCS [0..1] (associations inherited from SC_CoordinateReferenceSystem)
Note attached to usesCartesianCS and usesSphericalCS associations: {XOR}	
Public attributes: (none)	

Table 12 — Defining elements of SC_GeographicCRS class

Description:	A coordinate reference system 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.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum to CD_GeodeticDatum [1] usesCS to CS_EllipsoidalCS [1] (associations inherited from SC_CoordinateReferenceSystem)
Public attributes: (none)	

Table 13 — Defining elements of SC_EngineeringCRS class

Description:	A contextually local coordinate reference system; 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.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum to CD_EngineeringDatum [1] usesCS to CS_CoordinateSystem [1] (associations inherited from SC_CoordinateReferenceSystem)
Public Attributes:	(none)

Table 14 — Defining elements of SC_ImageCRS class

Description:	An engineering coordinate reference system applied to locations in images. Image coordinate reference systems are treated as a separate sub-type because a separate user community exists for images with its own terms of reference.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum to CD_ImageDatum [1] usesCartesianCS to CS_CartesianCS [0..1] usesObliqueCartesianCS to CS_ObliqueCartesianCS [0..1] (associations inherited from SC_CoordinateReferenceSystem)
Note attached to usesCartesianCS and usesObliqueCartesianCS associations: {XOR}	
Public attributes:	(none)

Table 15 — Defining elements of SC_VerticalCRS class

Description:	A 1D coordinate reference system used for recording heights or depths. Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but the 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.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum to CD_VerticalDatum [1] usesCS to CS_VerticalCS [1]] (associations inherited from SC_CoordinateReferenceSystem)
Public Attributes:	(none)

Table 16 — Defining elements of SC_TemporalCRS class

Description:	A 1D coordinate reference system used for the recording of time.
Stereotype:	(none)
Derived from	SC_CoordinateReferenceSystem
Association roles:	usesDatum CD_TemporalDatum [1] usesCS to CS_TemporalCS [1] (associations inherited from SC_CoordinateReferenceSystem)
Public attributes:	(none)

10 Coordinate System package

The Coordinate System package models two main concepts: coordinate system and coordinate system axis.

10.1 Coordinate System (informative)

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. In other words, a coordinate system implies how 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 properties of the coordinate space.

NOTE: The word ‘distances’ is used loosely in the above 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.

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

A coordinate system is composed of an ordered set of coordinate system axes, the number of axes being equal to the dimension of the space of which it describes the geometry. Coordinates in coordinate tuples shall be supplied in the same order as the coordinate axes are defined.

The dimension of the coordinate space, the names, the units of measure, the directions and sequence of the axes are all part of the Coordinate System definition. The number of coordinates in a tuple and consequently the number of coordinate axes in a coordinate system shall be equal to the number of coordinate axes in the coordinate system.

Example: It is therefore not permitted to supply a coordinate tuple with two heights of different definition in the same coordinate tuple.

Coordinate systems are divided into 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 as shown in the UML class diagram in Figure 8 below. A description of coordinate system subtypes is provided in Table 17.

Table 17 — Subtypes of coordinate system and constraints in its relationship with coordinate reference system

CS subtype	Description	Used with CRS type(s)
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	2- or 3-dimensional 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.	Engineering

CS subtype	Description	Used with CRS type(s)
vertical	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
linear	1-dimensional coordinate system that consists of the points that lie on the single axis 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.	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

10.2 Coordinate system axis (informative)

A coordinate system is composed of an ordered set of coordinate system axes. Each of its axes is completely characterised by a unique combination of axis name, axis abbreviation, axis direction and axis unit of measure.

The concept of coordinate axis requires some clarification. Consider an arbitrary *x, y, z* coordinate system. The *x*-axis may be defined as the locus of points with $y = z = 0$. This is easily enough understood if the *x, y, z* coordinate system is a Cartesian system and the space it describes is Euclidean. It becomes a bit more difficult to understand in the case of a strongly curved space, such as the surface of an ellipsoid, its geometry described by an ellipsoidal coordinate system (2D or 3D). Applying the same definition by analogy to the curvilinear *latitude* and *longitude* coordinates the latitude axis would be the equator and the longitude axis would be the prime meridian, which is not a satisfactory definition.

Bearing in mind that the order of the coordinates in a coordinate tuple must be the same as the defined order of the coordinate axes, the '*i*-th' coordinate axis of a coordinate system is defined as the locus of points for which all coordinates with sequence number not equal to '*i*', have a constant value locally (whereby $i = 1 \ldots n$, and n is the dimension of the coordinate space).

It will be evident that the addition of the word 'locally' in this definition apparently adds an element of ambiguity and this is intentional. However, the definition of the coordinate parameter associated with any axis must be unique. The coordinate axis itself should not be interpreted as a unique mathematical object, the associated coordinate parameter should.

Example: Geodetic latitude is defined as the "Angle from the equatorial plane to the perpendicular to the ellipsoid through a given point, northwards usually treated as positive". However, when used in an ellipsoidal coordinate system the geodetic latitude axis will be described as pointing 'north'. In two different points on the ellipsoid the direction 'north' will be a spatially different direction, but the concept of latitude is the same.

Furthermore the specified direction of the coordinate axes is often only approximate; two geographic coordinate reference systems will make use of the same ellipsoidal coordinate system. These coordinate systems are associated with the earth through two different geodetic datums, which may lead to the two systems being slightly rotated w.r.t. each other.

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 18 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.

Table 18 — 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)
Vertical	Vertical	Gravity-related height
Vertical	Vertical	Depth
Cartesian	Projected	Easting, Northing
Cartesian	Projected	Westing, Southing

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.

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.

10.3 UML schema of CS Coordinate System package (normative)

Figures 7 below shows the UML class diagram of the Coordinate System package. The associations between Coordinate Reference System subtypes and Coordinate System subtypes are shown in the UML class diagram in Figure 8. The definition of the object classes of package CS_CoordinateSystem is provided in Tables 19 through 30.

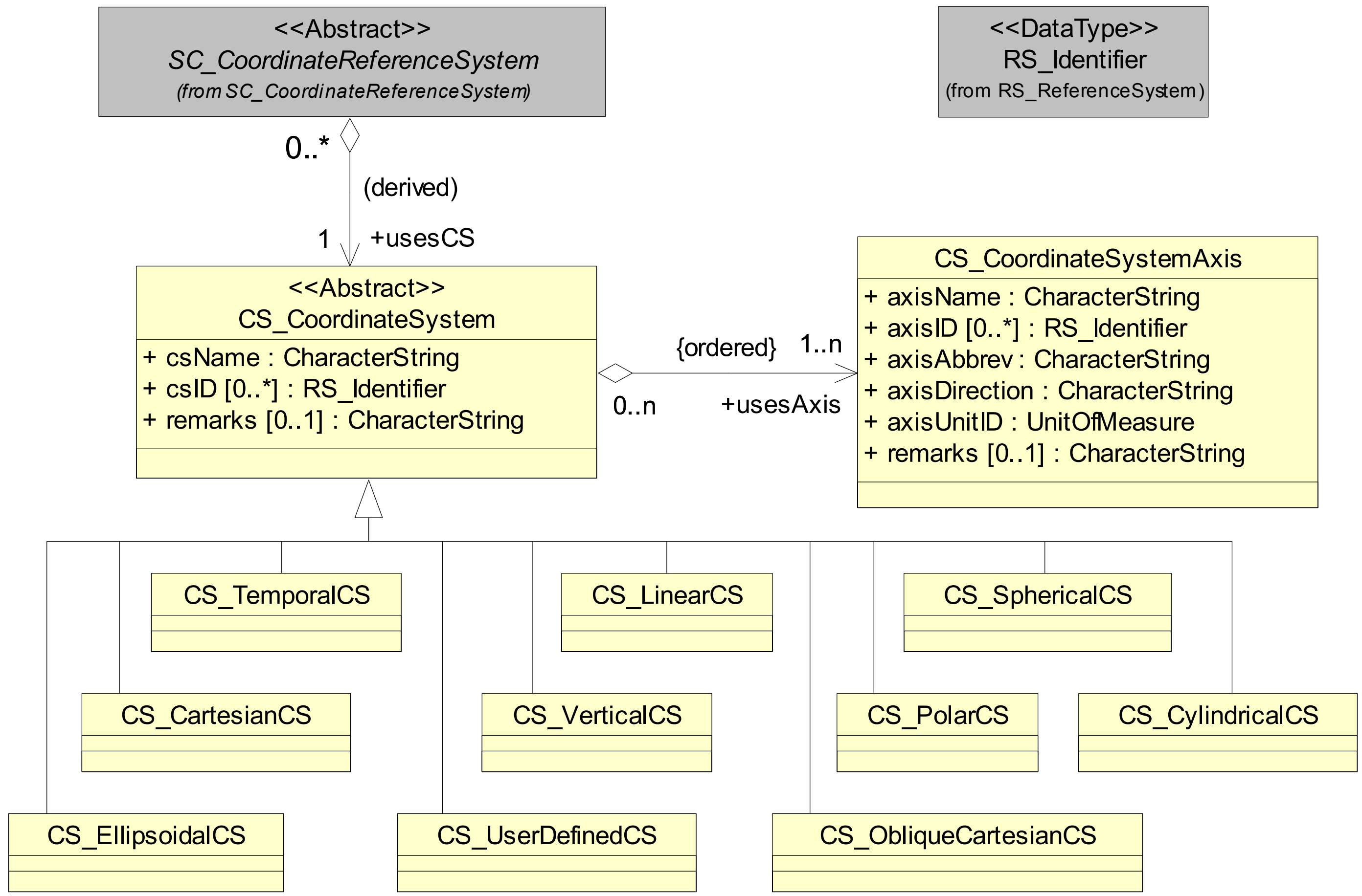

Figure 7 — CS Coordinate System package

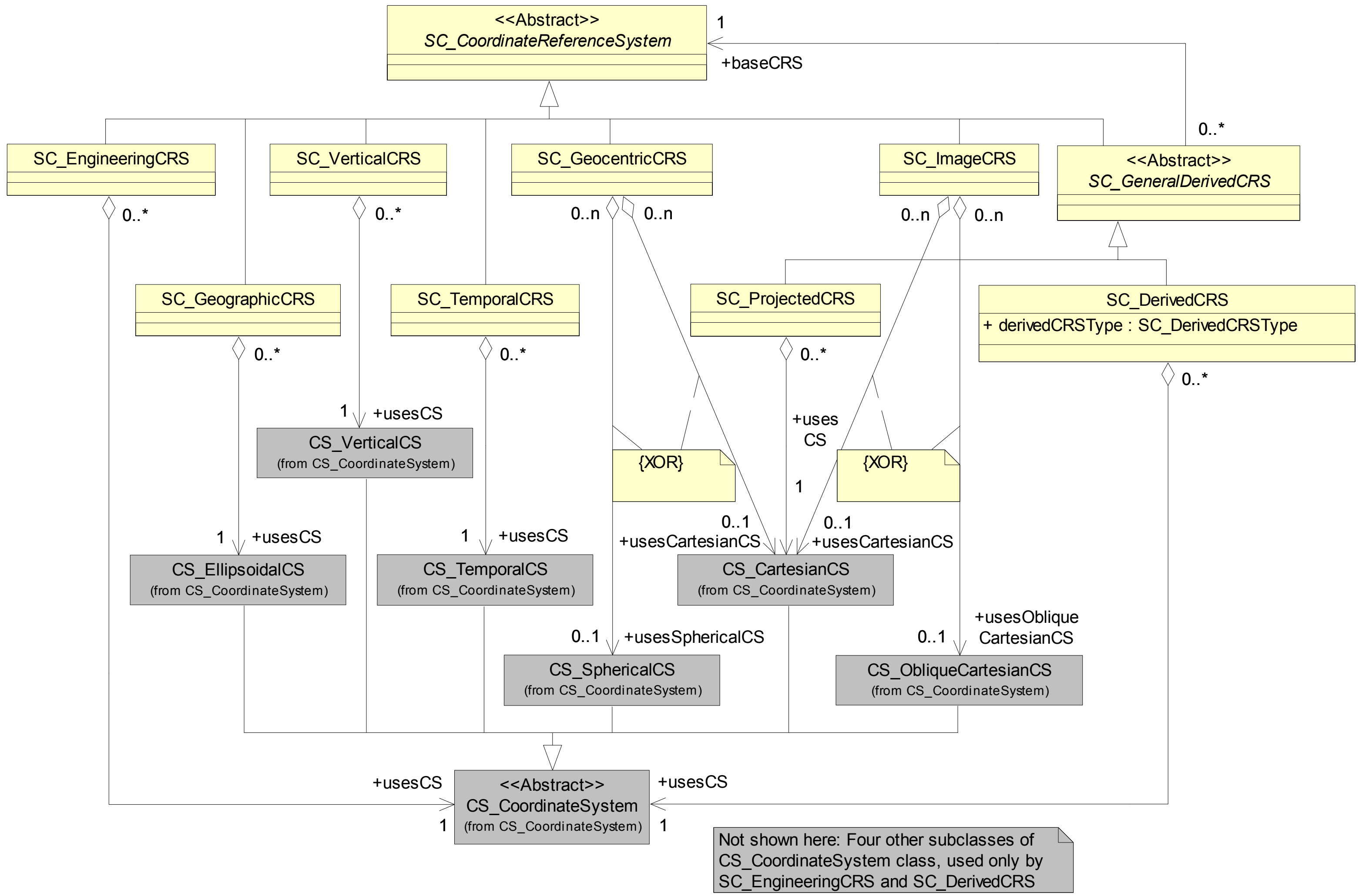

Figure 8 — Coordinate Reference System types associations to Coordinate System types

Table 19 — Defining elements of CS_CoordinateSystem class

Description:	A coordinate system (CS) is the set of coordinate system axes that spans a given coordinate space. A CS is derived from a set of (mathematical) rules for specifying how coordinates in a given space are to be assigned to points. The coordinate values in a coordinate tuple shall be recorded in the order in which the coordinate system axes associations are recorded, whenever those coordinates use a coordinate reference system that uses this coordinate system.
Stereotype:	Abstract
Derived from	(none)
Association roles:	usesAxis to CS_CoordinateSystemAxis [1..*] (ordered) usesCS from SC_EngineeringCRS [1] usesCS from SC_DerivedCRS [1] (derived) usesCS from SC_CoordinateReferenceSystem [1]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate system name	csName	CharacterString	M	1	The name by which this coordinate system is identified.
Coordinate system identifier	csID	RS_Identifier	O	N	Set of alternative identifications of the coordinate system. The first csID, if any, is normally the primary identification code, and any others are aliases.
Coordinate system remarks	remarks	CharacterString	O	1	Comments on or information about the coordinate system, including data source information.

Table 20 — Defining elements of CS_CartesianCS class

Description:	A 1-, 2-, or 3-dimensional coordinate system. 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 length unit of measure. A CartesianCS shall have one, two, or three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesCS from SC_ProjectedCRS [1] usesCartesianCS from SC_GeocentricCRS [0..1] usesCartesianCS from SC_ImageCRS [0..1] (associations inherited from CS_CoordinateSystem)
Note attached to usesCartesianCS and usesSphericalCS associations from SC_GeocentricCRS: {XOR}	
Note attached to usesCartesianCS and usesObliqueCartesianCS associations SC_ImageCRS: {XOR}	
Public attributes:	(none)

Table 21 — Defining elements of CS_ObliqueCartesianCS class

Description:	A two- or three-dimensional coordinate system with straight axes that are not necessarily orthogonal. An ObliqueCartesianCS shall have two or three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesObliqueCartesianCS from SC_ImageCRS [0..1] (associations inherited from CS_CoordinateSystem)
Note attached to usesCartesianCS and usesObliqueCartesianCS associations from SC_ImageCRS: {XOR}	
Public attributes:	(none)

Table 22 — Defining elements of CS_EllipsoidalCS class

Description:	A two- or three-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude, and (in the three-dimensional case) ellipsoidal height. An EllipsoidalCS shall have two or three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesCS from SC_GeographicCRS [1] (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 23 — Defining elements of CS_SphericalCS class

Description:	A three-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. A SphericalCS shall have three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesSphericalCS from SC_GeocentricCRS [0..1] (associations inherited from CS_CoordinateSystem)
Note attached to usesCartesianCS and usesSphericalCS associations: {XOR}	
Public attributes:	(none)

Table 24 — Defining elements of CS_CylindricalCS class

Description:	A three-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. A CylindricalCS shall have three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 25 — Defining elements of CS_PolarCS class

Description:	A two-dimensional coordinate system in which position is specified by the distance from the origin and the angle between the line from the origin to a point and a reference direction. A PolarCS shall have two usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 26 — Defining elements of CS_LinearCS class

Description:	A one-dimensional coordinate system that consists of the points that lie on the single axis 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. A LinearCS shall have one usesAxis association.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 27 — Defining elements of CS_VerticalCS class

Description:	A one-dimensional coordinate system used to record the heights (or depths) of points. Such a coordinate system is usually dependent on the Earth's gravity field, perhaps loosely as when atmospheric pressure is the basis for the vertical coordinate system axis. An exact definition is deliberately not provided as the complexities of the subject fall outside the scope of this specification. A VerticalCS shall have one usesAxis association.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesCS from SC_VerticalCRS [1] (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 28 — Defining elements of CS_TemporalCS class

Description:	A one-dimensional coordinate system containing a single time axis, used to describe the temporal position of a point in the specified time units from a specified time origin. A TemporalCS shall have one usesAxis association.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesCS from SC_TemporalCRS [1] (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 29 — Defining elements of CS_UserDefinedCS class

Description:	A two- or three-dimensional coordinate system that consists of any combination of coordinate axes not covered by any other Coordinate System type. An example is a multilinear coordinate system which contains one coordinate axis that may have any 1-D shape which has no intersections with itself. This non-straight axis is supplemented by one or two straight axes to complete a 2 or 3 dimensional coordinate system. The non-straight axis is typically incrementally straight or curved. A UserDefinedCS shall have two or three usesAxis associations.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 30 — Defining elements of CS_CoordinateSystemAxis class

Description:	Definition of a coordinate system axis.
Stereotype:	(none)
Derived from	(none)
Association roles:	usesAxis from CS_CoordinateSystem [1..*]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate system axis name	axisName	CharacterString	M	1	Name of the coordinate system axis.
Coordinate system axis identifier	axisID	RS_Identifier	O	N	Set of alternative identifications of 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.
Coordinate system axis direction	axisDirection	CharacterString	M	1	Direction of this coordinate system axis (or in the case of Cartesian projected coordinates, the direction of this coordinate system axis locally). Examples: north or south, east or west, up or down. Within any set of coordinate system axes, only one of each pair of terms can be used. For earth-fixed CRSs, this direction is often approximate and intended to provide a human interpretable meaning to the axis. When a geodetic datum is used, the precise directions of the axes may therefore vary slightly from this approximate direction. Note that an EngineeringCRS often requires specific descriptions of the directions of its coordinate system axes.
Coordinate system axis unit identifier	axisUnitID	UnitOf Measure	M	1	Identifier of the unit of measure used for this coordinate system axis. The value of this coordinate in a coordinate tuple shall be recorded using this unit of measure, whenever those coordinates use a coordinate reference system that uses a coordinate system that uses this axis.
Coordinate system remarks	remarks	CharacterString	O	1	Comments on or information about the coordinate system, including data source information.

11 Datum package

11.1 Types of datums (informative)

A datum specifies the relationship of a coordinate system to the earth or, in some applications to an Engineering CRS, to a moving platform, thus creating a coordinate reference system. A datum can be used as the basis for one-, 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, as shown in Figure 9 below. A geodetic datum is used with three-dimensional or horizontal (two-dimensional) coordinate reference systems, and requires an ellipsoid definition and a prime meridian definition. It is used to describe large portions of the earth's surface up to the entire earth's surface. 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.

11.2 Vertical datum (informative)

Further sub-typing is required to describe vertical datums adequately. The following types of vertical datum are distinguished:

a) 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. This is the default vertical datum type, because it is the most common one encountered.

b) 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.

c) 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).

d) 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.

11.3 Image datum (informative)

The image pixel 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.

11.4 Prime meridian (informative)

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 for any datum type other than geodetic, or if the datum type is geodetic and the prime meridian is Greenwich.

The prime meridian description is mandatory if the datum type is geodetic and its prime meridian is not Greenwich.

The data attributes of prime meridian are described in Table 11 in Subclause 11.5.

11.5 Ellipsoid (informative)

An ellipsoid is defined that approximates the surface of the geoid. Because of the area for which the approximation is valid – traditionally regionally, but with the advent of satellite positioning often globally – the ellipsoid is typically associated with Geographic and Projected CRSs. An ellipsoid specification shall not be provided if the datum type not geodetic.

One ellipsoid must be specified with every geodetic datum, even if the ellipsoid is not used computationally. The latter may be the case when a Geocentric CRS is used, e.g., in the calculation of satellite orbit and ground positions from satellite observations. Although use of a Geocentric CRS apparently obviates the need of an ellipsoid, the ellipsoid usually played a role in the determination of the associated geodetic datum. Furthermore one or more Geographic CRSs may be based on the same geodetic datum, which requires the correct ellipsoid the associated with any given geodetic datum.

An ellipsoid is defined either by its semi-major axis and inverse flattening, or by its semi-major axis and semi-minor axis. For some applications, for example small-scale mapping in atlases, a spherical approximation of the geoid's surface is used, requiring only the radius of the sphere to be specified

In the UML model, these options are modelled by a mandatory attribute "semiMajorAxis" in the class "SC_Ellipsoid", plus a "secondDefiningParameter" attribute. That attribute uses the CD_SecondDefiningParameter class with the stereotype "Union", meaning that one and only one of its attributes is used by an object. That class allows specification of the semiMinorAxis or inverseFlattening as the second defining ellipsoid parameter, or can specify that a spherical model is used. For a sphere, the attribute "semiMajorAxis" of the "Ellipsoid" class is interpreted as the radius of the sphere.

11.6 UML schema of the CD Datum package (normative)

Figures 9 shows the UML class diagram for the CD Datum package. The associations between Coordinate Reference System subtypes and Datum subtypes are shown in the UML class diagram in Figure 10. The definition of the object classes of this package is provided in Tables 31 through 41.

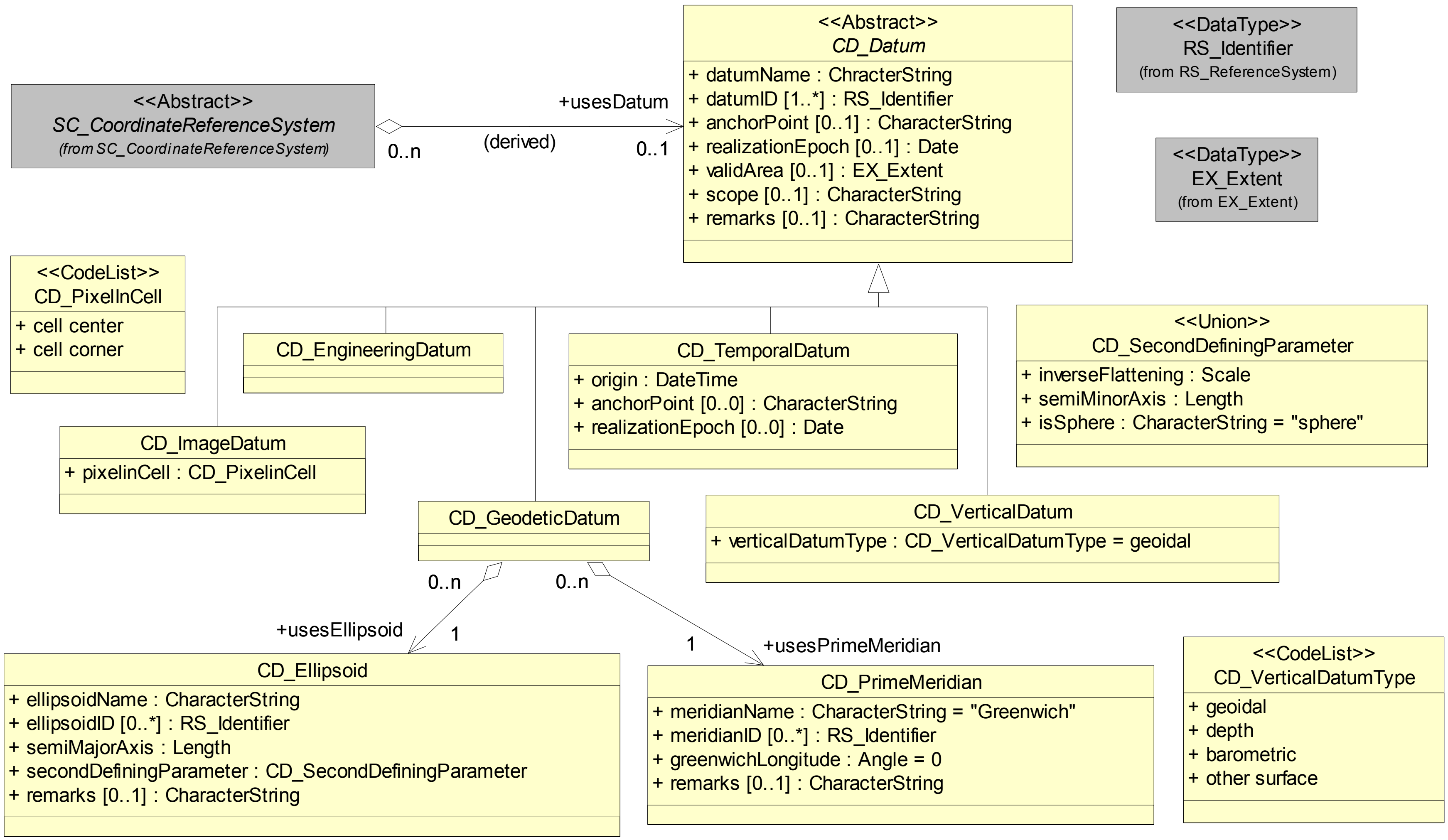

Figure 9 — CD Datum package

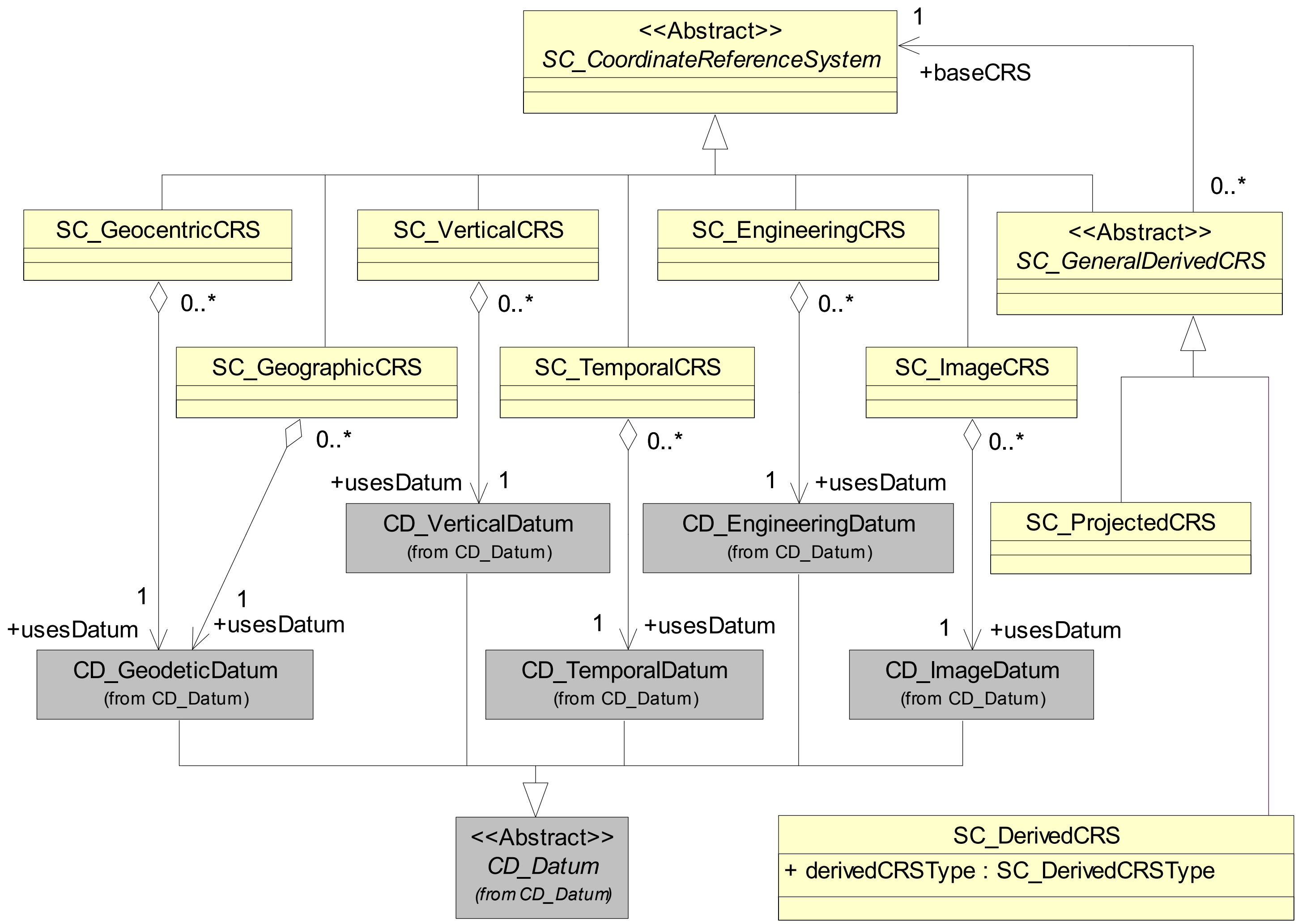

Figure 10 — Coordinate Reference System types associations to Datum types

Table 31 — Defining elements of CD_Datum class

Description:	A datum specifies the relationship of a coordinate system to the earth, thus creating a coordinate reference system. A datum uses a parameter or set of parameters that determine the location of the origin of the coordinate reference system. Each datum subtype can be associated with only specific types of coordinate systems.
Stereotype:	Abstract
Derived from	(none)
Association roles:	(derived) usesDatum from SC_CoordinateReferenceSystem [0..1]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Datum name	datumName	CharacterString	M	1	The name by which this datum is identified.
Datum identifier	datumID	RS_Identifier	O	N	Set of alternative identifications of this datum. The first datumID, if any, is normally the primary identification code, and any others are aliases.
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 the "origin", especially for Engineering and Image Datums. - For a geodetic datum, this point is also known as the fundamental point, which is traditionally the point where the relationship between geoid and ellipsoid is defined. In some cases, the "fundamental point" may consist of a number of points. In those cases, the parameters defining the geoid/ellipsoid relationship have then been averaged for these points, and the averages adopted as the datum definition. - For an engineering datum, the anchor point may be a physical point, or it may be a point with defined coordinates in another CRS. - For an image datum, the anchor point is usually either the centre of the image or the corner of the image. - For a temporal datum, this attribute is not defined. Instead of the anchor point, a temporal datum carries a separate time origin of type DateTime.

Datum realization epoch	realizationEpoch	Date	O	1	The time after which this datum definition is valid. This time may be precise (e.g. 1997.0 for IRTF97) or merely a year (e.g. 1983 for NAD83). In the latter case, the epoch usually refers to the year in which a major recalculation of the geodetic control network, underlying the datum, was executed or initiated. An old datum can remain valid after a new datum is defined. Alternatively, a datum may be superseded by a later datum, in which case the realization epoch for the new datum defines the upper limit for the validity of the superseded datum.
Datum valid area	validArea	EX_Extent	O	1	Area or region in which this CRS object is valid.
Datum scope	scope	CharacterString			Description of domain of usage, or limitations of usage, for which this CRS object is valid.
Datum remarks	remarks	CharacterString	O	1	Comments on or information about this datum, including source information.

Table 32 — Defining elements of CD_GeodeticDatum class

Description:	A geodetic datum defines the location and precise orientation in 3-dimensional space of a defined ellipsoid (or sphere) that approximates the shape of the earth, or of a Cartesian coordinate system centered in this ellipsoid (or sphere).
Stereotype:	(none)
Derived from	CD_Datum
Association roles:	usesEllipsoid to CD_Ellipsoid [1] usesPrimeMeridian to CD_PrimeMeridian [1] usesDatum from SC_GeocentricCRS [1] usesDatum from SC_GeographicCRS [1]
Public attributes:	(none)

Table 33 — Defining elements of CD_EngineeringDatum class

Description:	An engineering datum defines the origin of an engineering coordinate reference system, and is used in a region around that origin. This origin can be fixed with respect to the earth (such as a defined point at a construction site), or be a defined point on a moving vehicle (such as on a ship or satellite).
Stereotype:	(none)
Derived from	CD_Datum
Association roles:	usesDatum from SC_EngineeringCRS [1]
Public attributes:	(none)

Table 34 — Defining elements of CD_ImageDatum class

Description:	An image datum defines the origin of an image coordinate reference system, and is used in a local context only. For an image datum, the anchor point is usually either the centre of the image or the corner of the image.				
Stereotype:	(none)				
Derived from	CD_Datum				
Association roles:	usesDatum from SC_ImageCRS [1]				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Pixel in Cell	pixelinCell	CD_PixelinCell	M	1	Specification of the way the image grid is associated with the image data attributes.

Table 35 — Defining elements of CD_PixelinCell class

Description:	Specification of the way the image grid is associated with the image data attributes.				
Stereotype:	CodeList				
Derived from	(none)				
Association roles:	(none)				
Used by:	CD_ImageDatum				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Cell center	cell center	CharacterString	C	1	The origin of the image coordinate system is the centre of a grid cell or image pixel.
Cell corner	cell corner	CharacterString	C	1	The origin of the image coordinate system is the corner of a grid cell, or half-way between the centres of adjacent image pixels.

Table 36 — Defining elements of CD_VerticalDatum class

Description:	A textual description and/or a set of parameters identifying a particular reference level surface used as a zero-height surface, including its position with respect to the Earth for any of the height types recognized by this standard. There are several types of Vertical Datums, and each may place constraints on the Coordinate Axis with which it is combined to create a Vertical CRS.				
Stereotype:	(none)				
Derived from	CD_Datum				
Association roles:	usesDatum from SC_VerticalCRS [1]				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Vertical datum type	vertDatumType	CD_VerticalDatumType	M	1	Type of this vertical datum. Default is “geoidal”.

Table 37 — Defining elements of CD_VerticalDatumType class

Description:	Type of a vertical datum.
Stereotype:	CodeList
Derived from	(none)
Association roles:	(none)
Used by:	CD_VerticalDatum
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Geoidal	geoidal	CharacterString	C	1	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	depth	CharacterString	C	1	The zero point of the vertical axis is defined by a surface that has meaning for the purpose which 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.
Barometric	barometric	CharacterString	C	1	Atmospheric pressure is the basis for the definition of the origin of the associated vertical coordinate system axis.
Other surface	other surface	CharacterString	C	1	In some cases, e.g. oil exploration and production, a geological feature, such as the top or bottom of a geologically identifiable and meaningful subsurface layer, is used as a vertical datum. Other variations to the above three vertical datum types may exist and are all included in this type.
Condition: One and only one of these attributes must be supplied					

Table 38 — Defining elements of CD_TemporalDatum class

Description:	A temporal datum defines the origin of a temporal coordinate reference system.
Stereotype:	(none)
Derived from	CD_Datum
Association roles:	usesDatum from SC_TemporalCRS [1]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occur-rence	Attribute description
Origin	origin	DateTime	M	1	The date and time origin of this temporal datum.
Anchor Point	anchorPoint	CharacterString	M	0	This attribute is not used by a Temporal Datum.
Realization epoch	realizationEpoch	Date	M	0	This attribute is not used by a Temporal Datum.

Table 39 — Defining elements of CD_Ellipsoid class

Description:	An ellipsoid is a geometric figure that can be used to describe the approximate shape of the earth. In mathematical terms, it is a surface formed by the rotation of an ellipse about its minor axis.
Stereotype:	(none)
Derived from	(none)
Association roles:	usesEllipsoid from CD_GeodeticDatum [1]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occur-rence	Attribute description
Ellipsoid name	ellipsoidName	CharacterString	M	1	The name by which this ellipsoid is identified.
Ellipsoid identifier	ellipsoidID	RS_Identifier	O	N	Set of alternative identifications of this ellipsoid. The first ellipsoidID, if any, is normally the primary identification code, and any others are aliases.
Length of semi-major axis	semiMajorAxis	Length	M	1	Length of the semi-major axis of the ellipsoid.
Second defining parameter	secondDefiningParameter	CD_SecondDefiningParameter	M	1	Definition of the second parameter which describes the shape of this ellipsoid.
Ellipsoid remarks	remarks	CharacterString	O	1	Comments on or information about this ellipsoid, including source information.

Table 40 — Defining elements of CD_SecondDefiningParameter class

Description:	Definition of the second parameter that defines the shape of an ellipsoid. An ellipsoid requires two defining parameters: semi-major axis and inverse flattening or semi-major axis and semi-minor axis. When the reference body is a sphere rather than an ellipsoid, only a single defining parameter is required, namely the radius of the sphere; in that case, the semi-major axis "degenerates" into the radius of the sphere.

Stereotype: Union Derived from (none) Association roles: (none) Used by: CD_Ellipsoid Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occur-rence**	**Attribute description**
Inverse Flattening	inverseFlattening	Scale	C	1	Inverse flattening value of the ellipsoid.
Length of semi-minor axis	semiMinorAxis	Length	C	1	Length of the semi-minor axis of the ellipsoid.
“Ellipsoid = Sphere” indicator	isSphere	CharacterString	C	1	The ellipsoid is degenerate and is actually a sphere. The sphere is completely defined by the semi-major axis, which is the radius of the sphere. This attribute has the fixed text value "Sphere".
Condition: One and only one of these three elements must be supplied.					

Table 41 — Defining elements of CD_PrimeMeridian class

Description: A prime meridian defines the origin from which longitude values are determined.					
Stereotype: (none) Derived from (none) Association roles: usesPrimeMeridian from CD_GeodeticDatum [1] Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occur-rence**	**Attribute description**
Prime meridian name	meridianName	CharacterString	M	1	The name by which this prime meridian is identified. The meridianName initial value is “Greenwich”, and that value shall be used when the greenwichLongitude value is zero.
Prime meridian identifier	meridianID	RS_Identifier	O	N	Set of alternative identifications of this prime meridian. The first meridianID, if any, is normally the primary identification code, and any others are aliases.
Prime meridian Greenwich longitude	greenwich Longitude	Angle	C	1	Longitude of the prime meridian measured from the Greenwich meridian, positive eastward. The greenwichLongitude initial value is zero, and that value shall be used when the meridianName value is “Greenwich”.
Prime meridian remarks	remarks	CharacterString	O	1	Comments on the prime meridian including data source information.
Condition: The provision of a value is optional, but if no prime meridian name is provided, the prime meridian name is taken to be "Greenwich" and the Greenwich longitude value is taken to be zero.					

12 Coordinate operation package

12.1 General characteristics of coordinate operations (informative)

If the relationship between any two coordinate reference systems is known, coordinates can be *transformed* or *converted* to another coordinate reference system. The UML model therefore specifies a source and a target coordinate reference system for such coordinate operations. For that reason, a coordinate operation is often popularly said to *"transform coordinate reference system 'A' into coordinate reference system 'B'"*. Although this wording may be good enough for conversation, it should be realised that coordinate operations do <u>not</u> 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. In all these cases, the coordinate reference systems involved must be defined before the coordinate operation.

NOTE: There is an exception to the rule of explicit specification of source and target coordinate reference systems. This exception, related to so-called "defining coordinate conversions", is described in Subclause 12.2 below.

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 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. Because of this several transformations may exist for a given pair of coordinate reference systems, differing in their transformation method, parameter values and accuracy characteristics.

A coordinate operation (transformation or conversion) can be time-varying, and must be time-varying if either the source or target CRS is time varying. When the coordinate operation is time-varying, the operation method used will also be time-varying, and some of the parameters used by that operation method will involve time. For example, some of the parameters may have time, velocity, and/or acceleration values and units.

12.2 Coordinate conversions (informative)

Coordinate conversions are coordinate operations that make use of exact, defined (rather than measured or computed), and therefore error-free parameter values. Corresponding pairs of coordinate tuples in each of the two coordinate reference systems connected through a coordinate conversion have a fixed arithmetic relationship. Additionally one of the two tuples cannot exist without specification of the coordinate conversion and the 'source' coordinate reference system. Coordinate conversions are therefore intimately related to the earlier-defined concept of Derived CRS.

The best-known example of this source-derived relationship is a projected coordinate reference system, which is always 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 11 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 coordinates in the 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.

12.3 Concatenated coordinate operation (informative)

A concatenated coordinate operation is an ordered sequence 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. 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 in the SC_GeneralDerivedCRS, by specifying the base (i.e., source) CRS and the defining conversion. The derived coordinate reference system itself is the target CRS in this situation. 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.

12.4 Pass-through coordinate operation (informative)

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 combining two or more other coordinate reference systems, not themselves compound, introduces a difficulty. For example, 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 has been solved by defining a pass-through operation. This operation specifies what subset of a coordinate tuple is subject to a requested transformation. It takes the form of referencing another coordinate operation and specifying a sequence of numbers defining the positions in the coordinate tuple of the coordinates affected by that transformation.

NOTE. The order of the coordinates in a coordinate tuple shall agree with the order of the coordinate system axes as defined for the associated coordinate system.

12.5 operation method and parameters (informative)

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

Most parameter values are numeric, but for some 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 that the operation formulae be included or referenced in the relevant object, and if possible a worked example.

12.6 Parameter groups (informative)

Some operation methods may require a large number of coordinate operation parameters. Also, some operation methods require that groups of parameters be repeatable as a group. In such cases, it is helpful to group related parameters in parameter groups. Two or more parameter groups are then associated with a particular operation method, and each parameter group consists of a set of operation parameters, or other, nested parameter groups. This way of modelling is not mandatory; all coordinate operation parameters may be assigned directly to the coordinate operation method.

12.7 Implementation considerations (informative)

This explanation is not complete without giving some thought to implementations. 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 or inverse operations. The reason is that is practically impossible to store all possible pairs of coordinate reference systems in explicitly defined coordinate operations. 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; but 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 and the conclusion that there is no overlap between these.

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.

12.8 UML schema of Coordinate Operations package (normative)

Figures 11 and 12 contain the two parts of the UML class diagram for the CC Coordinate Operation package. As indicated by the note in Figure 11, Figure 12 shows additional classes and associations from the CC_Operation class shown in Figure 11.

The definition of the object classes of the CC Coordinate Operations package is provided in Tables 42 through 54.

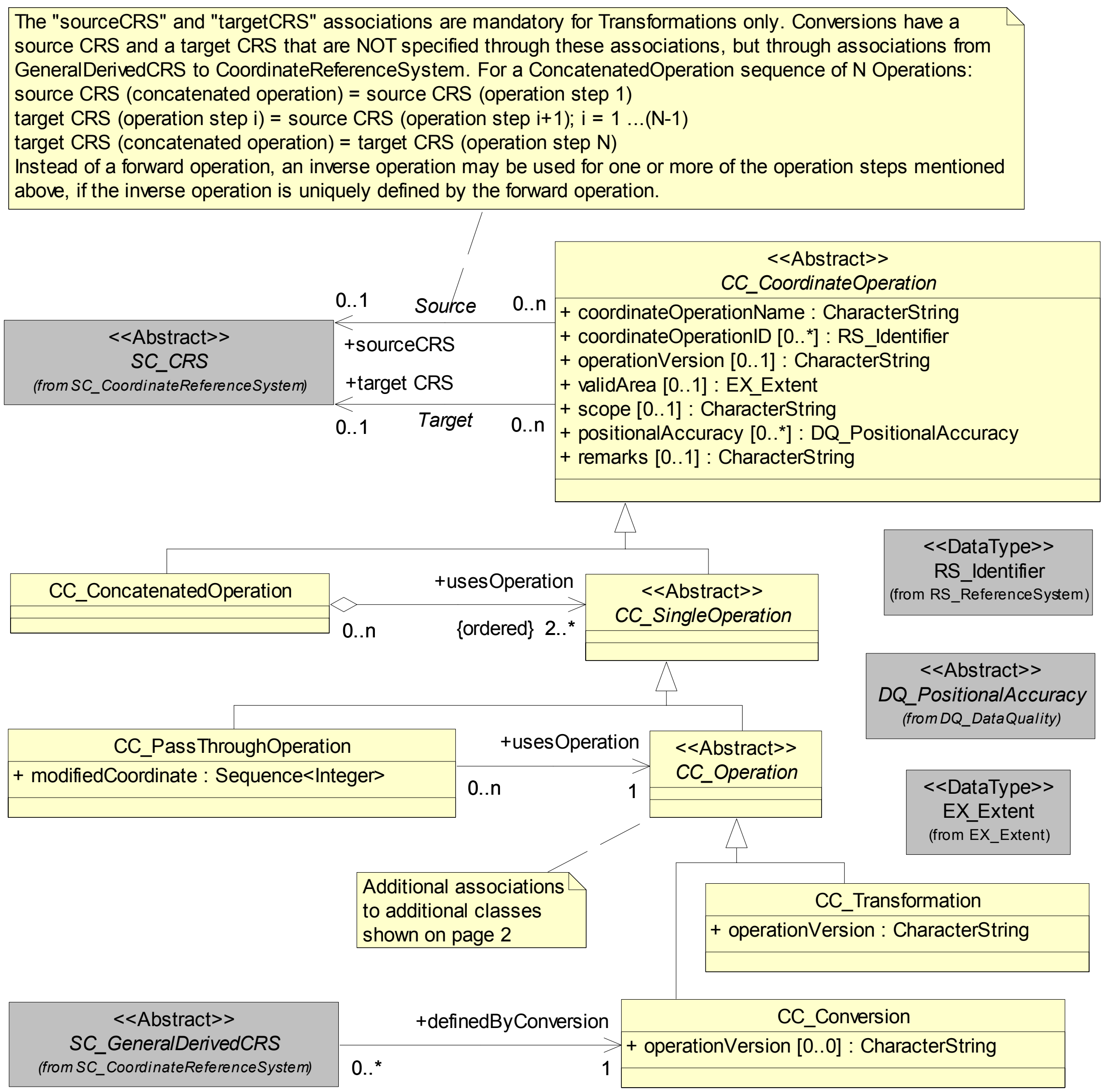

Figure 11 — CC Coordinate Operation package part 1

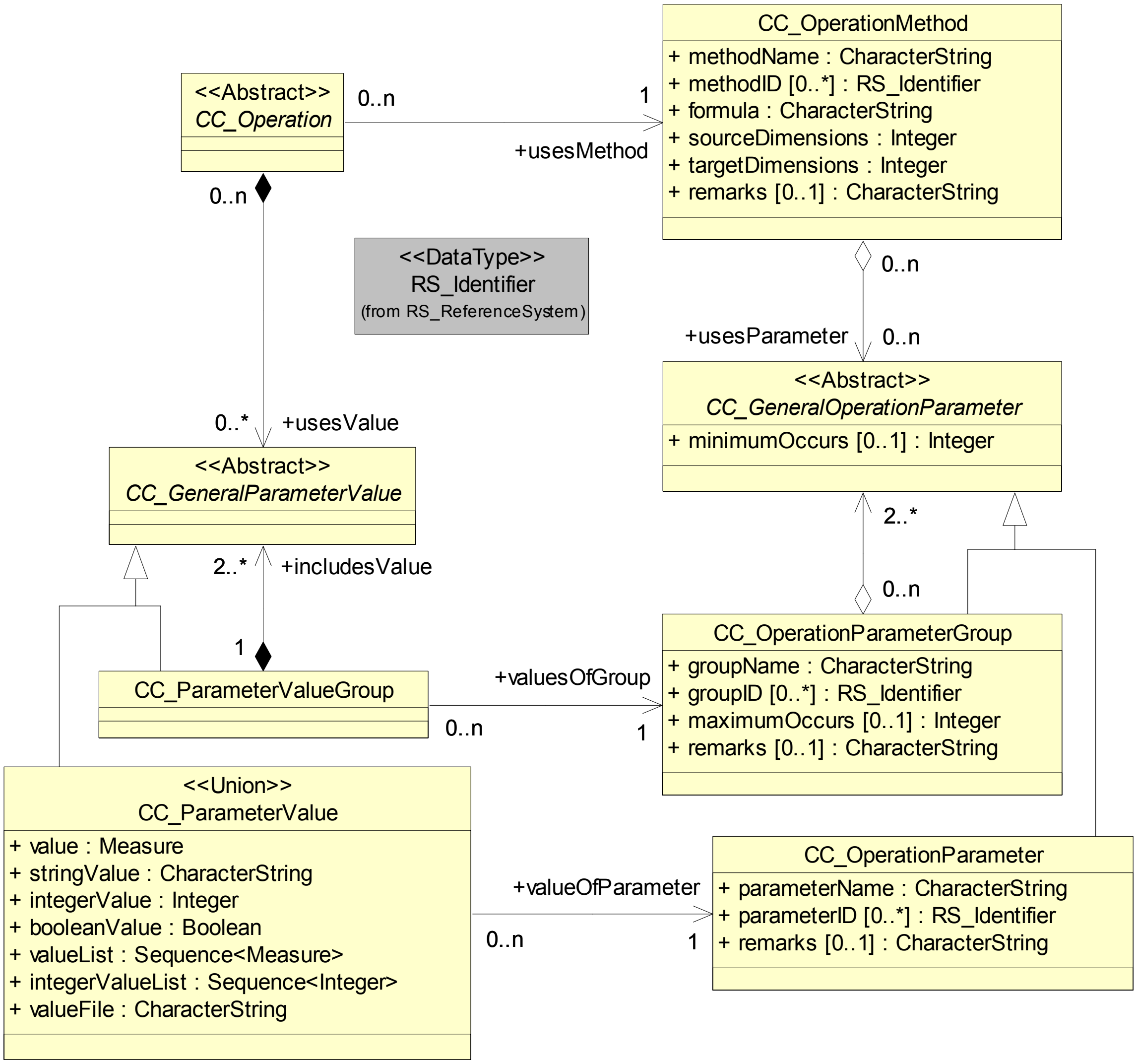

Figure 12 — CC Coordinate Operation package part 2

Table 42 — Defining elements of CC_CoordinateOperation class

Description:	A mathematical operation on coordinates that transforms or converts coordinates to another coordinate reference system. Many but not all coordinate operations (from CRS A to CRS B) also uniquely define the inverse operation (from CRS B to CRS A). In some cases, the operation method algorithm for the inverse operation is the same as for the forward algorithm, but the signs of some operation parameter values must be reversed. In other cases, different algorithms are required for the forward and inverse operations, but the same operation parameter values are used. If (some) entirely different parameter values are needed, a different coordinate operation shall be defined.
Stereotype:	Abstract
Derived from:	(none)
Association roles:	sourceCRS to SC_CRS [0..1], association named Source targetCRS to SC_CRS [0..1], association named Target
Note attached to sourceCRS and targetCRS associations:	
	The "sourceCRS" and "targetCRS" associations are mandatory for Transformations only. Conversions have a source CRS and a target CRS that are NOT specified through these associations, but through associations from GeneralDerivedCRS to CoordinateReferenceSystem. For a ConcatenatedOperation sequence of N Operations: source CRS (concatenated operation) = source CRS (operation step 1) target CRS (operation step i) = source CRS (operation step i+1); i = 1 ...(N-1) target CRS (concatenated operation) = target CRS (operation step N) Instead of a forward operation, an inverse operation may be used for one or more of the operation steps mentioned above, if the inverse operation is uniquely defined by the forward operation.
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate operation name	coordinateOperationName	CharacterString	M	1	The name by which this coordinate operation is identified.
Coordinate operation identifier	coordinateOperationID	RS_Identifier	O	N	Set of alternative identifications of this coordinate operation. The first coordinateOperationID, if any, is normally the primary identification code, and any others are aliases.
Coordinate operation version	operationVersion	CharacterString	C	1	Version of the coordinate transformation (i.e., instantiation due to the stochastic nature of the parameters). Mandatory when describing a transformation, and should not be supplied for a conversion.
Coordinate operation valid area	validArea	Ex_Extent	O	1	Area in which this CRS object is valid
Coordinate operation scope	scope	CharacterString	O	1	Description of domain of usage, or limitations of usage, for which this CRS object is valid.
Position error estimates	positional Accuracy	DQ_PositionalAccuracy	O	N	Estimate(s) of the impact of this operation on point accuracy. Gives position error estimates for target coordinates of this coordinate operation, assuming no errors in source coordinates.
Coordinate operation remarks	remarks	CharacterString	O	1	Comments on the coordinate operation including source information

Table 43 — Defining elements of CC_ConcatenatedOperation class

Description:	An ordered sequence of two or more single 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. Instead of a forward operation, an inverse operation may be used for one or more of the operation steps mentioned above, if the inverse operation is uniquely defined by the forward operation.
Stereotype:	(none)
Derived from:	CC_CoordinateOperation
Association roles:	usesOperation to CC_SingleOperation [2..*] {ordered} (associations inherited from CC_CoordinateOperation)
Public attributes:	(none)

Table 44 — Defining elements of CC_SingleOperation class

Description:	A single (not concatenated) coordinate operation.
Stereotype:	Abstract
Derived from:	CC_CoordinateOperation
Association roles:	(aggregation) usesOperation from CC_PassThroughOperation [2..*] (associations inherited from CC_CoordinateOperation)
Public attributes:	(none)

Table 45 — Defining elements of CC_PassThroughOperation class

Description:	A pass-through operation specifies that a subset of a coordinate tuple is subject to a specific coordinate operation.
Stereotype:	(none)
Derived from:	CC_SingleOperation
Association roles:	(aggregation) usesOperation to CC_SingleOperation [0..1] (associations inherited from CC_SingleOperation)
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Modified coordinates	modifiedCoordinate	Sequence<Integer>	M	1	Ordered sequence of positive integers defining the positions in a coordinate tuple of the coordinates affected by this pass-through operation.

Table 46 — Defining elements of CC_Operation class

Description:	A single (not concatenated) coordinate operation.
Stereotype:	Abstract
Derived from:	CC_SingleOperation
Association roles:	usesOperation from CC_PassThroughOperation [1] usesMethod to CC_OperationMethod [1] usesValue to CC_GeneralParameterValue [0..*] (associations inherited from CC_SingleOperation)
Public attributes:	(none)

Table 48 — Defining elements of CC_Conversion class

Description:	Definition of an algorithm used to perform a coordinate operation. Most operation methods use a number of operation parameters, although some coordinate conversions use none. Each coordinate operation using the method assigns values to these parameters.
Stereotype:	(none)
Derived from:	CC_Operation
Association roles:	definedByConversion from SC_GeneralDerivedCRS [1] (associations inherited from CC_Operation)
Public attributes:	

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Operation version	operationVersion	CharacterString	O	0	This attribute is not used in a Conversion.

Table 47 — Defining elements of CC_Transformation class

Description:	An operation on coordinates that usually includes a change of Datum. The parameters of a coordinate transformation are empirically 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.
Stereotype:	(none)
Derived from:	CC_Opereration
Association roles:	(associations inherited from CC_Operation)
Public attributes:	

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Operation version	operationVersion	CharacterString	M	1	Version of the coordinate transformation (i.e., instantiation due to the stochastic nature of the parameters). This attribute is mandatory in a Transformation.

Table 48 — Defining elements of CC_OperationMethod class

Description:	The method (algorithm or procedure) used to perform the coordinate operation				
Stereotype:	(none)				
Derived from:	(none)				
Association roles:	(aggregation) usesParameter to CC_GeneralOperationParameter [0..*] usesMethod from CC_Operation [1]				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Operation method name	methodName	CharacterString	M	1	The name by which this operation method is identified.
Coordinate operation method identifier	methodID	RS_Identifier	O	N	Set of alternative identifications of this coordinate operation method. The first methodID, if any, is normally the primary identification code, and any others are aliases.
Coordinate operation method formula	formula	CharacterString	M	1	Formula(s) or procedure used by this operation method. This may be a reference to a publication. Note that the operation method may not be analytic, in which case this attribute references or contains the procedure, not an analytic formula.
Dimension of source CRS	sourceDimensions	Integer	M	1	Number of dimensions in the source CRS of this operation method.
Dimension of target CRS	targetDimensions	Integer	M	1	Number of dimensions in the target CRS of this operation method.
Coordinate operation method remarks	remarks	CharacterString	O	1	Comments on the coordinate operation method including source information

Table 49 — Defining elements of CC_GeneralOperationParameter class

Description:	Abstract definition of a parameter or group of parameters used by an operation method.				
Stereotype:	Abstract				
Derived from:	(none)				
Association roles:	(aggregation) usesParameter from CC_OperationMethod [0..*] (aggregation) includesParameter from CC_OperationParameterGroup [2..*]				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Minimum occurrences	minimumOccurs	Integer	O	1	The minimum number of times that values for this parameter group or parameter are required. If this attribute is omitted, the minimum number is one.

Table 50 — Defining elements of CC_OperationParameterGroup class

Description:	The definition of a group of related parameters used by an operation method.				
Stereotype:	(none)				
Derived from:	CC_GeneralOperationParameter				
Association roles:	(aggregation) includesParameter to CC_GeneralOperationParameter [2..*] valuesOfGroup from CC_ParameterValueGroup [1] (associations inherited from CC_GeneralOperationParameter)				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Oblig ation**	**Maxi-mum Occur -rence**	**Attribute description**
Operation parameter group name	groupName	CharacterString	M	1	The name by which this operation parameter group is identified.
Operation parameter group identifier	groupID	RS_Identifier	O	N	Set of alternative identifications of this operation parameter group. The first groupID, if any, is normally the primary identification code, and any others are aliases.
Maximum occurrences	maximumOccurs	Integer	O	1	The maximum number of times that values for this parameter group or parameter can be included. If this attribute is omitted, the minimum number is one.
Operation parameter remarks	remarks	CharacterString	O	1	Comments on or information about this operation parameter group, including source information.

Table 51 — Defining elements of CC_OperationParameter class

Description:	The definition of a parameter used by an operation method. Most parameter values are numeric, but other types of parameter values are possible.				
Stereotype:	(none)				
Derived from:	CC_GeneralOperationParameter				
Association roles:	valueOfParameter from CC_ParameterValue [1] (associations inherited from CC_GeneralOperationParameter)				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Oblig ation**	**Maxi-mum Occur -rence**	**Attribute description**
Operation parameter name	parameterName	CharacterString	M	1	The name by which this operation parameter is identified.
Operation parameter identifier	parameterID	RS_Identifier	O	1	Set of alternative identifications of this operation parameter. The first parameterID, if any, is normally the primary identification code, and any others are aliases.
Operation parameter remarks	remarks	CharacterString	O	1	Comments on the operation parameter including source information

Table 52 — Defining elements of CC_GeneralParameterValue class

Description:	Abstract parameter value or group of parameter values.
Stereotype:	Abstract
Derived from:	(none)
Association roles:	(composition) usesValue from CC_Operation [0..*] (composition) includesValue from CC_ParameterValueGroup [2..*]
Public attributes:	(none)

Table 53 — Defining elements of CC_ParameterValueGroup class

Description:	A group of related parameter values. The same group can be repeated more than once in an Operation or higher level ParameterValueGroup, if those instances contain different values of one or more ParameterValues which suitably distinquish among those groups.
Stereotype:	(none)
Derived from:	CC_GeneralParameterValue
Association roles:	(aggregation) includesValue to CC_GeneralParameterValue [2..*] valuesOfGroup to CC_OperationParameterGroup [1] (associations inherited from CC_GeneralParameterValue)
Public attributes:	(none)

Table 54 — Defining elements of CC_ParameterValue class

Description:	A parameter value, ordered sequence of values, or reference to a file of parameter values.
Stereotype:	Union
Derived from:	CC_GeneralParameterValue
Association roles:	valueOfParameter to CC_OperationParameter [1] (associations inherited from CC_GeneralParameterValue)
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Operation parameter numeric value	value	Measure	C	1	Numeric value of the coordinate operation parameter with its associated unit of measure.
Operation parameter string value	stringValue	CharacterString	C	1	String value of an operation parameter. A string value does not have an associated unit of measure.
Operation parameter integer value	integerValue	Integer	C	1	Positive integer value of an operation parameter, usually used for a count. An integer value does not have an associated unit of measure.
Operation parameter Boolean value	booleanValue	Boolean	C	1	Boolean value of an operation parameter. A Boolean value does not have an associated unit of measure.
Operation parameter value list	valueList	Sequence<Measure>	C	1	Ordered sequence of two or more numeric values of an operation parameter list, where each value has the same associated unit of measure.
Operation parameter integer value list	integerValueList	Sequence<Integer>	C	1	Ordered sequence of two or more integer values of an operation parameter list, usually used for counts. These integer values do not have an associated unit of measure.
Operation parameter file reference	valueFile	CharacterString	C	1	Reference to a file or a part of a file containing one or more parameter values. When referencing a part of a file, that file must contain multiple identified parts, such as an XML encoded document. Furthermore, the referenced file or part of a file can reference another part of the same or different files, as allowed in XML documents.

Condition: the provision of one and only one from this list is mandatory.

13 Data Quality package

13.1 Accuracy of coordinates and impact of transformations (informative)

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. Because a covariance matrix is symmetrical, only the upper or lower diagonal part (including the main diagonal) needs to be specified.

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 separate quality measures may be specified for horizontal and for vertical position in those objects.

13.2 UML schema of the DQ Data Quality package (normative)

Figure 13 contains the UML class diagram for the DQ Data Quality package. Tables 55 through 59 list the elements defining the object classes in this package.

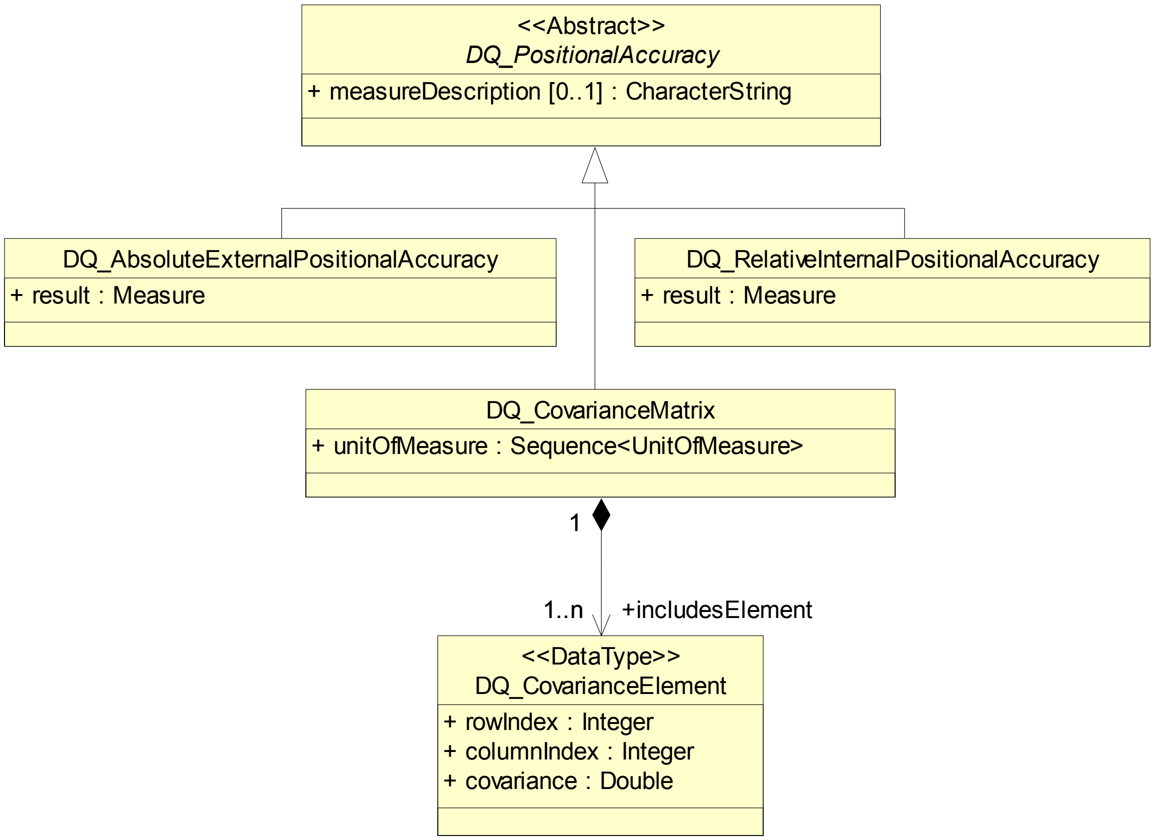

Figure 13 — Data Quality package

Table 55 — Defining elements of DQ_PositionalAccuracy class

Description:	Position error estimate (or accuracy) data.
Stereotype:	Abstract
Derived from	(none)
Association roles:	(none)
Used by:	CC_CoordinateOperation
Public attributes:	

Attribute name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur -rence	Attribute description
Accuracy measure description	measureDescription	CharacterString	O	1	A description of the accuracy parameter(s) provided.

Table 56 — Defining elements of DQ_CovarianceMatrix class

Description:	Error estimate covariance matrix.
Stereotype:	(none)
Derived from:	DQ_PositionalAccuracy
Association roles:	(composition) includesElement from DQ_CovarianceMatrix [1..*]
Used by:	(inherited from CC_CoordinateOperation)
Public attributes:	

Attribute name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Attribute description
Covariance units of measure	unitsOf Measure	Sequence<UnitOf Measure>	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

Table 57 — Defining elements of DQ_CovarianceElement class

Description:	An element of a covariance matrix.
Stereotype:	DataType
Derived from:	(none)
Association roles:	(composition) includesElement from DQ_CovarianceMatrix [1..*]
Public attributes:	

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

Table 58 — Defining elements of DQ_AbsoluteExternalPositionalAccuracy class

Description:	Closeness of reported coordinate values to values accepted as or being true.
Stereotype:	(none)
Derived from:	DQ_PositionalAccuracy
Association roles:	(none)
Used by:	(inherited from CC_CoordinateOperation)
Public attributes:	

Element name	UML identifier	Data type	Obliga-tion	Maxi-mum Occur-rence	Description
Absolute accuracy estimate	result	Measure	M	1	A quantitative result defined by the evaluation procedure used, and identified by the measureDescription.

Table 59 — Defining elements of DQ_RelativeInternalPositionalAccuracy class

Description:	Closeness of the relative positions of two or more positions to their respective relative positions accepted as or being true.
Stereotype:	(none)
Derived from	DQ_PositionalAccuracy
Association roles:	(none)
Used by:	(inherited from CC_CoordinateOperation)
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Description
Relative accuracy estimate	result	Measure	M	1	A quantitative result defined by the evaluation procedure used, and identified by the measureDescription.

Annex C
(informative)

Differences from ISO 19111

EDITOR'S NOTE This annex has not yet been updated from document 02-102.

C.1 General re: UML Schema

Inheritance of attributes is not dealt with consistently in ISO 19111 DIS. 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.

Conflict with ISO 19111?

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

C.2 Coordinate Reference System subtypes

ISO 19111 DIS do not mention 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 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:

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

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

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

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

Implemented in this document as an attribute with enumerated values. Might alternatively be implemented by subclassing, but this would result in a very complex model. A notable addition to the list not mentioned in ISO 19111 is the subtype 'Temporal CRS'.

Conflict with ISO 19111?

Yes, although it could be seen as a permitted addition where ISO 19111 describes minimum requirements.

C.3 Coordinate System subtypes

ISO 19111 introduce subtyping 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). The ISO taxonomy is, with this exception, by geometry of the coordinate frame. This document honours this subtyping, but adds some types, notably ‘linear CS’ and ‘temporal CS’.

Conflict with ISO 19111?

Yes, although it could be seen as a permitted addition where ISO 19111 describes minimum requirements.

C.4 Derived Coordinate Reference Systems

This document adds a concept that is not at all modeled in ISO 19111, viz. ‘Derived CRS’. Some CRSs cannot exist without the relationship with a source CRS having been defined, as is the case with a projected CRS. This requires the following changes to the ISO 19111 model:

- a self-reference relationship in SC_CoordinateReferenceSystem, permitting a source CRS to be defined for a derived CRS.

- 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 Defining Conversion. Leaving these relationships mandatory would lead to a potential data conflict, as the information about source and target CRS would be duplicated.

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. Since the same diagram shows a relationship to CC_Operation, equally not found back in the text, it is assumed that this is an (unsatisfactory) attempt to model projected CRSs. It is unsatisfactory because the document gives no indication how this is to be done. Furthermore, any literal implementation would result in a number of practical problems. It is for these reasons that the constructs in this document are proposed as an alternative, improved way to achieve inferred objective.

Conflict with ISO 19111?

Yes

C.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.

Bibliography

[1] ISO 31 (all parts), *Quantities and units.*

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

[3] ISO 19112, *Geographic information - Spatial referencing by geographic identifier*s.

[4] ISO 19113, *Geographic information – Quality Principles.*

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

[6] OGC Document 02-102*, The OpenGIS® Abstract Specification – Topic 2: Spatial Reference Systems.*

