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1. Background

OGC Abstract Specification Topic 2, Spatial referencing by coordinates, has been submitted to ISO as a proposed revision of 19111. In May 2004 ISO TC 211 resolved to submit a new work item proposal for the revision of 19111 based upon OGC 03-073r4 together with comments received. Document 04-046 was the proposed revision draft. Comments upon it received by the editor by 22nd July were considered before submission to ISO.

This document 04-046r3 is the draft circulated within ISO TC211 as a New Work Item Proposal to revise ISO 19111 - revision of 19111, Spatial referencing by coordinates. A small number of editorial corrections were made to the document circulated as 04-046r2. This OGC document is revised for completeness.

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Secretariat: SN

Geographic information — Spatial referencing by coordinates

Information géographique — Système de références spatiales par coordonnées

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Foreword

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

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

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

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

ISO 19111 was prepared by Technical Committee ISO/TC 211, *Geographic information / Geomatics*.

This second edition cancels and replaces the first edition (ISO 19111:2003), which has been technically revised.

Introduction

Geographic information contains spatial references which relate the features represented in the data to positions in the real world. Spatial references fall into two categories:

— those using coordinates;

— those based on geographic identifiers.

This International Standard deals only with spatial referencing by coordinates. Spatial referencing by geographic identifiers is defined in ISO 19112, *Geographic information — Spatial referencing by geographic identifiers*.

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 which has a reference to the Earth. This International Standard describes the elements that are necessary to define fully various types of coordinate systems and coordinate reference systems applicable to geographic information. The subset of elements required is partially dependent upon the type of coordinates. This International Standard also includes optional fields to allow for the inclusion of non-essential coordinate reference system information. The elements are intended to be both machine and human readable. A coordinate set, which by definition uses one coordinate reference system, requires one coordinate reference system description.

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

Geographic information — Spatial referencing by coordinates

1 Scope

This International Standard defines the conceptual schema for the description of spatial referencing by coordinates, optionally extended to spatio-temporal referencing. It describes the minimum data required to define 1-, 2- and 3-dimensional spatial coordinate reference systems with an extension to merged spatial-temporal 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.

This International Standard 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 requirements

This International Standard defines two classes of conformance, Class A for conformance of coordinate reference systems and Class B for coordinate operations between two coordinate reference systems. Any coordinate reference system claiming conformance to this International Standard shall satisfy the requirements given in Annex A, Clause A.1. Any coordinate operation claiming conformance to this International Standard shall satisfy the requirements given in Annex A, Clause A.2.

3 Normative references

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

ISO 1000, *SI units and recommendations for use of their multiples and of certain other units*

ISO/TS 19103:—[1)], *Geographic information — Conceptual schema language*

ISO 19108, *Geographic Information – Temporal schema*

ISO 19115, *Geographic Information – Metadata*

Normative reference to ISO 19115 is restricted as follows. In this International Standard normative reference to 19115 excludes the MD_CRS class and its component classes. ISO 19115 class MD_CRS and its component, aggregated, classes specify descriptions of coordinate reference systems elements. These elements are modelled in this International Standard.

ISO 19123, *Geographic Information – Schema for coverage geometry and functions*

1) To be published.

4 Terms and definitions

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

4.1
affine coordinate system
coordinate system in Euclidean space with straight axes that are not necessarily mutually perpendicular

4.2
Cartesian coordinate system
coordinate system which gives the position of points relative to n mutually perpendicular axes

NOTE *n* is 1, 2 or 3 for the purposes of this International Standard.

4.3
compound coordinate reference system
coordinate reference system using at least two independent **coordinate reference systems** describing horizontal position and/or vertical position and/or temporal position or positions

NOTE A compound coordinate reference system does not contain another compound coordinate reference system.

4.4
concatenated operation
coordinate operation consisting of sequential application of multiple **coordinate operations**

4.5
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 are qualified by units.

4.6
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 ellipsoidal and Cartesian coordinate systems or between geographic coordinates and projected coordinates, or change of units such as from radians to degrees or feet to meters.

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

4.7
coordinate operation
change of **coordinates**, based on a one-to-one relationship, from one **coordinate reference system** to another

NOTE Supertype of coordinate transformation and coordinate conversion.

4.8
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.

4.9
coordinate set
dataset of **coordinate tuples** related to the same **coordinate reference system**

4.10
coordinate system
set of mathematical rules for specifying how **coordinates** are to be assigned to points

4.11
coordinate 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 coordinate transformation uses parameters which are derived empirically by a set of points with known coordinates in both coordinate reference systems.

4.12
coordinate tuple
tuple composed of a **sequence** of **coordinates**

NOTE The number of coordinates in the coordinate tuple equals the dimension of the coordinate system; the order of coordinates in the coordinate tuple is identical to the order of the axes of the coordinate system.

4.13
cylindrical coordinate system
three-dimensional **coordinate system** with two distance and one angular **coordinates**

4.14
datum
parameter or set of parameters that define the position of the origin, the scale, and the orientation of a **coordinate reference system**

4.15
depth
distance of a point from a chosen reference surface measured downward along a line perpendicular to that surface

NOTE 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 where it is generally measured along the wellbore path. This path may vary significantly from the local vertical. Nevertheless the distance along the wellbore path is referred to as 'depth'.

4.16
dimension
coordinate dimension
number of measurements or axes needed to describe a position in a **coordinate system**

[ISO 19107]

4.17
easting
E
distance in a **coordinate system**, eastwards (positive) or westwards (negative) from a north-south reference line

4.18
ellipsoid
surface formed by the rotation of an ellipse about a main axis

NOTE In this International Standard, ellipsoids are always oblate, meaning that the axis of rotation is always the minor axis.

4.19
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**

4.20
ellipsoidal height
geodetic height
h
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 ellipsoidal coordinate system and never on its own.

4.21
engineering coordinate reference system
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 coordinate reference systems associated with orbiting spacecraft.

NOTE 1 A coordinate 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 coordinate reference system 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.

4.22
engineering datum
local datum
datum describing the relationship of a **coordinate system** to a local reference

NOTE Engineering datum excludes both geodetic and vertical datums.

EXAMPLE A system for identifying relative positions within a few kilometres of the reference point.

4.23
flattening
f
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; $1/f$ is also known as reciprocal flattening.

4.24
geocentric coordinate reference system
3-dimensional **coordinate reference system** with its origin at the centre of the modelled Earth

4.25
geodetic datum
datum describing the relationship of a 3D or 2D **coordinate system** to the Earth

4.26
geodetic latitude
ellipsoidal latitude
φ
angle from the equatorial plane to the perpendicular to the **ellipsoid** through a given point, northwards treated as positive

4.27
geodetic longitude
ellipsoidal longitude
λ
angle from the **prime meridian** plane to the **meridian** plane of a given point, eastward treated as positive

4.28
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 A geographic coordinate system can be 2D or 3D. In a 3D geographic coordinate system, the third dimension is height above the ellipsoid surface.

4.29
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 which is everywhere perpendicular to the direction of gravity.

4.30
gravity-related height
H
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 mean sea level.

4.31
Greenwich meridian
meridian that passes through the position of the Airy Transit Circle at the Royal Observatory Greenwich, United Kingdom

NOTE Most geodetic datums use the Greenwich meridian as the prime meridian. Its precise position differs slightly between different datums.

4.32
height
h, H
distance of a point from a chosen reference surface measured upward along a line perpendicular to that surface

NOTE A height below the reference surface will have a negative value.

4.33
image coordinate reference system
engineering coordinate reference system applied to locations in images

4.34
image datum
engineering datum which defines the origin of an **image coordinate reference system**

4.35
linear coordinate system
one-dimensional **coordinate system** in which a linear feature forms the axis

EXAMPLES Distances along a pipeline; depths down a deviated oil well bore.

4.36
map projection
coordinate conversion from an **ellipsoidal coordinate system** to a plane

4.37
mean sea level
average level of the surface of the sea over all stages of tide and seasonal variations

NOTE Mean sea level in a local context normally means mean sea level for the region calculated from observations 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 m.

4.38
meridian
intersection of an **ellipsoid** by a plane containing the **semi-minor axis** of the **ellipsoid**

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

4.39
northing
N
distance in a **coordinate system**, northwards (positive) or southwards (negative) from an east-west reference line

4.40
pixel
smallest element of a digital image to which attributes are assigned

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

4.41
polar coordinate system
two-dimensional **coordinate system** in which position is specified by distance and direction from the origin

NOTE In three dimensions called spherical coordinate system.

4.42
prime meridian
zero meridian
meridian from which the longitudes of other **meridians** are quantified

4.43
projected coordinate reference system
coordinate reference system derived from a two-dimensional **geographic coordinate reference system** by applying a **map projection** and using a **Cartesian coordinate system**

4.44
semi-major axis
a
semi-diameter of the longest axis of an **ellipsoid**

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

4.45
semi-minor axis
b
semi-diameter of the shortest axis of an **ellipsoid**

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

4.46
sequence
finite, ordered collection of related items (objects or values) that may be repeated

[ISO 19107]

4.47
spatial reference
description of position in the real world

NOTE This may take the form of a label, code or set of coordinates.

4.48
spherical coordinate system
three-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.

4.49
temporal reference system
reference system against which time is measured

[ISO 19108]

4.50
temporal datum
datum defining the origin of a **temporal reference system**

4.51
time coordinate system
one-dimensional **coordinate system** containing a time axis used in a **temporal reference system** to describe the temporal position of a point in the specified time **units** from a specified **temporal datum**

4.52
tuple
ordered list of values

[ISO 19136]

4.53
unit
unit of measure
defined quantity in which dimensioned parameters are expressed

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

4.54
vertical coordinate reference system
one-dimensional **coordinate reference system** used for **gravity-related height** or **depth** measurements

4.55
vertical datum
datum describing the relation of **gravity-related heights** or **depths** to the Earth

NOTE In most cases the vertical datum will be related to mean 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

a	semi-major axis
b	semi-minor axis
E	easting
f	flattening
H	gravity-related height
h	ellipsoidal height
N	northing
λ	geodetic longitude
φ	geodetic latitude
E, N	Cartesian coordinates in a projected coordinate reference system
X, Y, Z	Cartesian coordinates in a geocentric coordinate reference system

Editor's note to ISO secretariat. The use of upper case X, Y and Z is deliberate. Upper case is conventional in the geographic information/geomatics community. In this community the lower case of these symbols have alternative meanings outside of the scope of this standard. Please do not change the symbols to lower case. Thank you.

i, j, [k]	Cartesian coordinates in an engineering coordinate reference system
r, θ	polar coordinates in a 2D engineering coordinate reference system
r, Ω, θ	spherical coordinates in a 3D engineering or geocentric coordinate reference system

5.2 Abbreviated terms

CC	change coordinates (package abbreviation in UML model)
CD	coordinate datum (package abbreviation in UML model)
CCRS	compound coordinate reference system
CRS	coordinate reference system
CS	coordinate system (also, package abbreviation in UML model)

IO	identified object (package abbreviation in UML model)
MSL	mean sea level
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
URI	Uniform Resource Identifier
1D	one-dimensional
2D	two-dimensional
3D	three-dimensional

5.3 UML Notation

In this International Standard, the conceptual schema for describing coordinate reference systems and coordinate operations is modelled with the Unified Modelling Language (UML). The basic data types are defined in ISO/TS 19103.

The UML notations used in this International Standard are described in Figure 1.

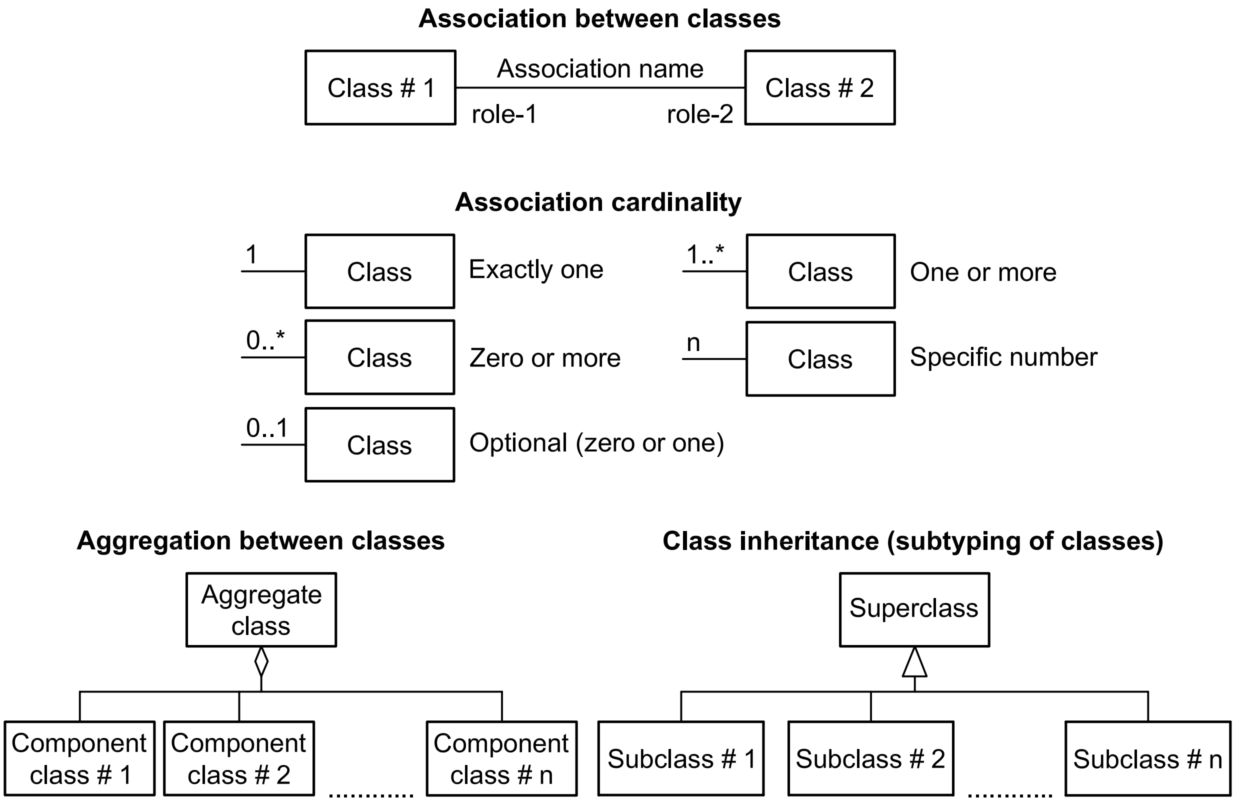


Figure 1 — UML notation

In this International 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.

The following data types defined in ISO/TS 19103 are used:

a) Angle – amount of rotation required to bring one line or plane into coincidence with another.

b) Boolean – a value specifying TRUE or FALSE.

c) CharacterString – a sequence of characters.

d) Date – a character string which comprises year, month and day in the format as specified by ISO 8601.

e) DateTime – a character string which comprises year, month, day and time of the day to the appropriate level of precision in the format as specified by ISO 8601

f) GenericName – a generic name structure in the context of namespaces, defined in ISO/TS 19103.

g) Integer – an integer number.

h) Length – the measure of distance.

i) Measure – result from performing the act or process of ascertaining the extent, dimensions or quantity of some entity.

j) Number – abstract class that can be sub-typed to a specific number type (real, integer, decimal, double, float).

k) Scale – the ratio of one quantity to another.

l) Unit of Measure – any of the systems devised to measure some physical quantity.

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>”.

5.4 Attribute status

In this International Standard, attributes are given an obligation status:

Obligation	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.

In this International Standard the Maximum Occurrence column indicates the maximum number of occurrences of attribute values that are permissible, with N indicating no upper limit.

6 The geodetic context of spatial referencing by coordinates

6.1 Coordinates

The geometry of spatial features might 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 impractical: performing calculations on spatial data would be a major effort. The expression of the position of a point by using 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, instead of one distance ratio and one angle, six coordinates are required. The inherent degrees of freedom (four in 2D, seven in 3D) have to be satisfied by choosing the origin of the coordinate axes, their unit of measure and the orientations of the axes. This choice underlines the fact that coordinates are human-defined quantities and **not** natural phenomena. Although this may seem self-evident, it is often overlooked and has consequences for the interpretation of coordinates and their error characteristics.

In this International Standard, a coordinate is one of *n* scalar values that define the position of a single point. A *coordinate tuple* is an ordered list of coordinates. The coordinate tuple is composed of one, two or three spatial coordinates. The coordinates shall be mutually independent and their number shall be equal to the dimension of the coordinate space; for example a coordinate tuple shall not contain two heights. The order of the elements of the tuple and their unit(s) of measure are parts of the coordinate reference system definition.

NOTE In other contexts the term *ordinate* is used for a single value and coordinate for multiple ordinates. Such usage is not part of this International Standard.

In this International Standard, a *coordinate set* is a collection of coordinate tuples. By definition, all coordinate tuples within a coordinate set shall be referenced to the same system. Conversely, if coordinate tuples are referenced to different systems they shall be segregated into different coordinate sets.

The concept of a *coordinate reference system* (CRS) captures the choice of values for the parameters that constitute the degrees of freedom of the coordinate space. The fact that such a choice has to be made, either arbitrarily or by adopting values from survey measurements, leads 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. Without the full specification of the coordinate reference system, coordinates are ambiguous at best and meaningless at worst. However for some interchange purposes it is sufficient to confirm the identity of the system without necessarily having the full system definition.

The concept of coordinates may be expanded from a strictly spatial context to include time. Time is then added as another coordinate 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 coordinate is expressed as the two-way travel time of a sound signal in milliseconds, as is common in seismic imaging. A second time-coordinate indicates the time of observation, usually expressed in whole years.

A coordinate reference system (CRS) identification or definition in accordance with this International Standard shall be associated with every coordinate tuple. It is not necessary to supply the CRS definition with every point; if a CRS is associated with a coordinate set, all coordinate tuples in that coordinate set inherit the association. One CRS identification or definition shall be associated with each coordinate set.

The description of quality of a spatial reference is covered by the provisions of ISO 19115.

6.2 Some geodetic concepts

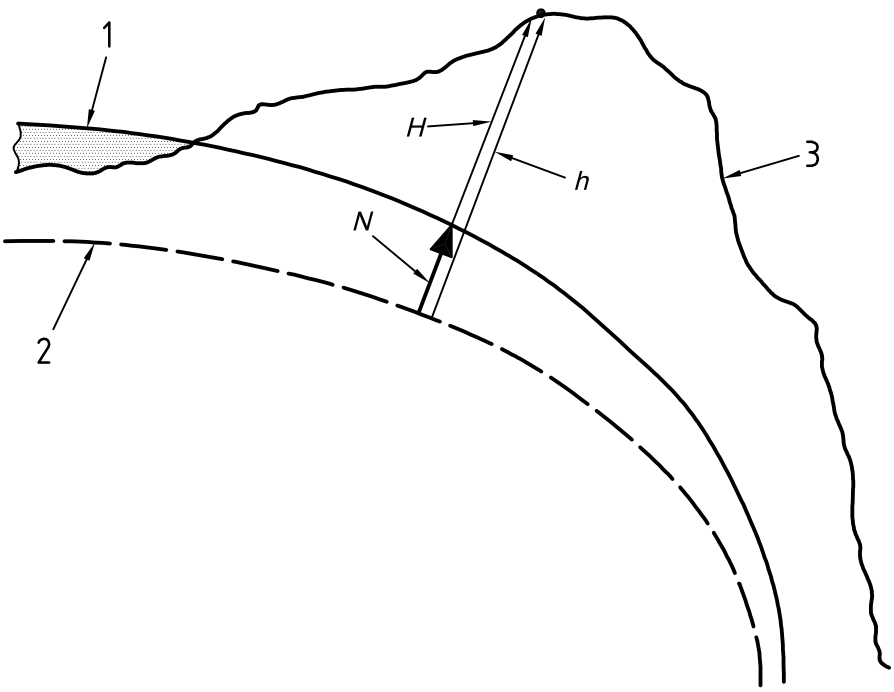
Geodesy is the applied science that aims to determine the size and shape of the earth. In a more practical and local sense, this may be understood to mean the determination of the relative positions of points on or near the earth's surface. Survey measurements and techniques are the means to achieve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

The most accurate reference shape approximating the earth is the geoid, a surface that is defined as having equal gravity potential and being approximately at mean sea level. The gravity vector at mean sea level is everywhere perpendicular to this surface. Topographic heights (H) are typically expressed relative to the geoid.

But due to the irregular mass distribution in the earth's interior the geoid has an irregular shape. This makes it difficult to use in calculations for horizontal spatial data.

To facilitate easier spatial calculations the geoid is approximated by the nearest regular body, an oblate ellipsoid, in which the oblateness corresponds to the flattening of the physical earth at the poles due to the earth's rotation. The ellipsoid is a reasonably accurate approximation of the geoid, the geoid undulating around the ellipsoid's surface with variations in the order of several tens of metres.

The ellipsoid forms the basis of the best-known type of coordinate reference system: the Geographic CRS. The position of a point relative to the ellipsoid is expressed by means of geographic coordinates: geodetic latitude (φ) and geodetic longitude (λ). The height above the ellipsoid (h) is an inseparable element of a geographic 3D coordinate tuple. Note however that ellipsoidal height (h) differs from "topographic" heights related to the geoid (H) by the amount by which the geoid undulates relative to the ellipsoid – see Figure 2. Geodetic science distinguishes several different types of gravity-related heights (H), differentiated by the assumptions made about the earth's gravity field. The differences between these types of gravity-related height are beyond the scope of this International Standard.



Key

1 geoid

2 ellipsoid

3 surface of the Earth

h = ellipsoidal height, measured from ellipsoid along perpendicular passing through point; $h = H + N$

H = gravity-related height, measured along direction of gravity from vertical datum plane at geoide

N = geoid height, height of geoid above ellipsoid

Figure 2 — Ellipsoidal and gravity-related heights

There is not just one ellipsoid. An ellipsoid is a matter of choice, and therefore many choices are possible. The size and shape of an ellipsoid was traditionally chosen such that the surface of the geoid is matched as closely as possible locally, e.g. in a country. A number of global best-fit ellipsoids are now available. An association of an ellipsoid with the earth is made through the definition of the size and shape of the ellipsoid and the position and orientation of this ellipsoid with respect to the earth. Collectively this choice is captured by the concept of "geodetic datum". A change of size, shape, position or orientation of an ellipsoid will result in a change of geographic coordinates of a point and be described as a different geodetic datum. Conversely geographic coordinates are unambiguous only when associated with a 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. The same map projection can be applied to many geographic CRSs, resulting in many projected CRSs each of which is related to the same geodetic datum as the geographic CRS on which it was based.

7 The UML model for spatial referencing by coordinates – overview

The specification for spatial referencing by coordinates is defined in this International Standard in the form of a UML model with supplementary text. The UML model contains five primary UML packages, as shown in Figure 3, 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 arrowed line shows the dependency (at the head of the arrow) of one package upon another package.

Figure 3 — UML model packages and dependencies

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

8 Identified Object package

8.1 General

The Identified Object package contains attributes common to several objects used in spatial referencing by coordinates. These objects, for example datum, ellipsoid or coordinate system axis or coordinate operation, inherit attribute values from the Identified Object package.

One of the attributes is the object primary name. For example, a datum name might be "North American Datum of 1983". This may have alternative names or aliases, for example the abbreviation "NAD83". Object primary names have a data type RS_Identifier which is defined in ISO 19115 whilst aliases have a data type GenericName which is defined in ISO/TS 19103.

NOTE 1 Through its subclassing from RS_ReferenceSystem which is defined in ISO 19115, SC_CRS inherits the attribute *name*. Because of this inheritance the SC_CRS class does not use IO_IdentifiedObject for its primary name. But like other classes described in this International Standard, it may use the alias attribute from IO_IdentifiedObjectBase for aliases.

Another attribute is identifier. This is a unique code used to reference an object in a given place. For example, an external geodetic register might give the NAD83 datum a unique code of "6269". Identifiers have a data type of RS_Identifier.

In addition to the use of an identifier as a reference to a definition in a remote register, it may also be included in an object definition to allow remote users to refer to the object.

Object identification shall be through:

either (a) a full object description as defined in this International Standard;

or (b) reference to a full object description in a register of geodetic parameters conforming to the requirements of ISO 19127. The reference is made through the register's object identifier;

or (c) both full description and reference to a description in a register. If there is a conflict between the two the register description shall prevail.

(a) and (b) are alternative means of providing a full object description. (b) is recommended for simplicity but if the object description is not available from a register it shall be given explicitly and in full. In both methods the order of coordinates in each coordinate tuple shall be as given in the coordinate system description.

When using method (b), reference to a geodetic register, applications that require only to confirm the *identification* of an object can do so through the register citation and object unique identifier from that register. They do not need to retrieve the elements that constitute the full object *description* from the register unless there is a need to quote these or to perform a coordinate operation on the coordinate set.

NOTE 2 Implementers are warned that there may be issues associated with the specification of elements by identifier, referring to a publicly available register of geodetic parameters. The latest version or edition of the register may not be sufficient to uniquely describe the referenced element. In any register, errors in the data may be corrected in accordance with rules specific to that register and defined by the responsible registration authority. The rules for dealing with erroneous data need to be known to implementers in order to be able to find the data that is required by their application; either the most up-to-date register information or, because historically it was used to transform spatial data that is still in use, the erroneous information from the past.

8.2 UML schema of Identified Object package

Figure 4 shows the UML class diagram of the Identified Object package. The definition of the object classes are provided in Tables 1 and 2.

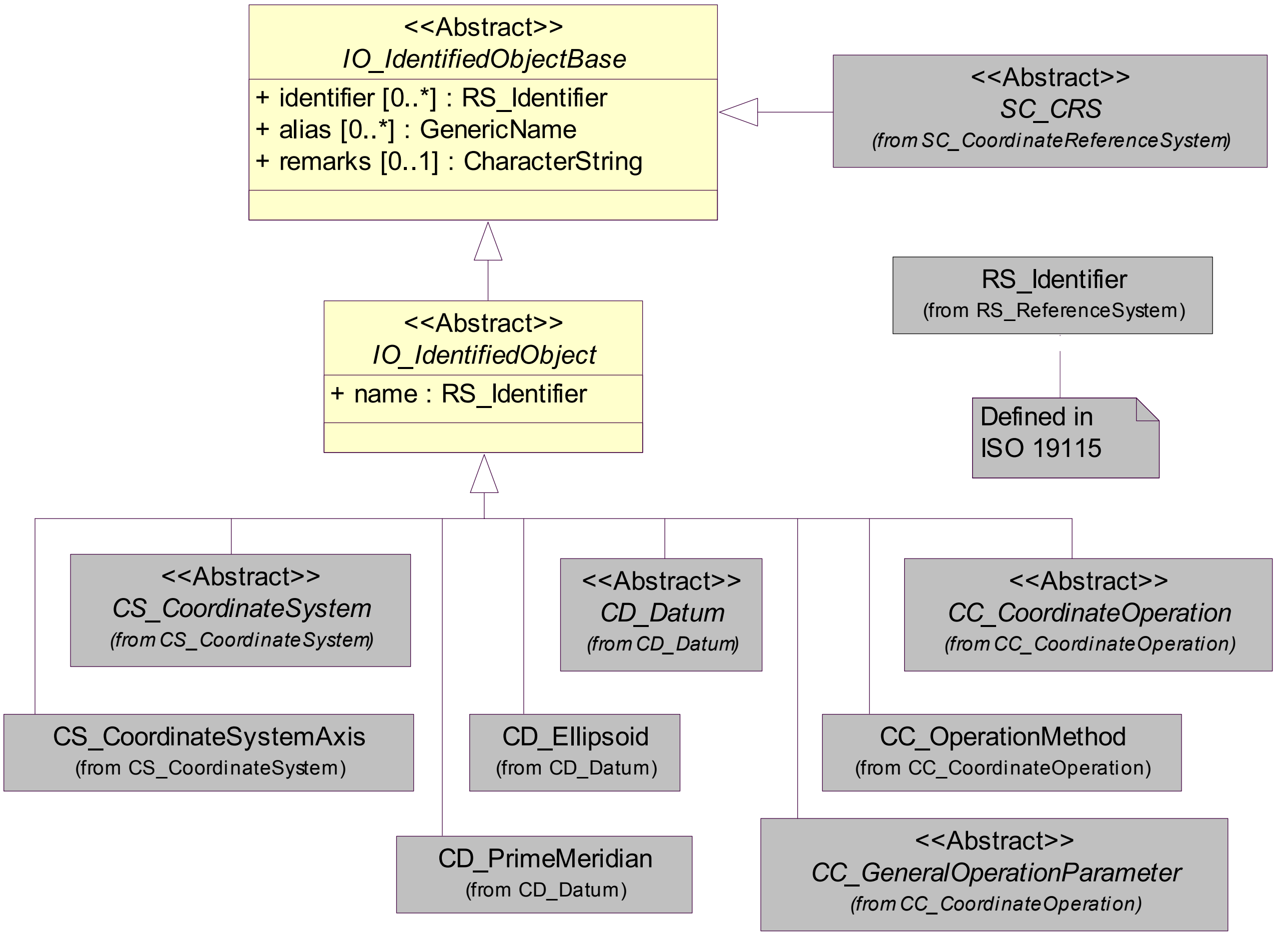


Figure 4 — IO Identified Object package

Table 1 — Defining elements of IO_IdentifiedObjectBase class

Description:	Supplementary identification and remarks information for a CRS or CRS-related object.				
Stereotype:	Abstract				
Derived from	(none)				
Association roles:	(none)				
Used by:	SC_CRS CS_CoordinateSystem CS_CoordinateSystemAxis CD_Datum CD_Ellipsoid CD_PrimeMeridian CC_CoordinateOperation CC_OperationMethod CC_GeneralOperationParmeter				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Object alias	alias	GenericName	O	N	An alternative name by which this object is identified.
Object identifier	identifier	RS_Identifier	O	N	An identifier which references elsewhere the object's defining information; alternatively an identifier by which this object can be referenced.
Object remarks	remarks	CharacterString	O	1	Comments on or information about this object, including data source information.

Table 2 — Defining elements of IO_IdentifiedObject class

Description:	Identifications of a CRS-related object.				
Stereotype:	Abstract				
Derived from	IO_IdentifiedObjectBase				
Association roles:	(none)				
Used by:	CS_CoordinateSystem CS_CoordinateSystemAxis CD_Datum CD_Ellipsoid CD_PrimeMeridian CC_CoordinateOperation CC_OperationMethod CC_GeneralOperationParmeter				
Public attributes:	3 attributes inherited from IO_IdentifiedObjectBase, plus:				
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Object name	name	RS_Identifier	M	1	The primary name by which this object is identified.

9 Coordinate Reference System package

9.1 Reference system

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 International Standard 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 International Standard and the associated UML model is confined to the description of position through coordinates.

The RS Reference System package and datatypes are described in ISO 19115. Table 3 shows the attributes inherited by the CRS class.

Table 3 — Attributes of RS_ReferenceSystem class inherited from ISO 19115

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Reference system name	name	RS_Identifier	M	1	Value uniquely identifying an object within a namespace.
Reference system validity	domainOfValidity	EX_Extent	O	N	Information about horizontal, vertical and temporal extent.

9.2 Coordinate reference system

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 reference 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 6.1. 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 shown in Figure 4.

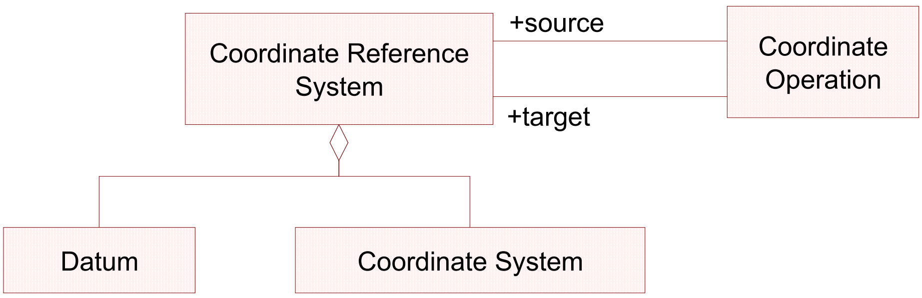


Figure 5 — High-level conceptual model for spatial referencing by coordinates

For the purposes of this International Standard, a coordinate reference system shall not change with time. For engineering coordinate reference systems defined on moving platforms such as cars, ships, aircraft and spacecraft, the transformation to an earth-fixed coordinate reference system may include a time element. The intention is to exclude the option to describe the time variability of geodetic coordinate reference systems as a result of for example 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.

9.3 Principal sub-types of coordinate reference system

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 ellipsoid; a 3D Geographic CRS is used when positions are described on, above or below the 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 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 coordinates referenced to geocentric, geographic or projected CRSs. These engineering 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 for images a separate user community with its own vocabulary exists. 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 therefore, ellipsoidal heights (*h*) cannot be captured in a vertical coordinate reference system: ellipsoidal heights cannot exist independently, but only as an 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.

9.4 Additional sub-types of coordinate reference system

9.4.1 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.

9.4.2 Compound coordinate reference system

The traditional separation of horizontal and vertical position described in Clause 6 has resulted in coordinate reference systems that are horizontal (2D) and vertical (1D) in nature, as opposed to truly 3-dimensional. 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 2D+1D coordinates are referenced combines the separate horizontal and vertical coordinate reference systems of the horizontal and vertical coordinates. Such a system is called a compound coordinate reference system (Compound CRS). It consists of a non-repeating sequence of two or more single coordinate reference systems, none of which can itself be compound. In general, a Compound CRS may contain any number of axes. The coordinate order within a coordinate tuple for a compound CRS shall follow the order of the component single CRSs and then the order of coordinates within the coordinate tuples for each of those component single CRSs.

For spatial coordinates, a number of constraints exist for the construction of Compound CRSs. Coordinate reference systems that are combined shall 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) + Vertical

f) Engineering (1D linear) + Vertical

Any single coordinate reference system, or any of the above listed combinations of spatial compound coordinate reference systems, can have a temporal reference system added. More than one temporal reference system may be added if these axes represent different time quantities.

When more than two systems are combined to form a compound coordinate reference system, nesting of CCRSs is not permitted – the individual single systems are aggregated together. Figure 6 shows examples of the possible composition of spatial and spatio-temporal compound coordinate reference systems.

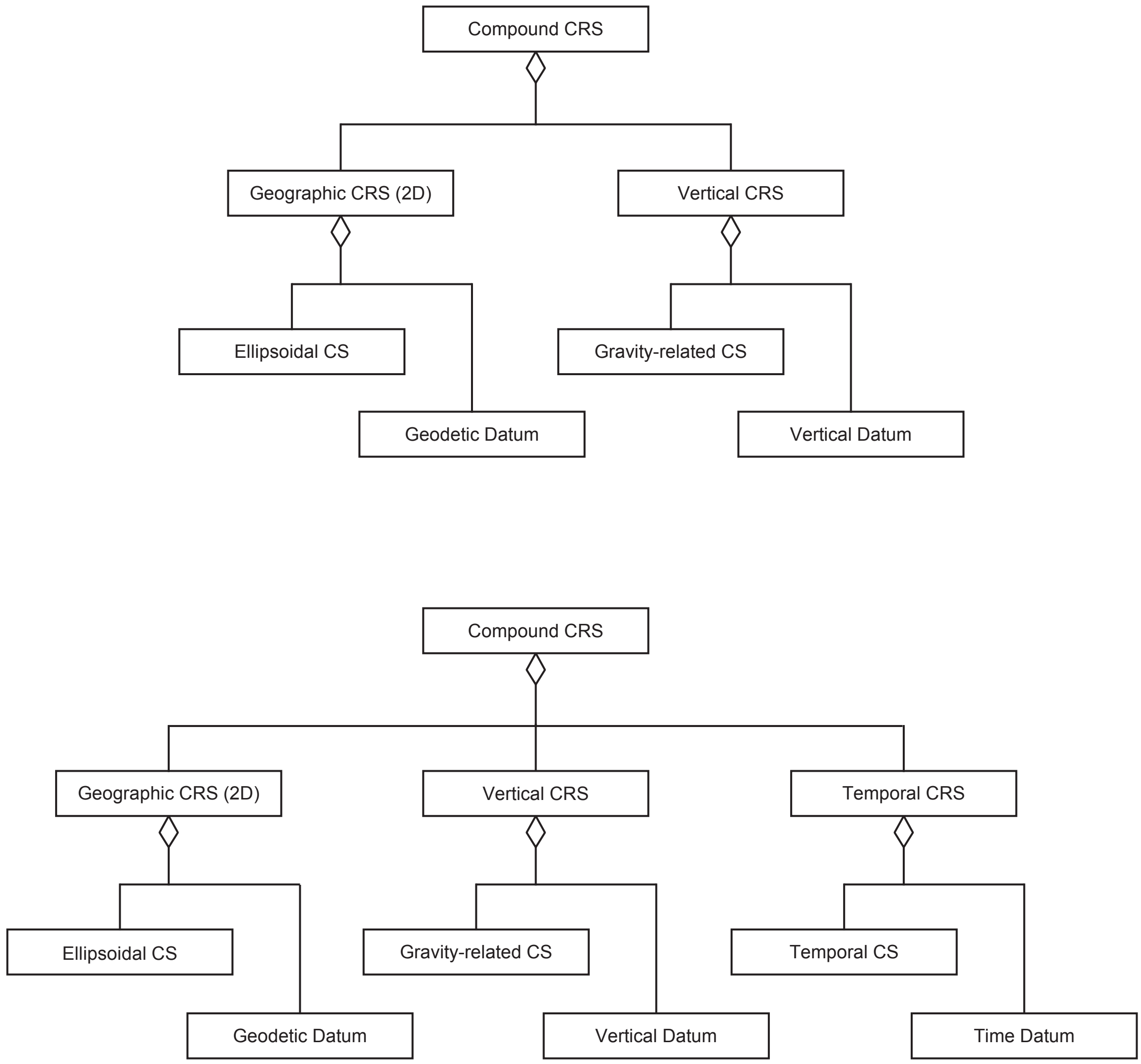


Figure 6 — Examples of spatial and spatio-temporal compound coordinate reference systems

9.4.3 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 from which it was derived is called the Base CRS. The best-known example of a Derived CRS is a Projected CRS, which is always derived from a base Geographic CRS by applying the coordinate conversion known as a map projection.

The principal subtypes of CRS discussed in Clause 9.3 all include one datum definition. A Derived CRS inherits its datum from its base CRS. These two cases are modelled with derived associations between SC_SingleCRS and SC_Datum. Principal CRS subtypes use direct associations, Derived CRSs use indirect associations.

In principle, all sub-types of single coordinate reference system may take on the role of either Base or Derived CRS with the exception of a Projected CRS. Projected CRS 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 most frequently encountered types of coordinate reference systems. A projected CRS always has a geographic CRS as its base CRS.

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 base CRS.

9.5 UML schema of Coordinate Reference System package

Figure 7 shows the UML class diagram of the Coordinate Reference System package. The definition of the object classes of the package are provided in Tables 4 through 16.

The diagram shows a derived association from the SC_SingleCRS class to the CS_CoordinateSystem class, with the usesCS rolename. This derived association is included to indicate that all of the subclasses of SC_SingleCRS have a direct association to CS_CoordinateSystem or one of its subclasses, as later detailed in Figure 9. In most cases, the multiplicity of the usesCS end of these associations is 1 (mandatory). In two cases, a subclass of SC_SingleCRS has a direct association to one of two alternative (XOR) subclasses of the CS_CoordinateSystem class.

The diagram also shows a derived association from SC_SingleCRS to the CD_Datum class, with the usesDatum rolename. This derived association indicates that many, but not all, of the subclasses of SC_SingleCRS have a direct association to CD_Datum or to one of its subclasses, as later shown in Figure 11. For the subclasses of SC_SingleCRS that have a direct association to CD_Datum or one of its subclasses, the multiplicity of the usesDatum end of the association is 1 (mandatory). For the subclasses of SC_SingleCRS that do not have a direct association to CD_Datum or one of its subclasses, the multiplicity of the usesDatum end of the association is 0 (no association). Please notice that SC_ProjectedCRS is modelled separately from SC_DerivedCRS to permit modelling of its more specific characteristics.

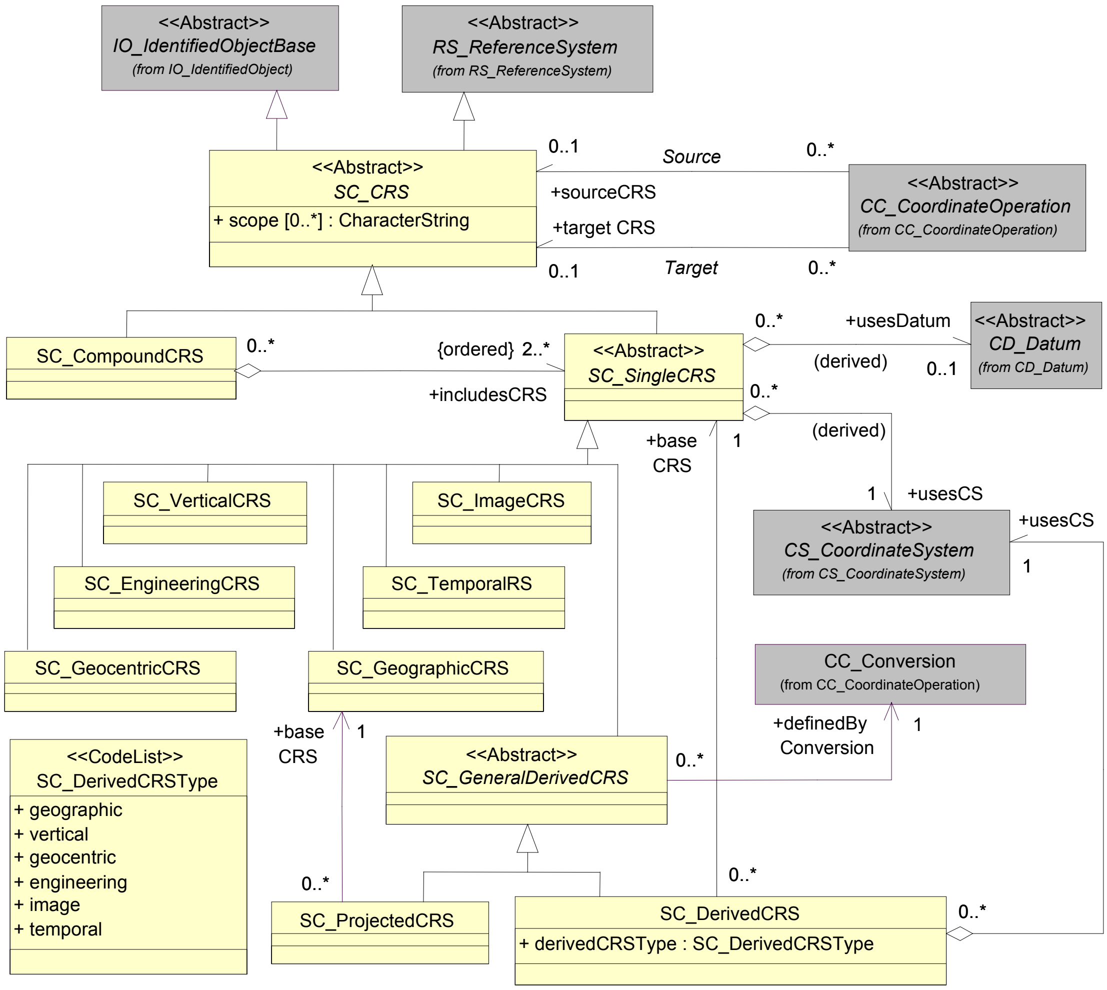


Figure 7 — SC Coordinate Reference System package

Table 4 — Defining elements of SC_CRS class

Description:	Coordinate reference system which is usually single but may be compound.
Stereotype:	Abstract
Derived from	RS_ReferenceSystem IO_IdentifiedObjectBase
Association roles:	sourceCRS from CC_CoordinateOperation [0..1] targetCRS from CC_CoordinateOperation [0..1]
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
CRS scope	scope	CharacterString	O	N	Description of usage, or limitations of usage, for which this CRS is valid.

5 attributes inherited from IO_IdentifiedObjectBase and from RS_ReferenceSystem:

Note: As an exception to elsewhere in this International Standard, inherited attributes are included in this class table to allow the CRS name, CRS alias and CRS identifier attributes to be shown together.

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
CRS name	name	RS_Identifier	M	1	This is the primary name for the CRS. Aliases and other identifiers may be given through the attributes CRSalias and identifier.
CRS alias	alias	GenericName	O	N	An alias by which this CRS is known.
CRS identifier	identifier	RS_Identifier	O	N	An identifier which references elsewhere the CRS's defining information; alternatively an identifier by which this CRS can be referenced.
CRS validity	domainOfValidity	EX_Extent	O	N	Area or region or timeframe in which this CRS is valid.
CRS remarks	remarks	CharacterString	O	1	Comments on or information about this CRS, including data source information.

Table 5 — Defining elements of SC_SingleCRS class

Description:	Coordinate reference system consisting of one Coordinate System and one Datum (as opposed to a Compound CRS). Note: In ISO 19111:2003, this class was called SC_CoordinateReferenceSystem.
Stereotype:	Abstract
Derived from	SC_CRS
Association roles:	(derived) usesDatum to CD_Datum [0..1] (derived) usesCS to CS_CoordinateSystem [1] baseCRS from SC_DerivedCRS [1] (associations inherited from SC_CRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

Table 6 — Defining elements of SC_CompoundCRS class

Description:	A coordinate reference system describing the position of points through two or more independent single coordinate reference systems. It is associated with a non-repeating sequence of two or more instances of SC_SingleCRS.
Stereotype:	(none)
Derived from	SC_CRS
Association roles:	includesCRS to SC_SingleCRS [2..*] {ordered} (associations inherited from SC_CRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

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.
Stereotype:	Abstract
Derived from	SC_SingleCRS
Association roles:	definedByConversion to CC_Conversion [1] (associations inherited from SC_SingleCRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

Table 8 — Defining elements of SC_DerivedCRS class

Description:	A single coordinate reference system that is defined by its coordinate conversion from another single coordinate reference system known as the base CRS. The base CRS cannot be a projected coordinate reference system.
Stereotype:	(none)
Derived from	SC_GeneralDerivedCRS
Association roles:	usesCS to CS_CoordinateSystem [1] baseCRS to SC_SingleCRS [1] (associations inherited from SC_ GeneralDerivedCRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS, plus:

Attribute name	UML identifier	Data type	Obliga tion	Maxi- mum Occur- rence	Attribute description
Derived CRS type	derivedCRStype	SC_DerivedCRST ype	M	1	Type of this derived coordinate reference system.

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.
Geocentric CRS	geocentric	CharacterString	C	1	A coordinate reference system with the origin at the centre of mass of the earth. A geocentric CRS deals with the earth's curvature by taking a 3D spatial view.
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 RS	temporal	CharacterString	C	1	A reference system used for the recording of time.
Condition: One and only one of the listed attributes shall be supplied.					

Table 10 — Defining elements of SC_GeocentricCRS class

Description:	A 3D coordinate reference system with the origin at the centre of mass of the earth. A geocentric CRS deals with the earth's curvature by taking a 3D spatial view.
Stereotype:	(none)
Derived from	SC_SingleCRS
Association roles:	usesDatum to CD_GeodeticDatum [1] usesCartesianCS to CS_CartesianCS [0..1] usesSphericalCS to CS_SphericalCS [0..1] (associations inherited from SC_SingleCRS) Note attached to usesCartesianCS and usesSphericalCS associations: {XOR}
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

Table 11 — 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_SingleCRS
Association roles:	usesDatum to CD_GeodeticDatum [1] usesCS to CS_EllipsoidalCS [1] baseCRS from ProjectedCRS [0..*] (associations inherited from SC_SingleCRS)
Public Attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

Table 12 — 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] baseCRS to SC_GeographicCRS [1 (associations inherited from SC_GeneralDerivedCRS)
Public Attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

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_SingleCRS
Association roles:	usesDatum to CD_EngineeringDatum [1] usesCS to CS_CoordinateSystem [1] (associations inherited from SC_SingleCRS)
Public Attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

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 for images a separate user community with its own terms of reference exists.
Stereotype:	(none)
Derived from	SC_SingleCRS
Association roles:	usesDatum to CD_ImageDatum [1] usesCartesianCS to CS_CartesianCS [0..1] usesAffineCS to CS_AffineCS [0..1] (associations inherited from SC_SingleCRS) Note attached to usesCartesianCS and usesAffineCS associations: {XOR}
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

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_SingleCRS
Association roles:	usesDatum to CD_VerticalDatum [1] usesCS to CS_VerticalCS [1]] (associations inherited from SC_SingleCRS)
Public Attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

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_SingleCRS
Association roles:	usesDatum to CD_TemporalDatum [1] usesCS to CS_TimeCS [1] (associations inherited from SC_SingleCRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS.

10 Coordinate System package

10.1 Introduction

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

10.2 Coordinate System

The coordinates of points are recorded in a coordinate system. A coordinate system is the set of coordinate system axes that spans the coordinate space. This concept implies the set of mathematical rules that determine how coordinates are associated with invariant quantities such as angles and distances. 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 in a map plane and vice versa 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 1 The word ‘distance’ 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 or temporal.

A coordinate system is composed of a non-repeating sequence 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 shall be equal to the number of coordinate axes in the coordinate system.

NOTE 2 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 9. 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 axis. In the multi-dimensional case, all axes shall have the same unit of measure.	Geocentric Projected Engineering Image
affine	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 from the origin and the angle between the line from origin to point and a reference direction.	Engineering
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.. Example: usage of the line feature representing a pipeline to describe points on or along that pipeline. This International Standard only lends itself to be used for simple (=continuous) linear systems. For a more extensive treatment of the subject, particularly as applied to the transportation industry, refer to ISO 19133.	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

10.3 Coordinate system axis

A coordinate system is composed of a non-repeating sequence 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 shall 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 $i = 1...n$, 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 has to 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'. At two different points on the ellipsoid the direction 'north' will be a spatially different direction, but the concept of latitude is the same.

The specified direction of the coordinate axes is often only approximate. For example, two geographic coordinate reference systems that make use of the same ellipsoidal coordinate system will usually be associated with the earth through two different geodetic datums. This may lead to the two uses of the coordinate system being slightly rotated with respect to each other.

In a number of cases usage of coordinate system axis names is constrained by geodetic custom, depending on the coordinate reference system type. These constraints are shown in Table 18. 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	depth or gravity-related height
Cartesian	projected	northing or southing, easting or westing

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.

10.4 UML schema of CS Coordinate System package

Figure 8 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 9. The definition of the object classes of package CS_CoordinateSystem is provided in Tables 19 through 32.

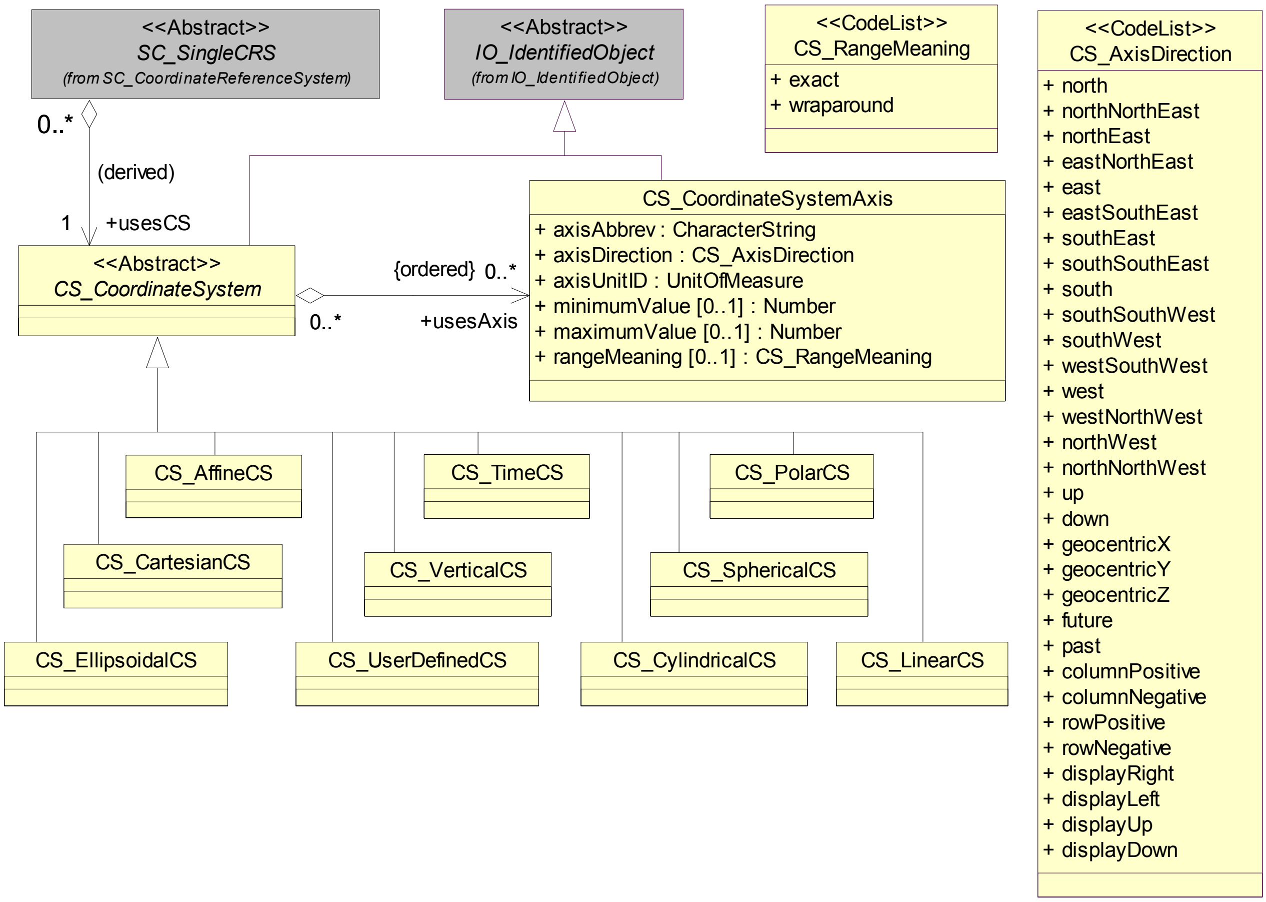


Figure 8 — CS Coordinate System package

See Figure 9 for detail of the associations between CS_CoordinateSystem and SC_SingleCRS.

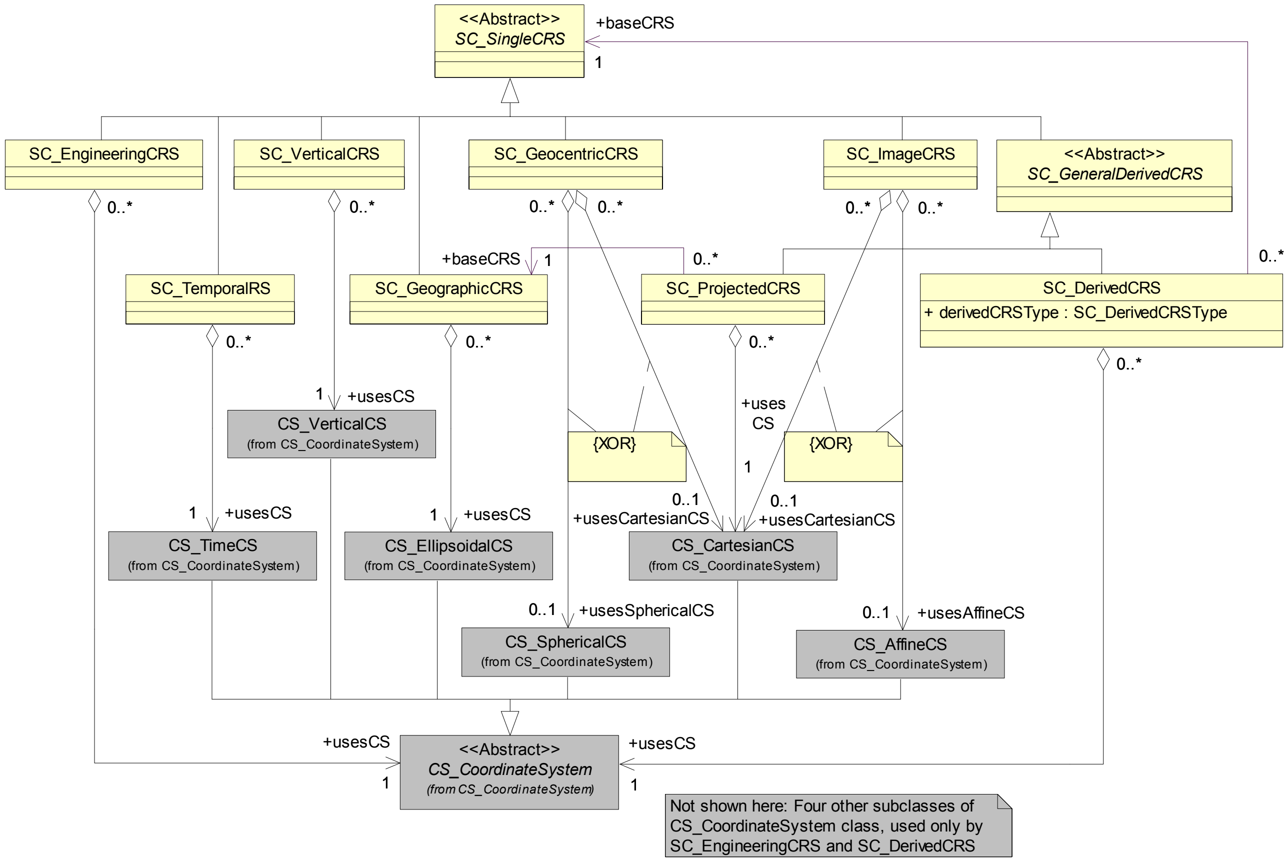


Figure 9 — Coordinate Reference System type associations to Coordinate System type

Table 19 — Defining elements of CS_CoordinateSystem class

Description:	A coordinate system (CS) is the non-repeating sequence 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.
Stereotype:	Abstract
Derived from	IO_IdentifiedObject
Association roles:	usesAxis to CS_CoordinateSystemAxis [1..*] (ordered) usesCS from SC_EngineeringCRS [1] usesCS from SC_DerivedCRS [1] (derived) usesCS from SC_SingleCRS [1]
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 20 — Defining elements of CS_CartesianCS class

Description:	A 1-, 2-, or 3-dimensional coordinate system. In the 1-dimensional case, it contains a single straight coordinate axis. In the 2- and 3-dimensional cases it gives the position of points relative to orthogonal straight axes. In the multi-dimensional cases, all axes shall have the same length unit of measure. A CartesianCS shall have one, two, or three usesAxis associations; the number of associations shall equal the dimension of the CS.
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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 21 — Defining elements of CS_AffineCS class

Description:	A two- or three-dimensional coordinate system with straight axes that are not necessarily orthogonal. An AffineCS shall have two or three usesAxis associations; the number of associations shall equal the dimension of the CS.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	uses AffineCS from SC_ImageCRS [0..1] (associations inherited from CS_CoordinateSystem) Note attached to usesCartesianCS and usesAffineCS associations from SC_ImageCRS: {XOR}
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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; the number of associations shall equal the dimension of the CS.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	usesCS from SC_GeographicCRS [1] (associations inherited from CS_CoordinateSystem)
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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 coordinate is the distance – with or without offset – from the specified datum to the point along the axis. Example: usage of the line feature representing a pipeline to describe points on or along that pipeline. A LinearCS shall have one usesAxis association.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 28 — Defining elements of CS_TimeCS class

Description:	A one-dimensional coordinate system containing a 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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

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; the number of associations shall equal the dimension of the CS.
Stereotype:	(none)
Derived from	CS_CoordinateSystem
Association roles:	(associations inherited from CS_CoordinateSystem)
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 30 — Defining elements of CS_CoordinateSystemAxis class

Description:	Definition of a coordinate system axis.
Stereotype:	(none)
Derived from	IO_IdentifiedObject
Association roles:	usesAxis from CS_CoordinateSystem [1..*]
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate system axis abbreviation	axisAbbrev	CharacterString	M	1	The abbreviation used for this coordinate system axis; this abbreviation is also used to identify the coordinates in the coordinate tuple. Examples are X and Y.
Coordinate system axis direction	axisDirection	CS_AxisDirection	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 minimum value	minimumValue	Number	O	1	The minimum value normally allowed for this axis, in the unit of measure for the axis.
Coordinate system axis maximum value	maximumValue	Number	O	1	The maximum value normally allowed for this axis, in the unit of measure for the axis.
Coordinate system axis range meaning	rangeMeaning	CS_RangeMeaning	C	1	Meaning of axis value range specified by minimumValue and maximumValue. This element shall be omitted when both minimumValue and maximumValue are omitted. It may be included when minimumValue and/or maximumValue are included. If this element is omitted when minimumValue or maximumValue are included, the meaning is unspecified.
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 a coordinate in a coordinate tuple shall be recorded using this unit of measure.

Table 31 — Defining elements of CS_RangeMeaning class

Description:	Meaning of the axis value range specified through maximumValue and minimumValue.				
Stereotype:	CodeList				
Derived from	(none)				
Association roles:	(none)				
Used by:	CS_CoordinateSystemAxis				
Public attributes:					
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Exact	exact	CharacterString	C	1	Any value between and including minimumValue and maximiumValue is valid.
Wraparound	wraparound	CharacterString	C	1	The axis is continuous with values wrapping around at the minimumValue and maximumValue. Values with the same meaning repeat modulo the difference between maximumValue and minimumValue.
Condition: One and only one of the listed attributes shall be supplied.					

Table 32 — Defining elements of CS_AxisDirection class

Description:	The direction of positive increase in the coordinate value for a coordinate system axis.
Stereotype:	CodeList
Derived from	(none)
Association roles:	(none)
Used by:	CS_CoordinateSystemAxis
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
north	north	CharacterString	C	1	Axis positive direction is north. In a geographic or projected CRS, north is defined through the geodetic datum. In an engineering CRS, north may be defined with respect to an engineering object rather than a geographical direction.
north-north-east	northNorthEast	CharacterString	C	1	Axis positive direction is approximately north-north-east.
north-east	northEast	CharacterString	C	1	Axis positive direction is approximately north-east.
east-north-east	eastNorthEast	CharacterString	C	1	Axis positive direction is approximately east-north-east.
east	east	CharacterString	C	1	Axis positive direction is $\pi/2$ radians clockwise from north.
east-south-east	eastSouthEast	CharacterString	C	1	Axis positive direction is approximately east-south-east.
south-east	southEast	CharacterString	C	1	Axis positive direction is approximately south-east.
south-south-east	southSouthEast	CharacterString	C	1	Axis positive direction is approximately south-south-east.
south	south	CharacterString	C	1	Axis positive direction is π radians clockwise from north.
south-south-west	southSouthWest	CharacterString	C	1	Axis positive direction is approximately south-south-west.
south-west	south-west	CharacterString	C	1	Axis positive direction is approximately south-west.
west-south-west	westSouthWest	CharacterString	C	1	Axis positive direction is approximately west-south-west.
west	west	CharacterString	C	1	Axis positive direction is $3\pi/2$ radians clockwise from north.
west-north-west	westNorthWest	CharacterString	C	1	Axis positive direction is approximately west-north-west.
north-west	northWest	CharacterString	C	1	Axis positive direction is approximately north-west.
north-north-west	northNorthWest	CharacterString	C	1	Axis positive direction is approximately north-north-west.
up	up	CharacterString	C	1	Axis positive direction is up relative to gravity.
down	down	CharacterString	C	1	Axis positive direction is down relative to gravity.
Geocentric X	geocentricX	CharacterString	C	1	Axis positive direction is in the equatorial plane from the centre of the modelled earth towards the intersection of the equator with the prime meridian.
Geocentric Y	geocentricY	CharacterString	C	1	Axis positive direction is in the equatorial plane from the centre of the modelled earth towards the intersection of the equator and the meridian $\pi/2$ radians eastwards from the prime meridian.
Geocentric Z	geocentricZ	CharacterString	C	1	Axis positive direction is from the centre of the modelled earth parallel to its rotation axis and towards its north pole.
future	future	CharacterString	C	1	Axis positive direction is towards the future.
past	past	CharacterString	C	1	Axis positive direction is towards the past.
column-positive	columnPositive	CharacterString	C	1	Axis positive direction is towards higher pixel column.
column-negative	columnNegative	CharacterString	C	1	Axis positive direction is towards lower pixel column.
row-positive	rowPositive	CharacterString	C	1	Axis positive direction is towards higher pixel row.
row-negative	rowNegative	CharacterString	C	1	Axis positive direction is towards lower pixel row.
display-right	displayRight	CharacterString	C	1	Axis positive direction is right in display.
display-left	displayLeft	CharacterString	C	1	Axis positive direction is left in display.
display-up	displayUp	CharacterString	C	1	Axis positive direction is towards top of approximately vertical display surface.
display-down	displayDown	CharacterString	C	1	Axis positive direction is towards bottom of approximately vertical display surface.
Condition: One and only one of the listed attributes shall be supplied.					

11 Datum package

11.1 Types of datums

A datum specifies the relationship of a coordinate system to the earth thus creating a coordinate reference system. A datum can be used as the basis for one-, two- or three-dimensional systems. In some applications for an Engineering CRS, the relationship is to a moving platform. In these applications the datum itself is not time-dependent, but any transformations of the associated coordinates to a earth-fixed or other coordinate reference system will contain time-dependent parameters.

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 11. 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. A temporal datum is used to define the origin of the time axis in a temporal coordinate reference system.

11.2 Vertical datum

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 for which the associated vertical measurements are used. For hydrographic charts, this is often a predicted nominal sea surface (that is, without waves or other wind and current effects) which occurs at low tide. Examples are Lowest Astronomical Tide (LAT) and Lowest Low Water Springs (LLWS). 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 coordinate, against which other parameters are measured. The latter case is applied routinely in meteorology.

d) Other surface. In some cases, for example oil exploration and production, geological features, such as 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

The image pixel grid is defined as the set of lines of constant integer coordinate values. The term "image grid" is often used in other standards to describe the concept of Image CRS. However, care has to 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 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. 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

A prime meridian defines the origin from which longitude values are specified. The prime meridian description is mandatory if the datum type is geodetic. Most geodetic datums use Greenwich as their prime meridian. Default values for the attributes prime meridian name and greenwichLongitude are "Greenwich" and 0 respectively. If the prime meridian name is "Greenwich" then the value of Greenwich longitude shall be 0 degrees.

A prime meridian description is not used for any datum type other than geodetic.

The data attributes of prime meridian are described in 11.6, Table 43.

11.5 Ellipsoid

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 is not geodetic.

One ellipsoid shall 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, for example 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 to be associated with that 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.

The data attributes of ellipsoid are described in 11.6, Tables 41 and 42.

11.6 UML schema of the CD Datum package

Figure 10 shows the UML class diagram for the CD Datum package. There are restrictions on the associations between Coordinate Reference System subtypes and Datum subtypes which are shown in the UML class diagram in Figure 11. The definition of the object classes of this package is provided in Tables 33 through 43.

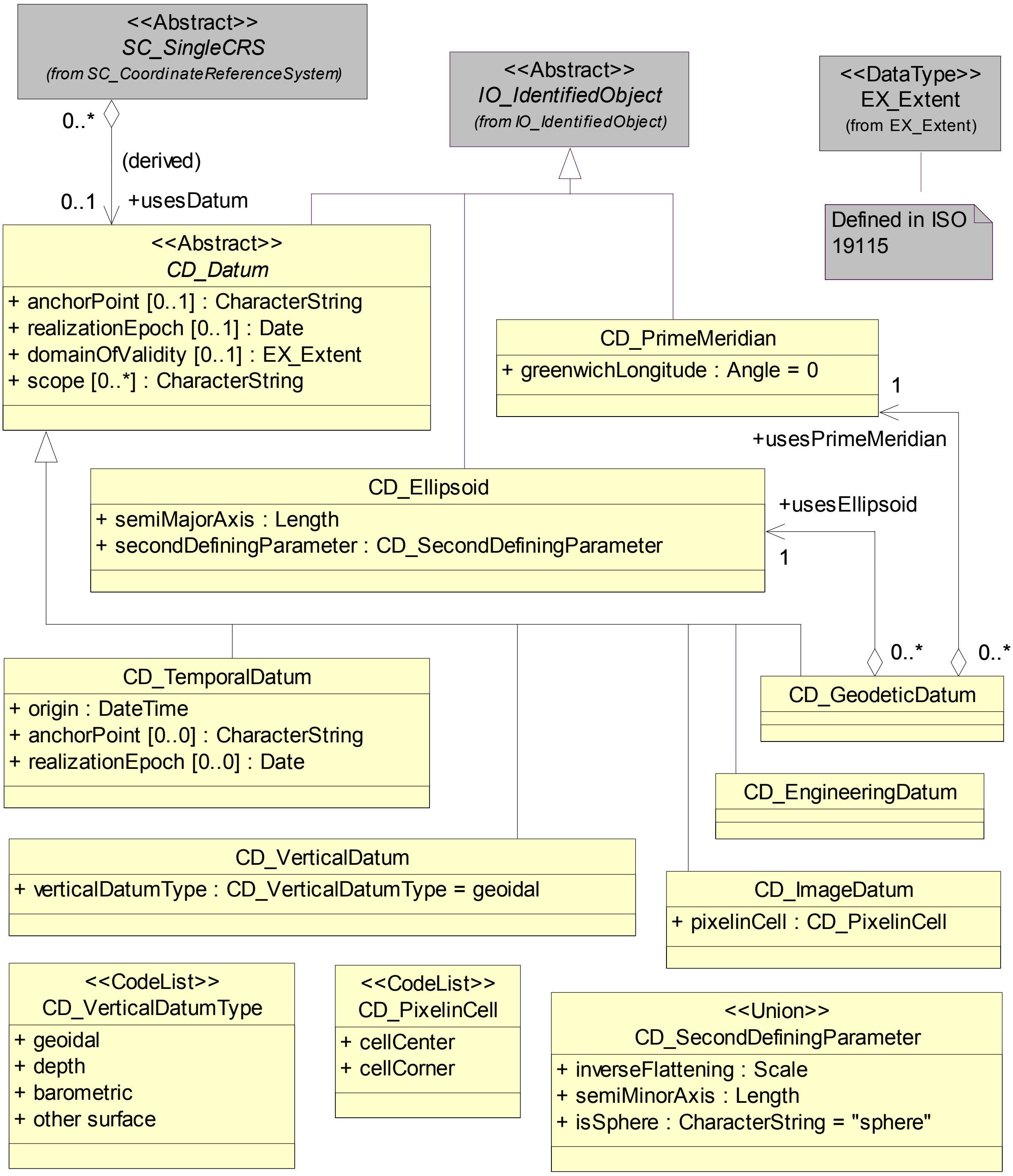


Figure 10 — CD Datum package

See Figure 11 for detail of the associations between CD_Datum and SC_SingleCRS.

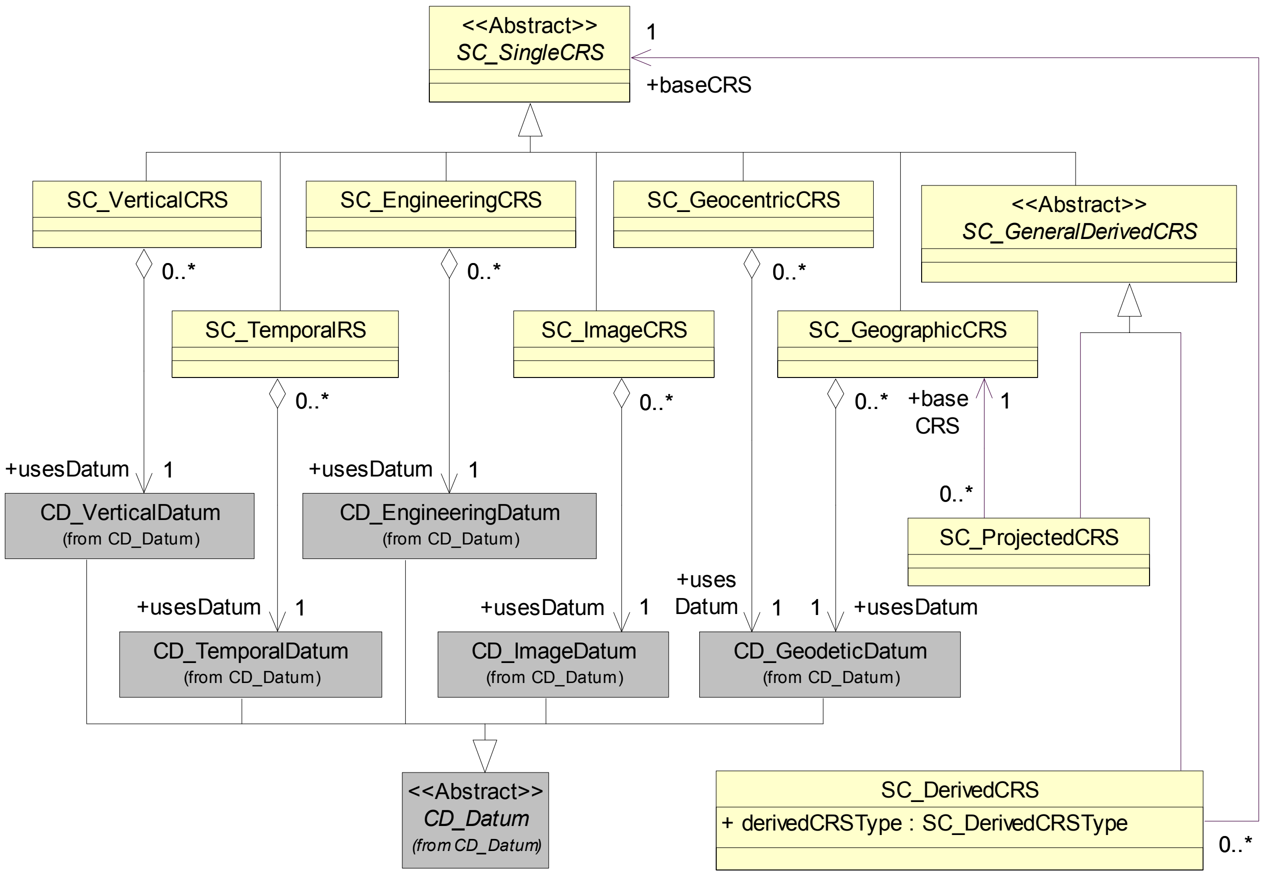


Figure 11 — Coordinate Reference System type associations with Datum type

Table 33 — 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 reference systems.
Stereotype:	Abstract
Derived from	IO_IdentifiedObject
Association roles:	(derived) usesDatum from SC_SingleCRS [0..1]
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
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. 1986 for NAD83(86)). 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 may remain valid after a new datum is defined. Alternatively, a datum may be replaced by a later datum, in which case the realization epoch for the new datum defines the upper limit for the validity of the replaced datum.
Datum validity	domainOfValidity	EX_Extent	O	1	Area or region or timeframe in which this datum is valid.
Datum scope	scope	CharacterString	O	N	Description of usage, or limitations of usage, for which this datum is valid.

Table 34 — 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:	8 attributes inherited from CD_Datum, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 35 — 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:	8 attributes inherited from CD_Datum, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 36 — 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:	8 attributes inherited from CD_Datum, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
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 37 — 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	cellCenter	CharacterString	C	1	The origin of the image coordinate system is the centre of a grid cell or image pixel.
Cell corner	cellCorner	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.
Condition: One and only one of the listed attributes shall be supplied.					

Table 38 — 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 or zero-depth surface, including its position with respect to the Earth. There are several types of vertical datum, 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:	8 attributes inherited from CD_Datum, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Vertical datum type	vertDatumType	CD_VerticalDatum Type	M	1	Type of this vertical datum. Default is “geoidal”.

Table 39 — 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	otherSurface	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 shall be supplied.					

Table 40 — Defining elements of CD_TemporalDatum class

Description:	A temporal datum defines the origin of a temporal reference system.				
Stereotype:	(none)				
Derived from	CD_Datum				
Association roles:	usesDatum from SC_TemporalRS [1]				
Public attributes:	8 attributes inherited from CD_Datum, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
Origin	origin	DateTime	M	1	The date and time origin of this temporal datum.
Of the 8 inherited attributes the following two are mofidied:					
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 41 — 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	IO_IdentifiedObject
Association roles:	usesEllipsoid from CD_GeodeticDatum [1]
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
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 that describes the shape of this ellipsoid.

Table 42 — 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 Occurrence	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 shall be supplied.					

Table 43 — Defining elements of CD_PrimeMeridian class

Description:	A prime meridian defines the origin from which longitude values are determined. Note: Default value for prime meridian name is "Greenwich". When default applies, value for greenwichLongitude shall be 0 (degrees).
Stereotype:	(none)
Derived from	IO_IdentifiedObject
Association roles:	usesPrimeMeridian from CD_GeodeticDatum [1]
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Prime meridian Greenwich longitude	greenwichLongitude	Angle	M	1	Longitude of the prime meridian measured from the Greenwich meridian, positive eastward. Default value: 0 degrees. Note: If the value of the prime meridian *name* is "Greenwich" then the value of greenwichLongitude shall be 0 degrees.

12 Coordinate operation package

12.1 General characteristics of coordinate operations

If the relationship between any two coordinate reference systems is known, coordinate tuples 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.

NOTE 1 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 **not** operate on coordinate reference systems, but on coordinates. This is important for the design of implementation specifications because it implies that a coordinate reference system 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, for example by converting the units of measure of the coordinates. In all these cases, the source and target coordinate reference systems involved have to exist before the coordinate operation can do.

NOTE 2 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 12.2.

Coordinate operations are divided into two subtypes:

Coordinate conversion – mathematical operation on coordinates in which there are no parameters or the parameters are defined rather than empirically derived. It does not involve any change of datum. The most frequently encountered type of coordinate conversion is a map projection.

Coordinate transformation – mathematical operation on coordinates in which the parameters are empirically derived. It does involve a change of datum. The stochastic nature of the parameters may result in several different versions of the same coordinate transformation. Therefore multiple coordinate transformations may exist for a given pair of coordinate reference systems, differing in their method, parameter values and accuracy characteristics.

A coordinate operation (transformation or conversion) can be time-varying, and shall be time-varying if either the source or target CRS is moving relative to the other CRS. When the coordinate operation is time-varying, the coordinate operation method used will also be time-varying, and some of the parameters used by that coordinate 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

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 coordinate tuples cannot exist without specification of the coordinate conversion **and** the ‘source’ or 'base' 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 related to a base geographic coordinate reference system. The associated map projection effectively **defines** the projected coordinate reference system from the geographic coordinate reference system. This concept is modelled in Figures 7 and 12 as a direct link between coordinate reference system and coordinate conversion.

Please note that this does not contradict the statement in the first paragraph of this subclause 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 coordinate conversion and to its source coordinate reference system.

12.3 Concatenated coordinate operation

A concatenated coordinate operation is a non-repeating sequence of coordinate operations. This sequence of coordinate operations is constrained by the requirement that the target coordinate reference system of each step shall be the same as the source coordinate reference system of the next step. 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 systems specified for the concatenated coordinate operation.

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

The source and target coordinate reference systems of a coordinate conversion are defined in the SC_GeneralDerivedCRS, by specifying the base (i.e. source) CRS and the defining coordinate conversion. The derived coordinate reference system itself is the target CRS in this situation. When used in a concatenated coordinate operation, the coordinate conversion’s source and target coordinate reference systems are subject to constraint of the target CRS of one step being the same as the source CRS of the next step.

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

12.4 Pass-through coordinate operation

Coordinate operations require input coordinate tuples of certain dimensions and produce output tuples of certain dimensions. The dimension of the source coordinate reference system need not be the same as that of the target source coordinate reference system.

The pass-through coordinate operation specifies what subset of a coordinate tuple is subject to a requested coordinate operation. 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 coordinate operation.

NOTE The ability to define compound coordinate reference systems combining two or more other coordinate reference systems 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 coordinate operation expecting 2-dimensional CRSs to (2+1)=3-dimensional coordinate tuples.

12.5 Coordinate operation method and parameters

The algorithm used to execute a coordinate operation is defined in the coordinate operation method. Each coordinate operation method uses a number of parameters (although some coordinate conversions use none), and each coordinate operation assigns a value to these parameters.

Most parameter values are numeric, but for some coordinate 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 NADCON coordinate transformation from NAD 27 to NAD 83 in the USA in which one pair of a series of pairs of grid files is used.

It is recommended to make extensive use of identifiers, referencing well-known registers 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 a coordinate operation method which this server does not recognise, although a perfectly valid method using a different name 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 coordinate operation method formulae be included or referenced in the relevant object, if possible with a worked example.

NOTE Concatenated coordinate operations and pass-through coordinate operations list single coordinate operations and themselves do not require a coordinate operation method to be specified.

12.6 Parameter groups

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

12.7 Implementation considerations

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 of 1983 coordinates to Geodetic Datum of Australia 1994 coordinates; but in a practical sense that operation would be meaningless. The key validation that would flag such a coordinate 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 from a forward coordinate operation (‘A’ to ‘B’) the inverse or complementary coordinate operation (from ‘B’ to ‘A’). Most permanent data stores for coordinate reference parameter data will record only one of these two coordinate operations. The logic to derive the inverse coordinate operation should be built into the application software that performs the coordinate operation, be it server or client.

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

Some polynomial coordinate operation methods require the signs of only most, but not all, parameter values to be reversed. Other coordinate operation methods imply two algorithms, one for the forward and one for the inverse coordinate 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 coordinate operation, with entirely different parameter values. This is the case with some polynomial and affine coordinate operation methods. In those cases the inverse coordinate operation cannot be inferred from the forward coordinate operation but has to be explicitly defined.

12.8 UML schema of Coordinate Operation package

Figures 12 and 13 contain the two parts of the UML class diagram for the CC Coordinate Operation package. As indicated by the note in Figure 12, Figure 13 shows additional classes and associations from the CC_Operation class shown in Figure 12. The definition of the object classes of the CC Coordinate Operations package is provided in Tables 44 through 57.

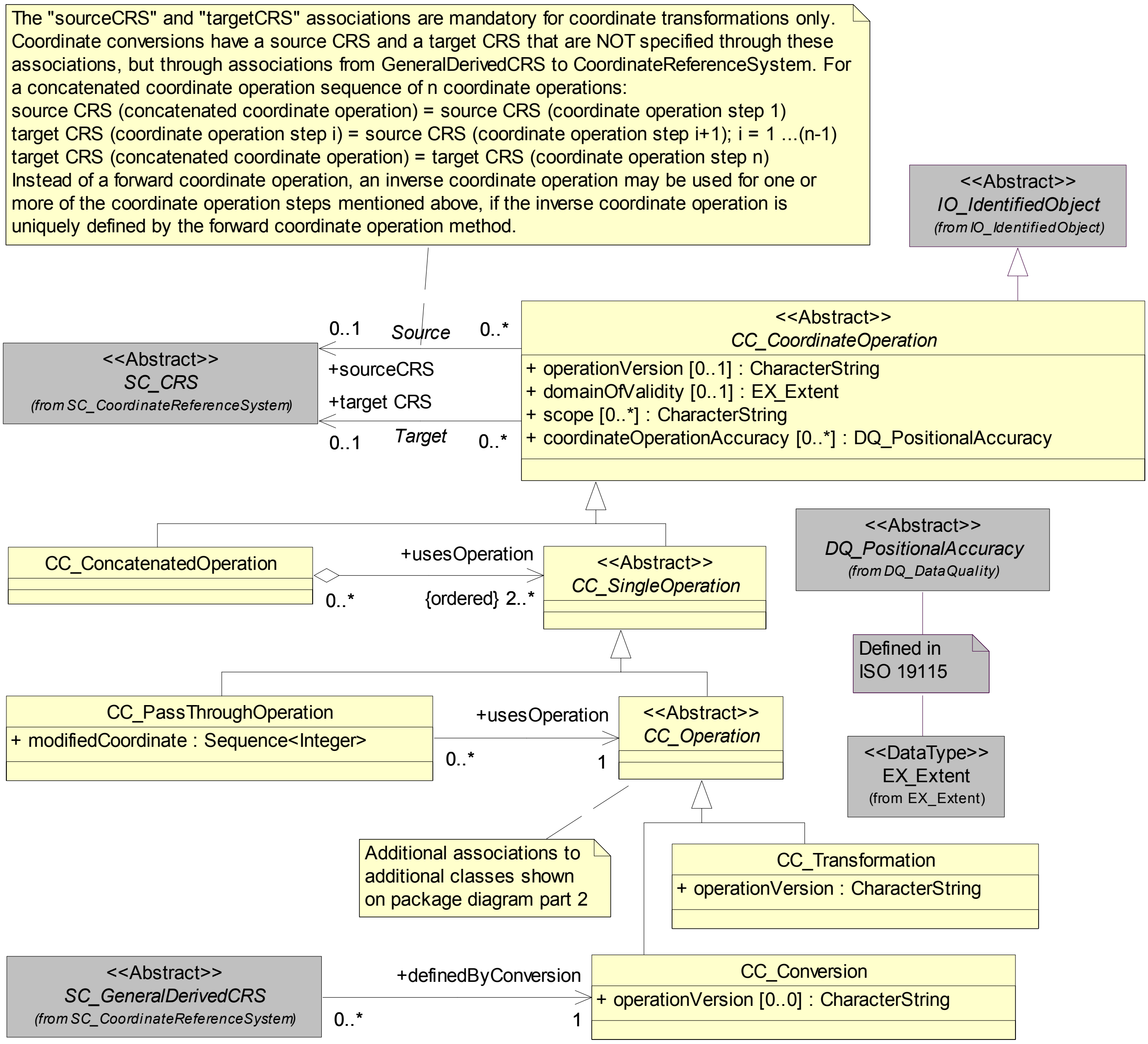


Figure 12 — CC Coordinate Operation package part 1

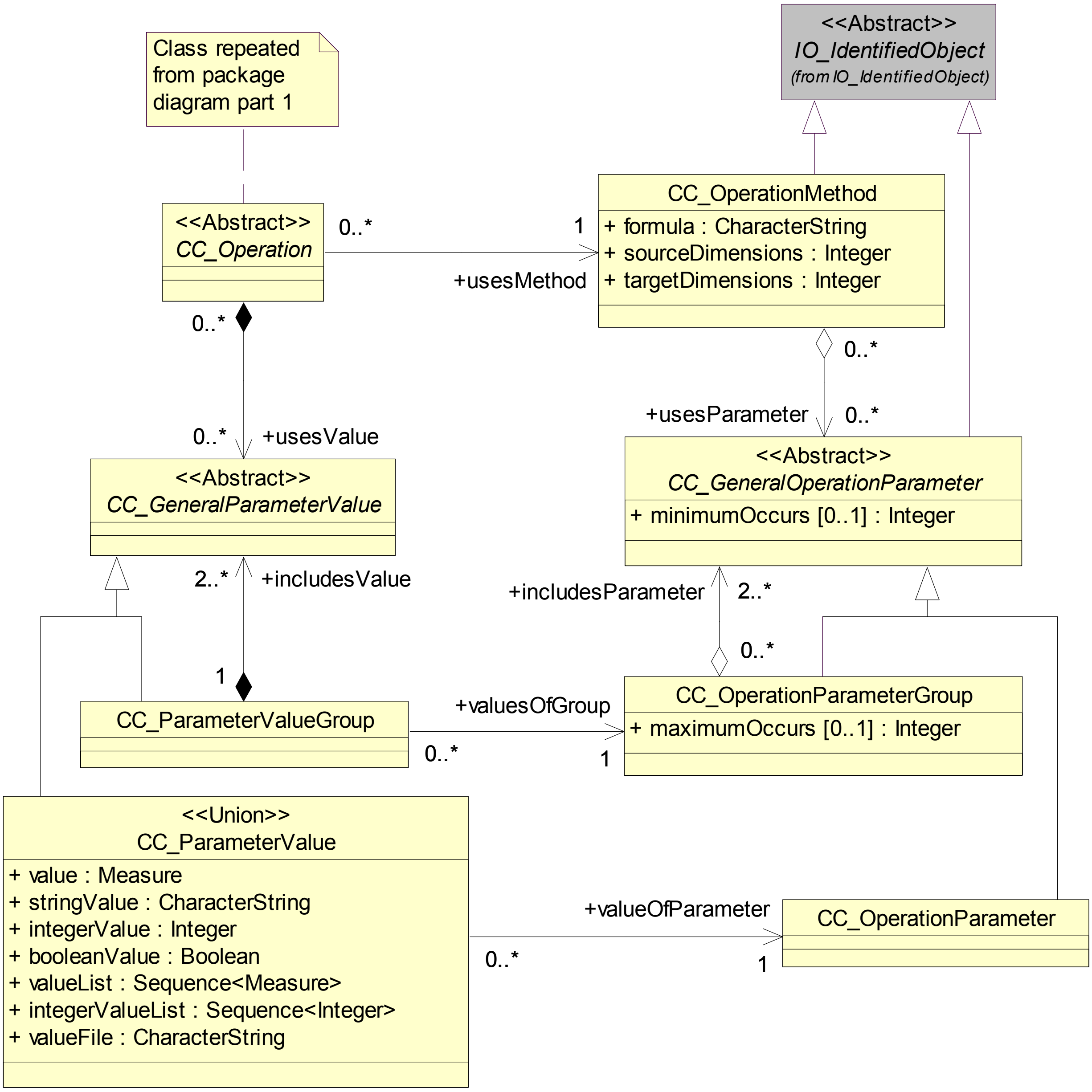


Figure 13 — CC Coordinate Operation package part 2

Table 44 — 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 coordinate operation (from CRS B to CRS A). In some cases, the coordinate operation method algorithm for the inverse coordinate operation is the same as for the forward algorithm, but the signs of some coordinate operation parameter values have to be reversed. In other cases, different algorithms are required for the forward and inverse coordinate operations, but the same coordinate operation parameter values are used. If (some) entirely different parameter values are needed, a different coordinate operation shall be defined.
Stereotype:	Abstract
Derived from:	IO_IdentifiedObject
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 coordinate transformations only. Coordinate 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 concatenated coordinate operation sequence of n coordinate operations: source CRS (concatenated coordinate operation) = source CRS (coordinate operation step 1) target CRS (coordinate operation step i) = source CRS (coordinate operation step i+1); i = 1 ...(n-1) target CRS (concatenated coordinate operation) = target CRS (coordinate operation step n) Instead of a forward coordinate operation, an inverse coordinate operation may be used for one or more of the coordinate operation steps mentioned above, if the inverse coordinate operation is uniquely defined by the forward coordinate operation method.
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
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 coordinate transformation, and should not be supplied for a coordinate conversion.
Coordinate operation validity	domainOfValidity	EX_Extent	O	1	Area or region or timeframe in which this coordinate operation is valid.
Coordinate operation scope	scope	CharacterString	O	N	Description of usage, or limitations of usage, for which this coordinate operation is valid.
Coordinate operation accuracy	coordinateOperation Accuracy	DQ_PositionalAcc uracy	O	N	Estimate(s) of the impact of this coordinate operation on point accuracy. Gives position error estimates for target coordinates of this coordinate operation, assuming no errors in source coordinates.

Table 45 — Defining elements of CC_ConcatenatedOperation class

Description:	An ordered sequence of two or more single coordinate operations. The sequence of coordinate operations is constrained by the requirement that the source coordinate reference system of step (n+1) shall 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 coordinate operation. Instead of a forward coordinate operation, an inverse operation may be used for one or more of the coordinate operation steps mentioned above, if the inverse coordinate operation is uniquely defined by the forward coordinate operation method.
Stereotype:	(none)
Derived from:	CC_CoordinateOperation
Association roles:	usesOperation to CC_SingleOperation [2..*] {ordered} (associations inherited from CC_CoordinateOperation)
Public attributes:	8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 46 — 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:	8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 47 — Defining elements of CC_PassThroughOperation class

<table>
<tr><td>Description:</td><td colspan="5">A pass-through coordinate operation specifies that a subset of a coordinate tuple is subject to a specific coordinate operation.</td></tr>
<tr><td>Stereotype:</td><td colspan="5">(none)</td></tr>
<tr><td>Derived from:</td><td colspan="5">CC_SingleOperation</td></tr>
<tr><td>Association roles:</td><td colspan="5">(aggregation) usesOperation to CC_SingleOperation [0..1] (associations inherited from CC_SingleOperation)</td></tr>
<tr><td>Public attributes:</td><td colspan="5">8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:</td></tr>
<tr><th>Attribute name</th><th>UML identifier</th><th>Data type</th><th>Obliga tion</th><th>Maxi- mum Occur- rence</th><th>Attribute description</th></tr>
<tr><td>Modified coordinates</td><td>modifiedCoordinate</td><td>Sequence<Integer ></td><td>M</td><td>1</td><td>Ordered sequence of positive integers defining the positions in a coordinate tuple of the coordinates affected by this pass-through operation.</td></tr>
</table>

Table 48 — Defining elements of CC_Operation class

Description:	A mathematical operation on coordinates that transforms or converts their values to values referenced to another coordinate reference system. A coordinate operation uses an operation method, usually with associated parameter values.
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:	8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 49 — Defining elements of CC_Conversion class

Description:	A coordinate operation that does not include any change of datum. The best-known example of a coordinate conversion is a map projection. The parameter values describing coordinate conversions are defined rather than empirically derived.				
Stereotype:	(none)				
Derived from:	CC_Operation				
Association roles:	definedByConversion from SC_GeneralDerivedCRS [1] (associations inherited from CC_Operation)				
Public attributes:	8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase, one of which is modified:				
Attribute 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 coordinate conversion.

Table 50 — Defining elements of CC_Transformation class

Description:	A coordinate operation othat 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 coodinate transformation. Also, the stochastic nature of the parameters may result in multiple (different) versions of the same coordinate transformations between the same source and target CRSs.				
Stereotype:	(none)				
Derived from:	CC_Opereration				
Association roles:	(associations inherited from CC_Operation)				
Public attributes:	8 attributes inherited from CC_CoordinateOperation, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
Attribute 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 coordinate transformation.

Table 51 — 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:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
Attribute name	**UML identifier**	**Data type**	**Obliga tion**	**Maxi-mum Occur-rence**	**Attribute description**
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.

Table 52 — Defining elements of CC_GeneralOperationParameter class

Description:	Definition of a parameter or group of parameters used by a coordinate operation method.				
Stereotype:	Abstract				
Derived from:	IO_IdentifiedObject				
Association roles:	(aggregation) usesParameter from CC_OperationMethod [0..*] (aggregation) includesParameter from CC_OperationParameterGroup [2..*]				
Public attributes:	4 attributes inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
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 53 — Defining elements of CC_OperationParameterGroup class

Description:	The definition of a group of related parameters used by a coordinate 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:	5 attributes inherited from CC_GeneralOperationParameter, IO_IdentifiedObject and IO_IdentifiedObjectBase, plus:				
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Attribute description**
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.

Table 54 — Defining elements of CC_OperationParameter class

Description:	The definition of a parameter used by a coordinate 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:	5 attributes inherited from CC_GeneralOperationParameter, IO_IdentifiedObject and IO_IdentifiedObjectBase.

Table 55 — Defining elements of CC_GeneralParameterValue class

Description:	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 56 — Defining elements of CC_ParameterValueGroup class

Description:	A group of related parameter values. The same group can be repeated more than once in a coordinate 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 inherited)

Table 57 — 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)				
Used by:	CC_Operation				
Public attributes:	(none inherited), plus:				
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 a coordinate 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 a coordinate 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 a coordinate operation parameter. A Boolean value does not have an associated unit of measure.
Operation parameter value list	valueList	Sequence<Measure>	C	1	Ordered collection, i.e. sequence, of two or more numeric values of a coordinate operation parameter list, where each value has the same associated unit of measure.
Operation parameter integer value list	integerValueList	Sequence<Integer>	C	1	Ordered collection, i.e. sequence, of two or more integer values of a coordinate 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 shall 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: One and only one of the listed attributes shall be supplied.					

Annex A
(normative)

Conformance

A.1 Class A – Conformance of a coordinate reference system

A.1.1 Abstract test suite

To check that a coordinate reference system is in conformance with this International Standard, check that it satisfies the requirements given in A.1.2 to A.1.5. For coordinate reference system descriptions, conformance shall be tested against the mandatory and conditional elements (where the condition is true) that are described in Clauses 8 to 11. If the type of coordinate reference system type is projected, the test shall be extended to the mandatory elements and conditional element attributes (where the condition is true), as required by Clause 12.

A.1.2 Test case identifier: Completeness test

a) Test purpose: To determine whether all of the relevant entities and elements which are specified to be mandatory or mandatory under the conditions specified have been provided in the description.

b) Test method: Check the coordinate reference system to ensure that the coordinate reference system description includes as a minimum all of the elements indicated as mandatory for that type of system in Tables 1 to 43 and, in the case of projected coordinate reference systems, additionally Tables 44 to 57.

c) Reference: Clauses 7 to 11 and, in the case of projected coordinate reference systems, also Clause 12.

d) Test type: Basic.

A.1.3 Test case identifier: Maximum occurrence test

g) Test purpose: To ensure each coordinate reference system element occurs not more than the number of times specified in the standard.

h) Test method: Examine the subject coordinate reference system for the number of occurrences of each entity and element provided to ensure that the number of occurrences for each shall be not more than the 'Maximum Occurrences' attribute specified in Clauses 7 to 11 and, in the case of projected coordinate reference systems, additionally Clause 12.

i) Reference: Clauses 7 to 11 and in the case of projected coordinate reference systems, also Clause 12.

d) Test type: Basic.

A.1.4 Test case identifier: Data type test

a) Test purpose: To determine if each coordinate reference system in the dataset uses the specified data type.

b) Test method: Check the data type of each element of the description of a coordinate reference system to ensure that it is of the data type specified in Clauses 7 to 11 and, in the case of projected coordinate reference systems, additionally Clause 12.

c) Reference: Clauses 7 to 11 and, in the case of projected coordinate reference systems, also Clause 12.

d) Test type: Basic.

A.1.5 Test case identifier: Unit test

a) Test purpose: To ensure that the units shall be in agreement with ISO 1000.

b) Test method: Check that any units of elements conform to ISO 1000.

c) Reference: Clauses 7 to 11 and, in the case of projected coordinate reference systems, also Clause 12.

d) Test type: Basic.

A.2 Class B - Conformance of a coordinate operation

A.2.1 Abstract test suite

To check that a coordinate operation is in conformance with this International Standard, check that it satisfies the requirements given in A.2.2 to A.2.5.

A.2.2 Test case identifier: Completeness test

a) Test purpose: To determine whether all of the relevant, entities and elements which are specified to be mandatory or mandatory under the conditions specified have been provided in the description.

b) Test method: Check the coordinate operation description includes all of the elements indicated as mandatory in Tables 44 to 57.

c) Reference: Clause 12.

d) Test type: Basic.

A.2.3 Test case identifier: Maximum occurrence test

a) Test purpose: To ensure each coordinate operation element occurs not more than the number of times specified in the standard.

b) Test method: Examine the coordinate operation dataset for the number of occurrences of each entity and element provided to ensure that the number of occurrences for each shall be not more than the 'Maximum Occurrences' attribute specified in Tables 44 to 57.

c) Reference: Clause 12.

d) Test type: Basic.

A.2.4 Test case identifier: Data type test

a) Test purpose: To determine if each coordinate operation element in the dataset uses the specified data type.

b) Test method: Check the data type of each element of the description of a coordinate operation to ensure that it is of the data type specified in Tables 44 to 57.

c) Reference: Clause 12.

d) Test type: Basic.

A.2.5 Test case identifier: Unit test

a) Test purpose: To ensure that the units shall be in agreement with ISO 1000.

b) Test method: Check that any units of elements conform to ISO 1000.

c) Reference: Clause 12.

d) Test type: Basic

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[4] ISO 19113, *Geographic information – Quality principles*

[5] ISO 19133, *Geographic information – Location based services tracking and navigation*