Open Geospatial Consortium Inc.

Date: 2010-04-27

Reference number of this OGC® document: **OGC 08-015r2**

Version: 4.0.0

Category: OGC® Abstract Specification

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The OGC® Abstract Specification

Topic 2: Spatial referencing by coordinates

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Document type: OGC® Publicly Available Standard
Document subtype: OGC® Abstract Specification
Document stage: Final
Document language: English

Contents

i. Preface

This document is consistent with the second edition (2007) of ISO 19111, Geographic Information - Spatial referencing by coordinates. ISO 19111:2007 was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics*, in close collaboration with the Open Geospatial Consortium (OGC). It replaces the first edition, ISO 19111:2003. The revision was based upon and replaces OGC document 03-074r4.

ii. Revision history

Date	Release	Author	Paragraph modified	Description
7 Sept 2001	01-063	RN	New document	First draft for internal OGC feedback
12 Nov 2001	01-063r1 v 1.0.1	RN	Various editorial comments and a modification of the UML model	Initial feedback from CT Working Group implemented
8 Jan 2002	01-063r2 v 1.0.2	RN	Various editorial comments and modifications of the UML model	Final feedback implemented from the CT Working Group
15 Oct 2003	03-073r3 v 2.0.0	RN/AW JH/DC	Revision of UML model and accompanying text	The degree of detail of the UML model has been increased to facilitate conversion to XML Schema. The previous model was supplemented by textual constraints. These constraints have now been expressed in the UML model. The changes to version 1.0.2 were separately described in OGC document 03-009r6. This version 2.0.0 is therefore a consolidation of that document and version 1.0.2 of this document. Main OGC document number updated to 03-073.
2 Mar 2004	03-073r4 v.2.0.1	RN/AW DC	Editorial changes	Minor editorial changes made, creating version 2.0.1 for information only of ISO TC211
8 Feb 2008	08-015 v3.0.0	RL	Revision of UML model and accompanying text	Consistent with ISO 19111 second edition, 2007-07-01.

Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Open Geospatial Consortium Inc. shall not be held responsible for identifying any or all such patent rights. However, to date, no such rights have been claimed or identified.

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This third edition cancels and replaces the second edition (OGC 03-074r4), 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.

Spatial referencing by geographic identifiers is defined in ISO 19112 [4]. This Abstract Specification describes the data elements, relationships and associated metadata required for spatial referencing by coordinates. It describes the elements that are necessary to fully define 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 Abstract Specification 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.

The traditional separation of horizontal and vertical position has resulted in coordinate reference systems that are horizontal (2D) and vertical (1D) in nature, as opposed to truly three-dimensional. It is established practice to define a three-dimensional position by combining the horizontal coordinates of a point with a height or depth from a different coordinate reference system. In this Abstract Specification, this concept is defined as a compound coordinate reference system.

The concept of coordinates can be expanded from a strictly spatial context to include time. ISO 19108 describes temporal schema. Time can be added as a temporal coordinate reference system within a compound coordinate reference system. It is even possible to add two time-coordinates, provided the two coordinates describe different independent quantities.

EXAMPLE An example 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.

Certain scientific communities use three-dimensional systems where horizontal position is combined with a non-spatial parameter. In these communities, the parameter is considered to be a third, vertical axis. The parameter, although varying monotonically with elevation or depth, does not necessarily vary in a simple manner; thus, conversion from the parameter to height or depth is non-trivial. The parameters concerned are normally absolute measurements and the datum is taken with reference to a direct physical measurement of the parameter. These non-spatial parameters are beyond the scope of this Abstract Specification. However, the modelling constructs described within this Abstract Specification can be applied through a profile specific to a community.

In addition to describing a coordinate reference system, this Abstract Specification provides for the description of a coordinate transformation or a coordinate conversion between two different coordinate reference systems. With such information, spatial data referred to different coordinate reference systems can be related to one specified coordinate reference system. This facilitates spatial data integration. Alternatively, an audit trail of coordinate reference system manipulations can be maintained.

OGC Abstract Specification — Topic 2: Spatial referencing by coordinates

1 Scope

This Abstract Specification 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 one-, two- and three-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 coordinates from one coordinate reference system to another.

In this Abstract Specification, a coordinate reference system does not change with time. For coordinate reference systems defined on moving platforms such as cars, ships, aircraft and spacecraft, the transformation to an Earth-fixed coordinate reference system can include a time element.

This Abstract Specification 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.

The schema described can be applied to the combination of horizontal position with a third non-spatial parameter which varies monotonically with height or depth. This extension to non-spatial data is beyond the scope of this Abstract Specification but can be implemented through profiles.

2 Conformance requirements

This Abstract Specification 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 Abstract Specification shall satisfy the requirements given in A.1. Any coordinate operation claiming conformance to this Abstract Specification shall satisfy the requirements given in 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/TS 19103, *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 Abstract Specification, normative reference to ISO 19115 excludes the MD_CRS class and its component classes. ISO 19115 class MD_CRS and its component classes specify descriptions of coordinate reference systems elements. These elements are modelled in this Abstract Specification.

NOTE The MD_CRS class and its component classes were deleted from ISO 19115:2003 through Technical Corrigendum 1:2006.

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 2 or 3 for the purposes of this Abstract Specification.

4.3
compound coordinate reference system
coordinate reference system using at least two independent **coordinate reference systems**

NOTE Coordinate reference systems are independent of each other if coordinate values in one cannot be converted or transformed into coordinate values in the other.

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
coordinate operation in which both **coordinate reference systems** are based on the same **datum**

EXAMPLE Conversion from an ellipsoidal coordinate reference system based on the WGS 84 datum to a Cartesian coordinate reference system also based on the WGS 84 datum, or change of units such as from radians to degrees or feet to meters.

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

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 that is related to an object by a **datum**

NOTE For geodetic and vertical datums, the object will be the Earth.

4.9
coordinate set
collection 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
coordinate operation in which the two **coordinate reference systems** are based on different **datums**

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 system**

4.15
depth

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

NOTE A depth above the reference surface will have a negative value.

4.16
easting

E

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

4.17
ellipsoid

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

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

4.18
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**

4.19
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.

4.20
engineering coordinate reference system
coordinate reference system based on an engineering datum

EXAMPLES Local engineering and architectural grids; coordinate reference system local to a ship or an orbiting spacecraft.

4.21
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.

4.22
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.

4.23
geodetic coordinate reference system
coordinate reference system based on a geodetic datum

4.24
geodetic datum
datum describing the relationship of a two- or three-dimensional **coordinate system** to the Earth

4.25
geodetic latitude
ellipsoidal latitude
□
angle from the equatorial plane to the perpendicular to the **ellipsoid** through a given point, northwards treated as positive

4.26
geodetic longitude
ellipsoidal longitude
□
angle from the **prime meridian** plane to the **meridian** plane of a given point, eastward treated as positive

4.27
geoid

equipotential surface of the Earth's gravity field which is everywhere perpendicular to the direction of gravity and which best fits **mean sea level** either locally or globally

4.28
gravity-related height

H

height dependent on the Earth's gravity field

NOTE This refers to in particular orthometric height or normal height, which are both approximations of the distance of a point above the mean sea level.

4.29
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.

4.30
image coordinate reference system

coordinate reference system based on an image datum

4.31
image datum

engineering datum which defines the relationship of a **coordinate system** to an image

4.32
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.

4.33
map projection

coordinate conversion from an **ellipsoidal coordinate system** to a plane

4.34
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.

4.35
meridian
intersection of an **ellipsoid** by a plane containing the shortest axis of the **ellipsoid**

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

4.36
northing
N
distance in a **coordinate system**, northwards (positive) or southwards (negative) from an east-west reference line

4.37
polar coordinate system
two-dimensional **coordinate system** in which position is specified by distance and direction from the origin

NOTE For the three-dimensional case, see **spherical coordinate system (4.44)**.

4.38
prime meridian
zero meridian
meridian from which the longitudes of other **meridians** are quantified

4.39
projected coordinate reference system
coordinate reference system derived from a two-dimensional **geodetic coordinate reference system** by applying a **map projection**

4.40
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.

4.41
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.

4.42
sequence
finite, ordered collection of related items (objects or values) that may be repeated

[ISO 19107]

4.43
spatial reference
description of position in the real world

NOTE This may take the form of a label, code or coordinate tuple.

4.44
spherical coordinate system
three-dimensional **coordinate system** with one distance measured from the origin and two angular **coordinates**, commonly associated with a **geodetic coordinate reference** system

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

4.45
tuple
ordered list of values

[ISO 19136]

4.46
unit
defined quantity in which dimensioned parameters are expressed

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

4.47
vertical coordinate reference system
one-dimensional **coordinate reference system** based on a **vertical datum**

4.48
vertical coordinate system
one-dimensional **coordinate system** used for **gravity-related height** or **depth** measurements

4.49
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
□	geodetic longitude
□	geodetic latitude
E, N	Cartesian coordinates in a projected coordinate reference system
X, Y, Z	Cartesian coordinates in a geodetic coordinate reference system
i, j, [k]	Cartesian coordinates in an engineering coordinate reference system
r, □	polar coordinates in a 2D engineering coordinate reference system
r, □, □	spherical coordinates in a 3D engineering or geodetic 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

pixel	a contraction of “picture element”, the smallest element of a digital image to which attributes are assigned
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 Abstract Specification, the conceptual schema for describing coordinate reference systems and coordinate operations is modelled with the Unified Modelling Language (UML). The basic data types and UML diagram notations are defined in ISO/TS 19103 and ISO/IEC 19501 [9].

In this Abstract Specification, 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) <<Type>> a class used for specification of a domain of objects together with operations applicable to the objects;

c) <<CodeList>> a flexible enumeration that uses string values for expressing a list of potential values;

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

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

- Angle amount of rotation required to bring one line or plane into coincidence with another;

- Boolean a value specifying TRUE or FALSE;

- CharacterString a sequence of characters;
- Date a character string which comprises year, month and day in the format as specified by ISO 8601;
- GenericName a generic name structure in the context of namespaces, defined in ISO/TS 19103;
- Integer an integer number;
- Length the measure of distance;
- Measure result from performing the act or process of ascertaining the extent, dimensions or quantity of some entity;
- Number abstract class that can be subtyped to a specific number type (real, integer, decimal, double, float);
- Scale the ratio of one quantity to another;
- 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>”.

In the UML diagrams in this Abstract Specification, grey boxes indicate classes from other packages.

5.4 Attribute status

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

6 Spatial referencing by coordinates — Overview

6.1 Relationship between coordinates and coordinate reference system

In this Abstract Specification, a *coordinate* is one of *n* scalar values that define the position of a single point. In other contexts, the term *ordinate* is used for a single value and coordinate for multiple ordinates. Such usage is not part of this Abstract Specification.

A *coordinate tuple* is an ordered list of *n* coordinates that define the position of a single point. In this Abstract Specification, the coordinate tuple shall be 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.

EXAMPLE A coordinate tuple cannot contain two heights.

Coordinates are ambiguous until the system to which those coordinates are related has been fully defined. Without the full specification of the system, coordinates are ambiguous at best and meaningless at worst. A *coordinate reference system* (CRS) defines the coordinate space such that the coordinate values are unambiguous. In this Abstract Specification, the order of the coordinates within the coordinate tuple and their unit(s) of measure shall be parts of the coordinate reference system definition.

In this Abstract Specification, a *coordinate set* shall be a collection of coordinate tuples referenced to the same coordinate reference system. A CRS identification or definition in accordance with this Abstract Specification shall be associated with every coordinate tuple. If only one point is being described, the association shall be direct. For a coordinate set, one CRS identification or definition may be associated with the coordinate set and then all coordinate tuples in that coordinate set inherit that association. The conceptual relationship of coordinate tuple and coordinate set to coordinate reference system is shown in Figure 1.

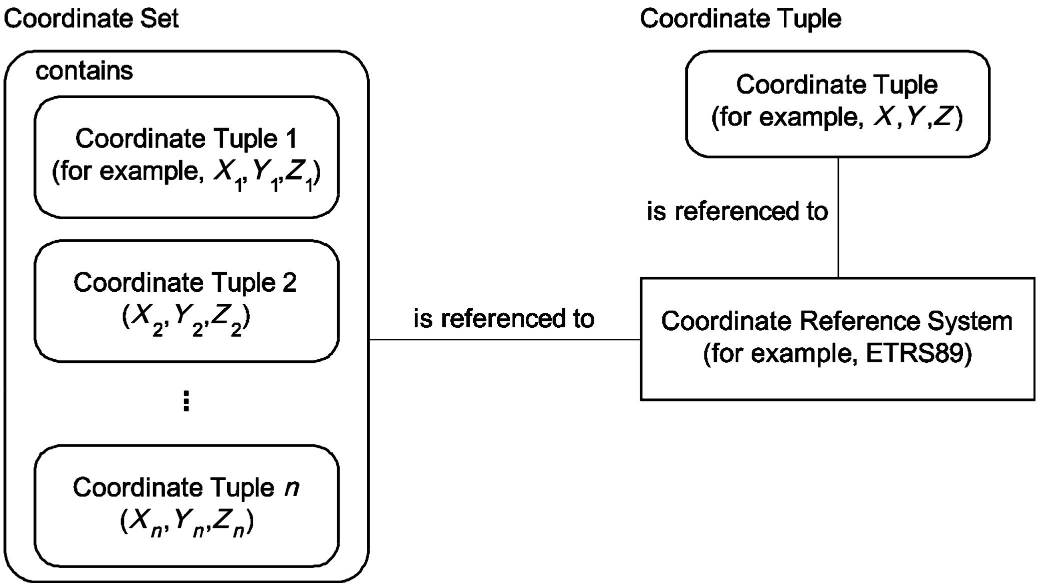


Figure 1 — Conceptual relationship of coordinates to coordinate reference system

The semantic meaning of coordinate tuple and coordinate set is reflected in the modelling of classes DirectPosition and GM_Object respectively; this modelling is in ISO 19107 [3].

In this Abstract Specification, a coordinate reference system shall be comprised of one coordinate system and one datum (see Figure 2).

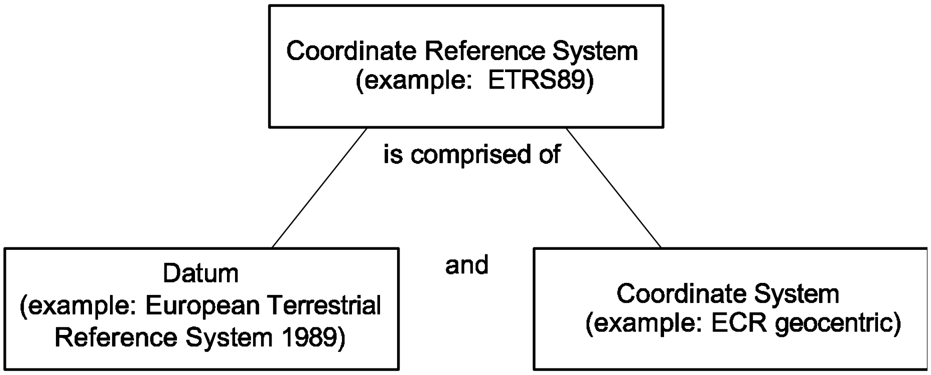
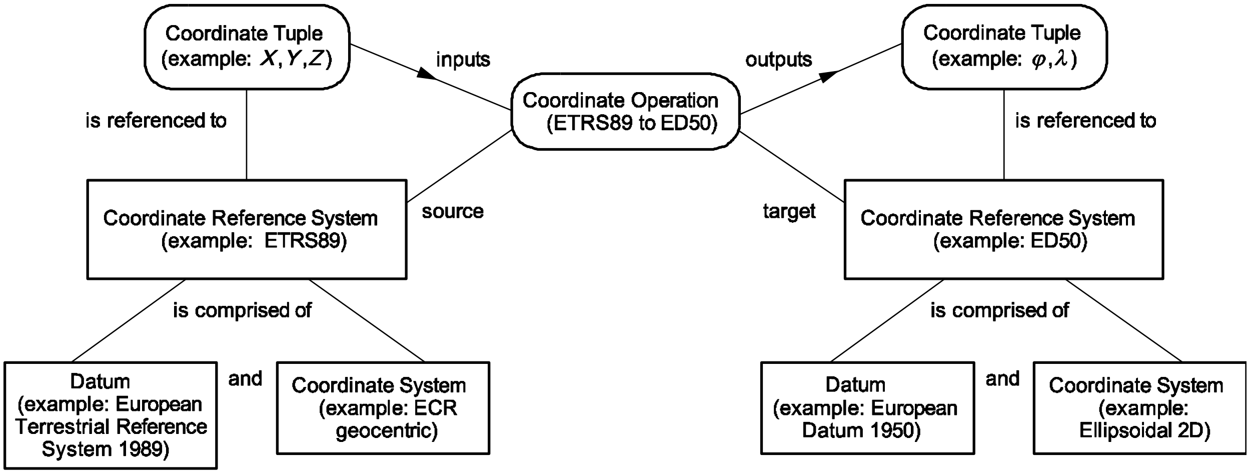

Coordinate Reference System
(example: ETRS89)
is comprised of
and
Datum
(example: European Terrestrial Reference System 1989)
Coordinate System
(example: ECR geocentric)

Figure 2 — Conceptual model of a coordinate reference system

The high level abstract model for spatial referencing by coordinates is shown in Figure 3. A coordinate transformation or coordinate conversion operates on coordinates, not on coordinate reference systems. Coordinate operation has been modelled in ISO 19107 [3] by the operation “Transform” of the GM_Object class.



NOTE A coordinate operation may be single or concatenated. Refer to Clause 11.

Figure 3 — Conceptual model for spatial referencing by coordinates

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

6.2 UML model for spatial referencing by coordinates — Overview

The specification for spatial referencing by coordinates is defined in this Abstract Specification in the form of a UML model with supplementary text. The UML model contains five primary UML packages, as shown in Figure 4. Each box represents a package, and contains the package name. Each arrowed line shows the dependency (at the head of the arrow) of one package upon another package.

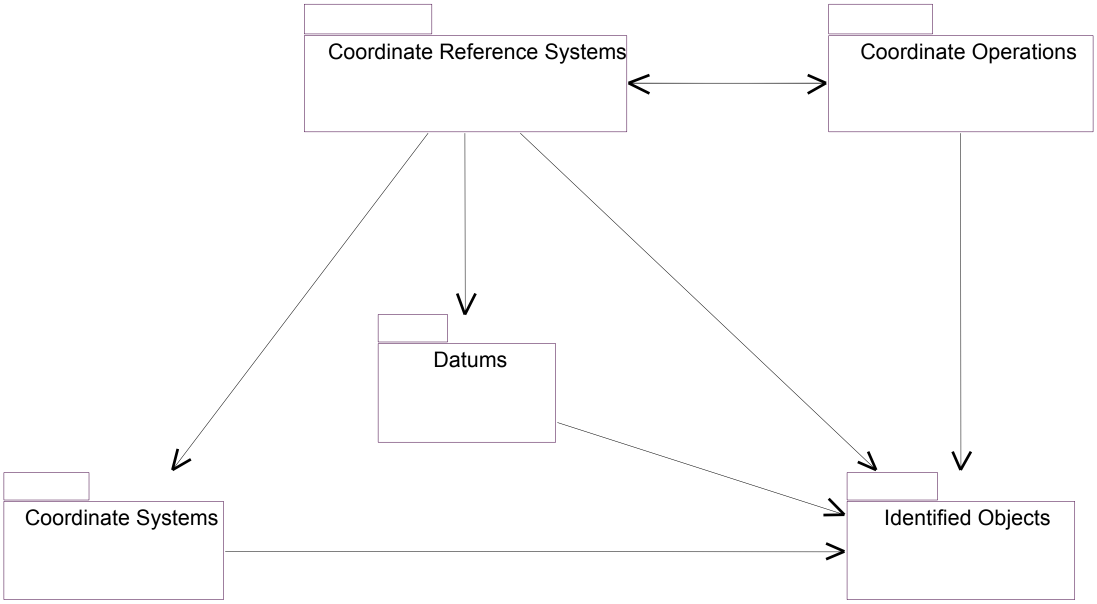


Figure 4 — UML model packages and dependencies

The five UML packages for spatial referencing by coordinates are more completely specified in the Clauses 7 through 11. Further context for the requirements of Clauses 7 through 11 is given in Annex B and some geodetic concepts underpinning spatial referencing by coordinates are given in Annex C. Examples illustrating how this Abstract Specification can be applied when defining a coordinate reference system or a coordinate operation are given in Annex D. Recommendations for referencing to classes defined in this Abstract Specification are given in Annex E.

7 Identified Object package

7.1 General

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

One of the attributes is the object primary name. This may have alternative names or aliases.

EXAMPLE 1 A datum name might be “North American Datum of 1983” and its 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.

Another attribute is identifier. This is a unique code used to reference an object in a given place.

EXAMPLE 2 A register of geodetic codes and parameters 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 register of geodetic codes and parameters, it may also be included in an object definition to allow reference to the object.

Object identification shall be through

a) a full object description as defined in this Abstract Specification, or

b) reference to a full object description in a register of geodetic parameters (the reference is made to 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 are required only to confirm the *identification* of an object can do so through the register citation and the 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 Implementers are warned that 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 recognized by applications referencing the register in order to be able to find the data that is required, i.e. usually the most up-to-date register information, but sometimes, because historically it was used to transform spatial data that is still in use, the erroneous information from the past.

7.2 UML schema for the Identified Object package

Figure 5 shows the UML class diagram of the IO_IdentifiedObject package. The definition of the object classes are provided in Tables 1 and 2.

NOTE 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 Abstract Specification, it may use the alias attribute from IO_IdentifiedObjectBase for aliases.

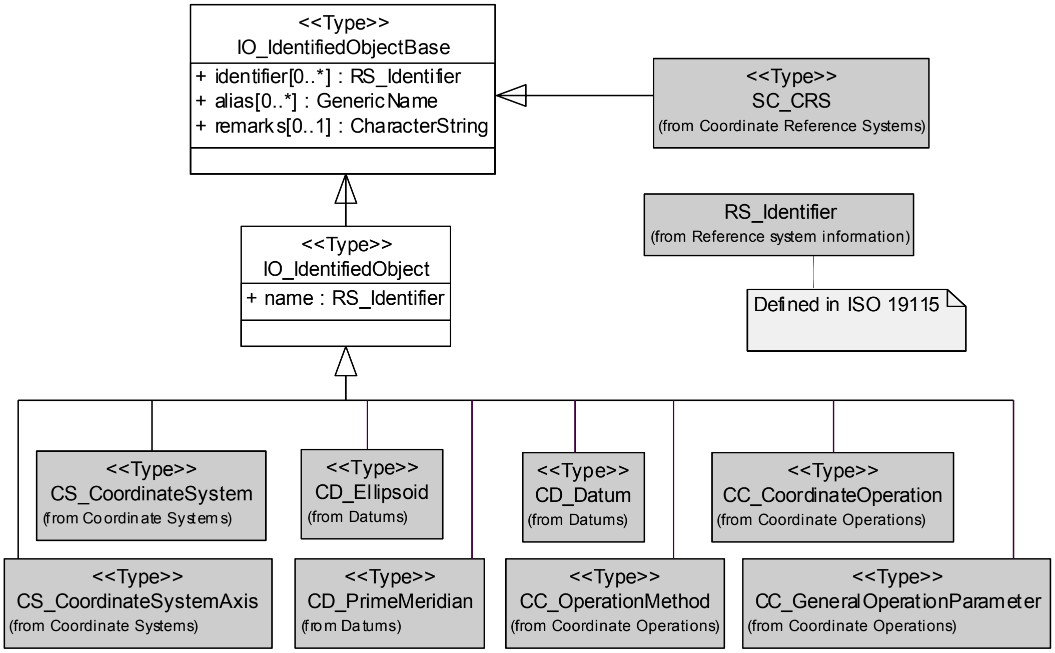


Figure 5 — IO_IdentifiedObject package

Table 1 — Defining elements of IO_IdentifiedObjectBase class

Description:	Supplementary identification and remarks information for a CRS or CRS-related object.
Stereotype:	Type
Class attribute:	Abstract
Inheritance from:	(none)
Association roles:	(none)
Used by:	SC_CRS CS_CoordinateSystem CS_CoordinateSystemAxis CD_Datum CD_Ellipsoid CD_PrimeMeridian CC_CoordinateOperation CC_OperationMethod CC_GeneralOperationParameter
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:	Type
Class attribute:	Abstract
Inheritance from:	IO_IdentifiedObjectBase
Association roles:	(none)
Used by:	CS_CoordinateSystem CS_CoordinateSystemAxis CD_Datum CD_Ellipsoid CD_PrimeMeridian CC_CoordinateOperation CC_OperationMethod CC_GeneralOperationParameter
Public attributes:	3 attributes (identifier, alias and remarks) 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.

8 Coordinate Reference System package

8.1 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 Abstract Specification and the associated model. The requirements for spatial referencing by geographic identifier are described in ISO 19112 [4].

b) Spatial referencing by coordinates. The scope of this Abstract Specification and the associated UML model is confined to the description of position through coordinates.

The RS_ReferenceSystem 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.

8.2 Coordinate reference system

8.2.1 General

In this Abstract Specification, a coordinate reference system shall be defined by one coordinate system and one datum. A datum specifies the relationship of a coordinate system to an object, 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 object's surface by means of coordinates. The object will generally, but not necessarily, be the Earth; for certain coordinate reference systems, the object may be a moving platform.

In this Abstract Specification, a coordinate reference system shall not change with time. For 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. Time-variability of coordinate reference systems may 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 realization of the datum shall then be included in its definition. Furthermore, it is recommended that the date of realization be included in the names of those datums and coordinate reference systems.

8.2.2 Principal subtypes of coordinate reference system

The classification criterion for subtyping of coordinate reference systems shall be by reference to the type of datum associated with the coordinate reference system. The following principal subtypes of coordinate reference system shall be distinguished:

a) **Geodetic** – a coordinate reference system that is associated with a geodetic datum;

b) **Vertical** – a coordinate reference system that is associated with a vertical datum;

c) **Engineering** – a coordinate reference system that is associated with an engineering datum;

d) **Image** – an Engineering CRS applied to images. The definition of the associated Image Datum contains two attributes not relevant to other engineering datums.

These principal subtypes of coordinate reference system are described further in B.1.2.

8.2.3 Additional subtypes of coordinate reference system

In addition to the principal subtypes of coordinate reference system, to permit modelling of certain relationships and constraints that exist, three more subtypes shall be distinguished. These additional sub-types are:

a) **Derived** – a coordinate reference system which is defined by applying a coordinate conversion to another coordinate reference system (A derived CRS inherits its datum from its base CRS);

b) **Projected** – a coordinate reference system which is derived from a base geodetic CRS by applying the coordinate conversion known as a map projection to latitude and longitude ellipsoidal coordinate values;

c) **Compound** – a non-repeating sequence of two or more coordinate reference systems none of which can itself be compound.

These subtypes of coordinate reference system are described further in B.1.2. Compound coordinate reference systems are also further detailed below.

8.2.4 Compound coordinate reference system

8.2.4.1 Spatial compound coordinate reference system

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 shall be the following.

a) Geodetic 2D + Vertical.

b) Geodetic 2D + Engineering 1D (near vertical).

c) Projected + Vertical.

d) Projected + Engineering 1D (near vertical).

e) Engineering (horizontal 2D) + Vertical.

f) Engineering (1D linear) + Vertical.

8.2.4.2 Spatio-temporal compound coordinate reference system

Any single coordinate reference system, or any of the combinations of spatial compound coordinate reference systems listed in 8.2.4.1, may be associated with a temporal coordinate reference system to form a spatio-temporal compound coordinate reference system. More than one temporal coordinate reference system may be included if these axes represent different time quantities. Temporal coordinate reference systems are described in ISO 19108.

8.2.4.3 Nesting of compound coordinate reference systems

Nesting of CCRSs shall not be permitted; the individual single systems shall be aggregated together. Figure B.1 in Annex B shows examples of the possible composition of spatial and spatio-temporal compound coordinate reference systems.

8.3 UML schema for the Coordinate Reference System package

Figure 6 shows the UML class diagram of the SC_CoordinateReferenceSystem package. The definition of the object classes of the package are provided in Tables 4 through 14.

The CRS UML class diagram shows an association named CoordinateSystem from the SC_SingleCRS class to the CS_CoordinateSystem class. This 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 8 in Clause 9. In two cases, the multiplicity of the target end of these associations is 1 (mandatory). In three cases, a subclass of SC_SingleCRS has an indirect association through a union class to one of several alternative subclasses of the CS_CoordinateSystem class.

The CRS UML class diagram also shows an association named DefiningDatum from SC_SingleCRS to the CD_Datum class. This 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 10 in Clause 10. For the subclasses of SC_SingleCRS that have a direct association to CD_Datum or one of its subclasses, the multiplicity of the target 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 target end of the association is 0 (no association).

SC_ProjectedCRS is modelled separately from SC_DerivedCRS to permit description of its specific association characteristics.

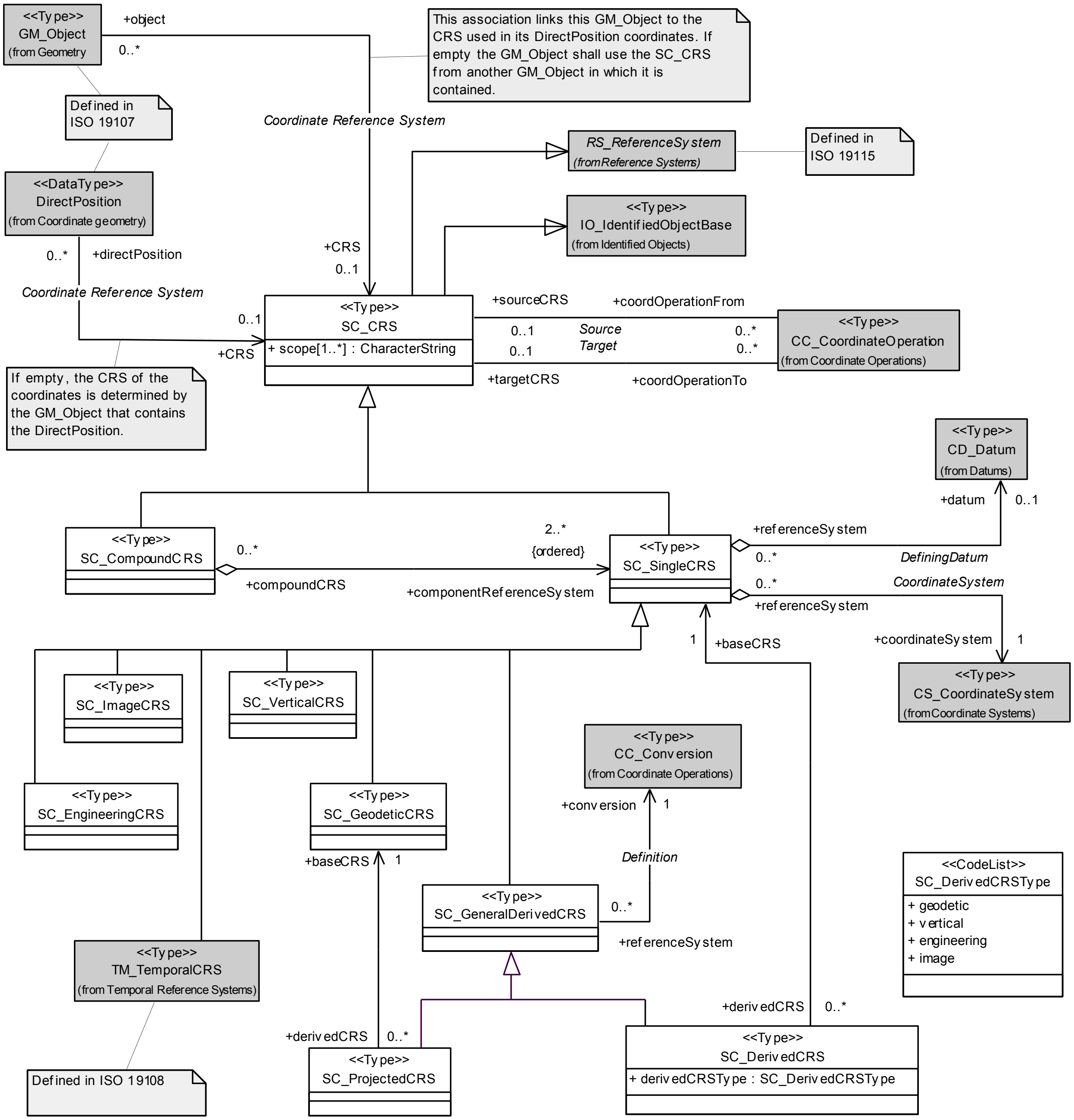


Figure 6 — SC_CoordinateReferenceSystem package

Table 4 — Defining elements of SC_CRS class

<table>
<tr><td>Description:</td><td colspan="5">Coordinate reference system which is usually single but may be compound.</td></tr>
<tr><td>Stereotype:
Class attribute:
Inheritance from:

Association roles:

Public attributes:</td><td colspan="5">Type
Abstract
RS_ReferenceSystem
IO_IdentifiedObjectBase
coordinateOperationFrom to CC_CoordinateOperation [0..*], association named <i>Source</i>
coordinateOperationTo to CC_CoordinateOperation [0..*], association named <i>Target</i>
CRS from GM_Object [0..1], association named <i>Coordinate Reference System</i>
<i>(reverse: object to GM_Object [0..*] navigable only from GM_Object – see ISO 19107)</i>
CRS from DirectPosition [0..1], association named <i>Coordinate Reference System</i>
<i>(reverse: directPosition to DirectPosition [0..*] navigable only from DirectPosition – see ISO 19107)</i></td></tr>
<tr><th>Attribute name</th><th>UML identifier</th><th>Data type</th><th>Obligation</th><th>Maximum Occurrence</th><th>Attribute description</th></tr>
<tr><td>CRS scope</td><td>scope</td><td>CharacterString</td><td>M</td><td>N</td><td>Description of usage, or limitations of usage, fo whichh this CRS is valid. If unknown, enter “not known”.</td></tr>
<tr><td colspan="6">The following 5 attributes are inherited from IO_IdentifiedObjectBase and from RS_ReferenceSystem – see Tables 1 and 3.
NOTE As an exception to elsewhere in this Abstract Specification, inherited attributes are included in this class table to allow the CRS name, CRS alias and CRS identifier attributes to be shown together.</td></tr>
<tr><th>Attribute name</th><th>UML identifier</th><th>Data type</th><th>Obligation</th><th>Maximum Occurrence</th><th>Attribute description</th></tr>
<tr><td>CRS name</td><td>name</td><td>RS_Identifier</td><td>M</td><td>1</td><td>This is the primary name for the CRS. Aliases and other identifiers may be given through the attributes alias and identifier.</td></tr>
<tr><td>CRS alias</td><td>alias</td><td>GenericName</td><td>O</td><td>N</td><td>An alias by which this CRS is known.</td></tr>
<tr><td>CRS identifier</td><td>identifier</td><td>RS_Identifier</td><td>O</td><td>N</td><td>An identifier which references elsewhere the CRS's defining information; alternatively an identifier by which this CRS can be referenced.</td></tr>
<tr><td>CRS validity</td><td>domainOfValidity</td><td>EX_Extent</td><td>O</td><td>N</td><td>Area or region or time frame in which this CRS is valid.</td></tr>
<tr><td>CRS remarks</td><td>remarks</td><td>CharacterString</td><td>O</td><td>1</td><td>Comments on or information about this CRS, including data source information.</td></tr>
</table>

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:	Type
Class attribute:	Abstract
Inheritance from:	SC_CRS
Association roles:	(aggregation) datum to CD_Datum [0..1], association named *DefiningDatum* (aggregation) coordinateSystem to CS_CoordinateSystem [1], association named *CoordinateSystem* baseCRS from SC_DerivedCRS [1] *(reverse: derivedCRS to SC_DerivedCRS [0..*] navigable only from SC_DerivedCRS – see Table 8)* (aggregation) componentReferenceSystem from SC_CompoundCRS [2..*] {ordered} *(reverse: compoundCRS to SC_CompoundCRS [0..*] navigable only from SC_CompoundCRS – see Table 6)* (associations inherited from SC_CRS)
Public attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

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. NOTE two coordinate reference systems are independent of each other if coordinate values in one cannot be converted or transformed into coordinate values in the other.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	SC_CRS
Association roles:	(aggregation) componentReferenceSystem to SC_SingleCRS [2..*] {ordered} (associations inherited from SC_CRS)
Public attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

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:	Type
Class attribute:	Abstract
Inheritance from:	SC_SingleCRS
Association roles:	conversion to CC_Conversion [1], association named *Definition* (associations inherited from SC_SingleCRS)
Public attributes:	6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

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: Type
Class attribute: Concrete
Inheritance from: SC_GeneralDerivedCRS
Association roles: baseCRS to SC_SingleCRS [1]
(associations inherited from SC_ GeneralDerivedCRS, including …
… (aggregation) coordinateSystem to CS_CoordinateSystem [1], association named CoordinateSystem)
Public attributes: 6 attributes inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks – see Table 4), plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occur-rence	Attribute description
Derived CRS type	derivedCRStype	SC_DerivedCRSType	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
Inheritance from: (none)
Association roles: (none)
Used by: SC_DerivedCRS
Public attributes:

Attribute name	UML identifier	Data type	Obligation	Maximum Occur-rence	Attribute description
Geodetic CRS	geodetic	CharacterString	C	1	A coordinate reference system based on a geodetic datum; provides an accurate representation of the geometry of geographic features for a large portion of the Earth's surface.
Vertical CRS	vertical	CharacterString	C	1	A coordinate reference system used for recording of heights or depths. Vertical CRSs make use of the direction of gravity to define the concept of height or depth, but the relationship with gravity may not be straightforward.
Engineering CRS	engineering	CharacterString	C	1	A contextually local coordinate reference system; which can be divided into two broad categories: - Earth-fixed systems applied to engineering activities on or near the surface of the Earth; - CRSs on moving platforms such as road vehicles, vessels, aircraft or spacecraft.
Image CRS	image	CharacterString	C	1	An engineering coordinate reference system applied to locations in images.

Condition: One and only one of the listed attributes shall be supplied.

Table 10 — Defining elements of SC_GeodeticCRS class

Description:	A coordinate reference system associated with a geodetic datum.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	SC_SingleCRS
Association roles:	(aggregation) datum to CD_GeodeticDatum [1], association named *DefiningDatum* (aggregation) coordinateSystem to CS_GeodeticCS [1], association named *CoordinateSystem* baseCRS from ProjectedCRS [1] *(reverse: derivedCRS to SC_ProjectedCRS [0..*] navigable only from SC_ProjectedCRS – see Table 11)* (associations inherited from SC_SingleCRS)
Public Attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

Table 11 — Defining elements of SC_ProjectedCRS class

Description:	A derived coordinate reference system which has a geodetic coordinate reference system as its base CRS and is converted using a map projection.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	SC_GeneralDerivedCRS
Association roles:	baseCRS to SC_GeodeticCRS [1] (aggregation) coordinateSystem to CS_CartesianCS [1], association named *CoordinateSystem* (associations inherited from SC_ GeneralDerivedCRS)
Public Attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

Table 12 — Defining elements of SC_EngineeringCRS class

Description:	A contextually local coordinate reference system associated with an engineering datum and 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:	Type
Class attribute:	Concrete
Inheritance from:	SC_SingleCRS
Association roles:	(aggregation) datum to CD_EngineeringDatum [1], association named *DefiningDatum* (aggregation) coordinateSystem to CS_EngineeringCS [1], association named *CoordinateSystem* (associations inherited from SC_SingleCRS
Public Attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

Table 13 — Defining elements of SC_ImageCRS class

Description:	A coordinate reference system associated with an image datum. Image coordinate reference systems are treated as a separate sub-type because the definition of the associated Image Datum contains two attributes not relevant to other engineering datums.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	SC_SingleCRS
Association roles:	(aggregation) datum to CD_ImageDatum [1], association named *DefiningDatum* (aggregation) coordinateSystem to CS_ImageCS [1], association named *CoordinateSystem* (associations inherited from SC_SingleCRS)
Public attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

Table 14 — 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 geodetic 3D coordinate reference system.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	SC_SingleCRS
Association roles:	(aggregation) datum to CD_VerticalDatum [1], association named *DefiningDatum* (aggregation) coordinateSystem to CS_VerticalCS [1], association named *CoordinateSystem* (associations inherited from SC_SingleCRS)
Public Attributes:	6 attributes (CRS name, CRS alias, CRS identifier, CRS validity, CRS scope and CRS remarks) inherited from IO_IdentifiedObjectBase, RS_ReferenceSystem and SC_CRS. See Table 4.

9 Coordinate System package

9.1 Introduction

In this Abstract Specification, the Coordinate System package models two main concepts: coordinate system and coordinate system axis.

9.2 Coordinate system

A coordinate system shall be composed of a non-repeating sequence of coordinate system axes. One coordinate system may be used by multiple coordinate reference systems. The dimension of the coordinate space, the names, the units of measure, the directions and sequence of the axes all shall be part of the coordinate system definition. The number of axes shall be equal to the dimension of the space of which it describes the geometry. It is therefore not permitted to supply a coordinate tuple with two heights of different definition.

The number of coordinates in a coordinate tuple shall be equal to the number of coordinate axes in the coordinate system. Coordinates in coordinate tuples shall be supplied in the order in which the coordinate system's axes are defined.

In this Abstract Specification, coordinate systems shall be 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 shall be used only with specific subtypes of coordinate reference system as shown in the UML class diagram in Figure 8 and Table 15. For derived CRSs, the constraints on CS association shall be by derived CRS subtype and follow the constraints for the equivalent subtype of principle CRS. A description of coordinate system subtypes is included in Table 15.

This Abstract Specification additionally allows for user-defined coordinate systems. Each of these shall be used with one of the coordinate reference system subtypes described in Clause 8.

Table 15 — Subtypes of coordinate system and constraints in its relationship with coordinate reference system

CS subtype	Description	Used with CRS type(s)
affine	two- or three-dimensional coordinate system with straight axes that are not necessarily orthogonal.	Engineering Image
Cartesian	two- or three-dimensional coordinate system which gives the position of points relative to orthogonal straight axes. All axes shall have the same unit of measure.	Geodetic Projected Engineering Image
cylindrical	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.	Engineering
ellipsoidal	two- or three-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude and (in the three-dimensional case) ellipsoidal height.	Geodetic
linear	one-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 Abstract Specification 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 [7].	Engineering
polar	two-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
spherical	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.	Geodetic Engineering
vertical	one-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

Coordinate systems are described further in B.2.1.

9.3 Coordinate system axis

A coordinate system shall be composed of a non-repeating sequence of coordinate system axes. Each of its axes shall be completely characterized by a unique combination of axis name, axis abbreviation, axis direction and axis unit. Aliases for these attributes may be used as described in Clause 7.

EXAMPLE 1 The combination {Latitude, Lat, north, degree} would lead to one instance of the object class "coordinate system axis"; the combination {Latitude, j, north, degree} to another instance, the axis abbreviation being different.

In this Abstract Specification, usage of coordinate system axis names shall be constrained by geodetic custom, depending on the coordinate reference system type. These constraints are shown in Table 16. This constraint shall work in two directions.

EXAMPLE 2 As "geodetic latitude" and "geodetic longitude" are used as names for coordinate axes forming a geodetic coordinate reference system, these terms cannot also be used in another context.

Aliases for these constrained names shall be permitted.

Table 16 — Naming constraints for coordinate system axis

CS type	When used in CRS type	Permitted coordinate system axis names
Cartesian	geodetic	geocentric X, geocentric Y, geocentric Z
Cartesian	projected	northing or southing, easting or westing
ellipsoidal	geodetic	geodetic latitude, geodetic longitude, [ellipsoidal height (if 3D)]
spherical	geodetic	spherical latitude, spherical longitude, geocentric radius
vertical	vertical	depth or gravity-related height

Image and engineering coordinate reference systems may make use of names specific to the local context or custom.

Coordinate system axes are described further in B.2.2.

9.4 UML schema for the Coordinate System package

Figure 7 shows the UML class diagram of the CS_CoordinateSystem package. The associations between Coordinate Reference System subtypes and Coordinate System subtypes are shown in the UML class diagram in Figure 8. The definitions of the object classes of the CS_CoordinateSystem package are provided in Tables 17 through 32.

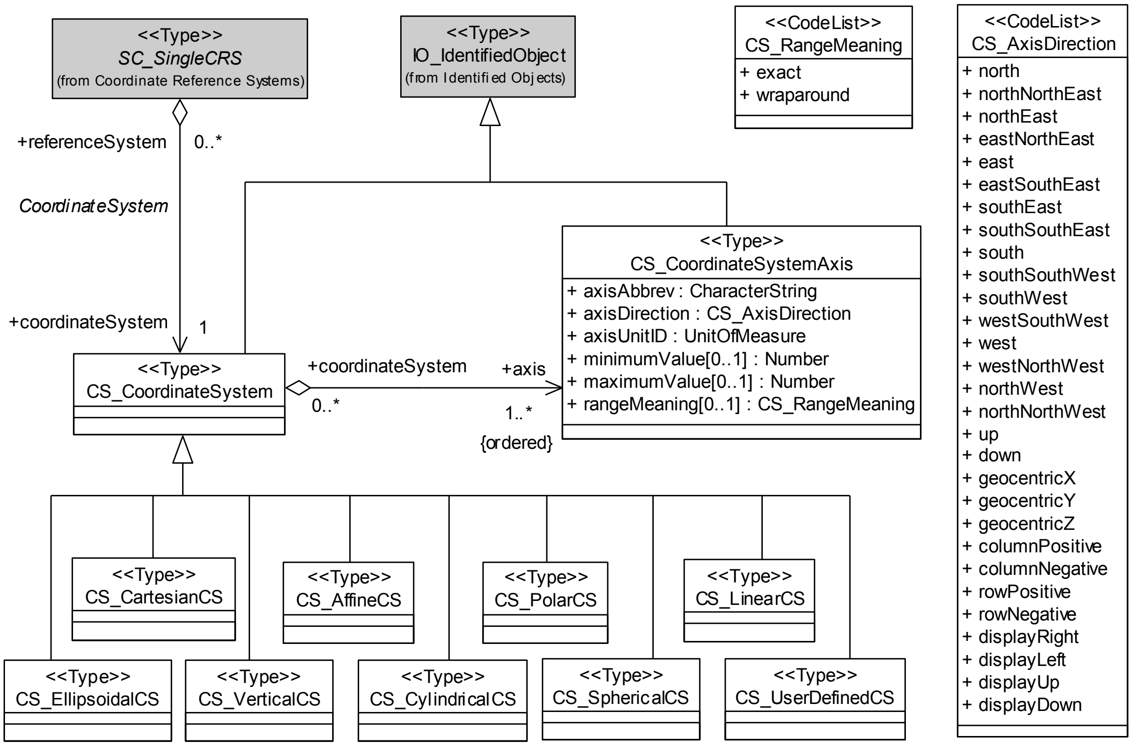


Figure 7 — CS_CoordinateSystem package

See Figure 8 for details of the association between the CS_CoordinateSystem and the SC_SingleCRS.

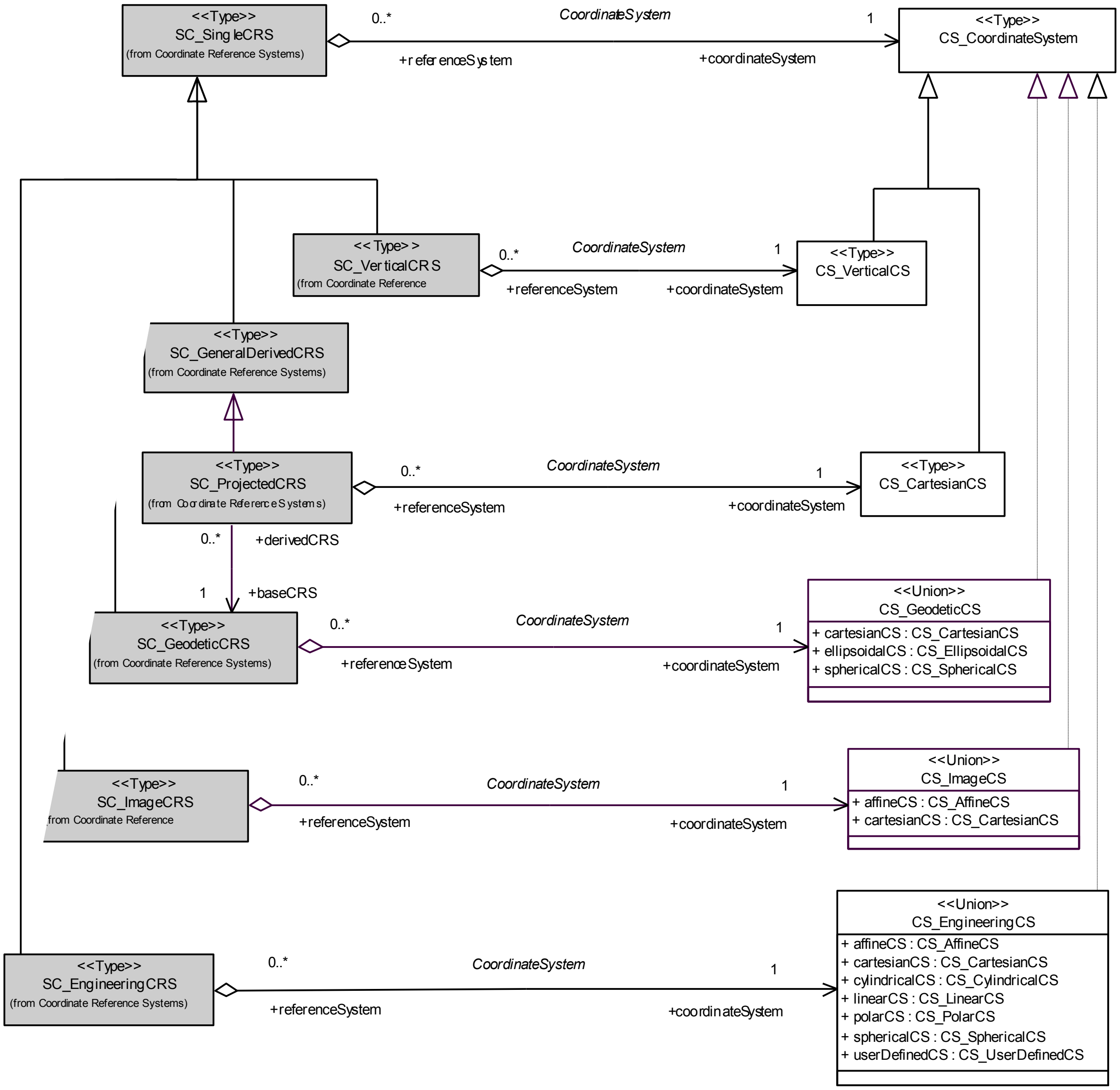


Figure 8 — Coordinate System type associations with Coordinate Reference System type

Table 17 — 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:	Type
Class attribute:	Abstract
Inheritance from:	IO_IdentifiedObject
Association roles:	(aggregation) axis to CS_CoordinateSystemAxis [1..*] {ordered} (aggregation) coordinateSystem from SC_SingleCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_SingleCRS [0..*] navigable only from SC_SingleCRS – see Table 5)*
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 18 — Defining elements of CS_CartesianCS class

Description:	A two- or three-dimensional coordinate system with orthogonal straight axes. In the 2D case, both axes shall have the same length unit; in the 3D case, all axes shall have the same length unit. A CartesianCS shall have two or three axis associations; the number of associations shall equal the dimension of the CS.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Association roles:	(aggregation) coordinateSystem from SC_ProjectedCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_ProjectedCRS [0..*] navigable only from SC_ProjectedCRS – see Table 11)* (associations inherited from CS_CoordinateSystem)
Used by:	CS_GeodeticCS CS_EngineeringCS CS_ImageCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 19 — 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 axis associations; the number of associations shall equal the dimension of the CS.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS CS_ImageCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 20 — 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 associations; the number of associations shall equal the dimension of the CS.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_GeodeticCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 21 — 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 axis associations.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 22 — 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 axis associations.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 23 — 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 axis associations.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 24 — 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 origin point, specified through the datum definition, 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 axis association.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 25 — 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. An exact definition is deliberately not provided as the complexities of the subject fall outside the scope of this document. A VerticalCS shall have one axis association.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Association roles:	(aggregation) coordinateSystem from SC_VerticalCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_VerticalCRS [0..*] navigable only from SC_VerticalCRS – see Table 14)* (associations inherited from CS_CoordinateSystem)
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 26 — 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 1D shape which has no intersections with itself. This non-straight axis is supplemented by one or two straight axes to complete a two- or three-dimensional coordinate system. The non-straight axis is typically incrementally straight or curved. A UserDefinedCS shall have two or three axis associations; the number of associations shall equal the dimension of the CS.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CS_CoordinateSystem
Used by:	CS_EngineeringCS
Public attributes:	4 attributes (CS name, CS alias, CS identifier and CS remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase. See Tables 1 and 2.

Table 27 — Defining elements of CS_CoordinateSystemAxis class

<table>
<tr><td colspan="6">Description: Definition of a coordinate system axis.</td></tr>
<tr><td colspan="6">Stereotype: Type
Class attribute: Concrete
Inheritance from: IO_IdentifiedObject
Association roles: (aggregation) axis from CS_CoordinateSystem [1..*] {ordered}
<i>(reverse: coordinateSystem to CS_CoordinateSystem [0..*] navigable only from CS_CoordinateSystem – see Table 17)</i>
Public attributes: 4 attributes (coordinate system axis name, coordinate system axis alias, coordinate system axis identifier and coordinate system axis remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase: see Tables 1 and 2, plus:</td></tr>
<tr><th>Attribute name</th><th>UML identifier</th><th>Data type</th><th>Obligation</th><th>Maximum Occurrence</th><th>Attribute description</th></tr>
<tr><td>Coordinate system axis abbreviation</td><td>axisAbbrev</td><td>CharacterString</td><td>M</td><td>1</td><td>The abbreviation used for this coordinate system axis; this abbreviation is also used to identify the coordinates in the coordinate tuple. Examples are <i>X</i> and <i>Y</i>.</td></tr>
<tr><td>Coordinate system axis direction</td><td>axisDirection</td><td>CS_AxisDirection</td><td>M</td><td>1</td><td>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.</td></tr>
<tr><td>Coordinate system axis unit identifier</td><td>axisUnitID</td><td>UnitOfMeasure</td><td>M</td><td>1</td><td>Identifier of the unit used for this coordinate system axis. The value of a coordinate in a coordinate tuple shall be recorded using this unit.</td></tr>
<tr><td>Coordinate system axis minimum value</td><td>minimumValue</td><td>Number</td><td>O</td><td>1</td><td>The minimum value normally allowed for this axis, in the unit for the axis.</td></tr>
<tr><td>Coordinate system axis maximum value</td><td>maximumValue</td><td>Number</td><td>O</td><td>1</td><td>The maximum value normally allowed for this axis, in the unit for the axis.</td></tr>
<tr><td>Coordinate system axis range meaning</td><td>rangeMeaning</td><td>CS_RangeMeaning</td><td>C</td><td>1</td><td>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.</td></tr>
</table>

Table 28 — 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**	**Maxi-mum Occur-rence**	**Attribute description**
north	north	CharacterString	C	1	Axis positive direction is north. In a geodetic 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 □/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 □ radians clockwise from north.
south-south-west	southSouthWest	CharacterString	C	1	Axis positive direction is approximately south-south-west.
south-west	southWest	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□/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 □/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.
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.					

Table 29 — Defining elements of CS_RangeMeaning class

Description:	Meaning of the axis value range specified through minimumValue and maximumValue.				
Stereotype:	CodeList				
Inheritance 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 maximumValue 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 30 — Defining elements of CS_GeodeticCS class

Description:	A coordinate system used by a Geodetic CRS. It shall be one of the following: a Cartesian coordinate system; an ellipsoidal coordinate system; or a spherical coordinate system.
Stereotype:	Union
Realization of:	CS_CoordinateSystem. As such, it must implement all inherited operations and associations. Furthermore, it must support all inherited attributes, at least as "read only".
Association roles:	(aggregation) coordinateSystem from SC_GeodeticCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_GeodeticCRS [0..*] navigable only from SC_GeodeticCRS – see Table 10)* (aggregation) cartesianCS to CS_CartesianCS [1] (aggregation) ellipsoidalCS to CS_EllipsoidalCS [1] (aggregation) sphericalCS to CS_SphericalCS [1] union (one of) constraint on cartesianCS, ellipsoidalCS and sphericalCS associations (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 31 — Defining elements of CS_EngineeringCS class

Description:	A coordinate system used by an Engineering CRS. It shall be one of the following: an affine coordinate system; a Cartesian coordinate system; a cylindrical coordinate system; a linear coordinate system; a polar coordinate system; a spherical coordinate system; or a user-defined coordinate system.
Stereotype:	Union
Realization of:	CS_CoordinateSystem. As such, it must implement all inherited operations and associations. Furthermore, it must support all inherited attributes, at least as "read only".
Association roles:	(aggregation) coordinateSystem from SC_EngineeringCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_EngineeringCRS [0..*] navigable only from SC_EngineeringCRS – see Table 12)* (aggregation) affineCS to CS_AffineCS [1] (aggregation) cartesianCS to CS_CartesianCS [1] (aggregation) cylindricalCS to CS_ CylindricalCS [1] (aggregation) linearCS to CS_LinearCS [1] (aggregation) polarCS to CS_PolarCS [1] (aggregation) sphericalCS to CS_SphericalCS [1] (aggregation) userDefinedCS to CS_UserDefinedCS [1] union (one of) constraint on affineCS, cartesianCS, cylindricalCS, linearCS, polar CS, sphericalCS and userDefinedCS associations (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

Table 32 — Defining elements of CS_ImageCS class

Description:	A coordinate system used by an Image CRS. It shall be either an affine coordinate system or a Cartesian coordinate system.
Stereotype:	Union
Realization of:	CS_CoordinateSystem. As such it must implement all inherited operations and associations. Furthermore it must support all inherited attributes, at least as "read only".
Association roles:	(aggregation) coordinateSystem from SC_ImageCRS [1], association named *CoordinateSystem* *(reverse: referenceSystem to SC_ImageCRS [0..*] navigable only from SC_ImageCRS – see Table 13)* (aggregation) affineCS to CS_AffineCS [1] (aggregation) cartesianCS to CS_CartesianCS [1] union (one of) constraint on affineCS and cartesianCS associations (associations inherited from CS_CoordinateSystem)
Public attributes:	(none)

10 Datum package

10.1 Types of datums

A datum can be used as the basis for one-, two- or three-dimensional systems. For geodetic and vertical coordinate reference systems, the datum shall relate the coordinate system to the Earth. With other types of coordinate reference systems, the datum may relate the coordinate system to another physical or virtual object. In some applications of an Engineering CRS, the object may be a platform moving relative to the Earth. In these applications, the datum itself is not time-dependent, but any transformations of the associated coordinates to an Earth-fixed or other coordinate reference system shall contain time-dependent parameters.

In this Abstract Specification, four subtypes of datum shall be recognized: geodetic; vertical; engineering; and image. Each datum subtype can be associated only with specific subtypes of coordinate reference systems, as shown in Figure 10. Constraints on geodetic datum are detailed below.

Datums are described further in B.3.

10.2 Geodetic datum

10.2.1 Prime meridian

If the datum subtype is geodetic, the description of the origin from which longitude values are specified – the prime meridian – shall be mandatory. Most geodetic datums use Greenwich as their prime meridian. Default values for the attributes prime meridian name and Greenwich Longitude shall be “Greenwich” and 0, respectively. If the prime meridian name is “Greenwich” then the value of Greenwich Longitude shall be 0 degrees.

The data attributes of prime meridian are described in Table 35.

10.2.2 Ellipsoid

If the datum subtype is geodetic, the description of one associated ellipsoid shall be mandatory. An ellipsoid specification shall not be provided if the datum subtype is not geodetic.

An ellipsoid shall be defined either by its semi-major axis and inverse flattening, or by its semi-major axis and semi-minor axis, or as being a sphere.

The data attributes of ellipsoid are described in Tables 36 and 37.

10.3 UML schema for the Datum package

Figure 9 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 10. The definition of the object classes of this package is provided in Tables 33 through 41.

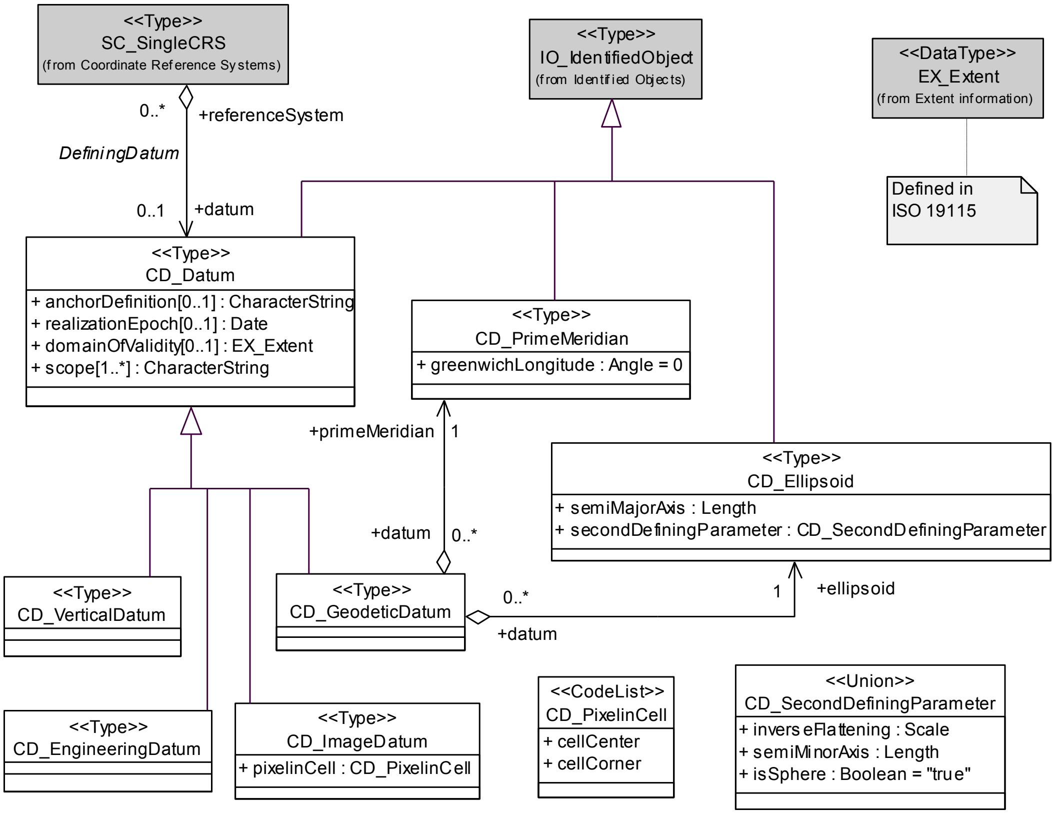


Figure 9 — CD_Datum package

See Figure 10 for details of the associations between the CD_Datum and the SC_SingleCRS.

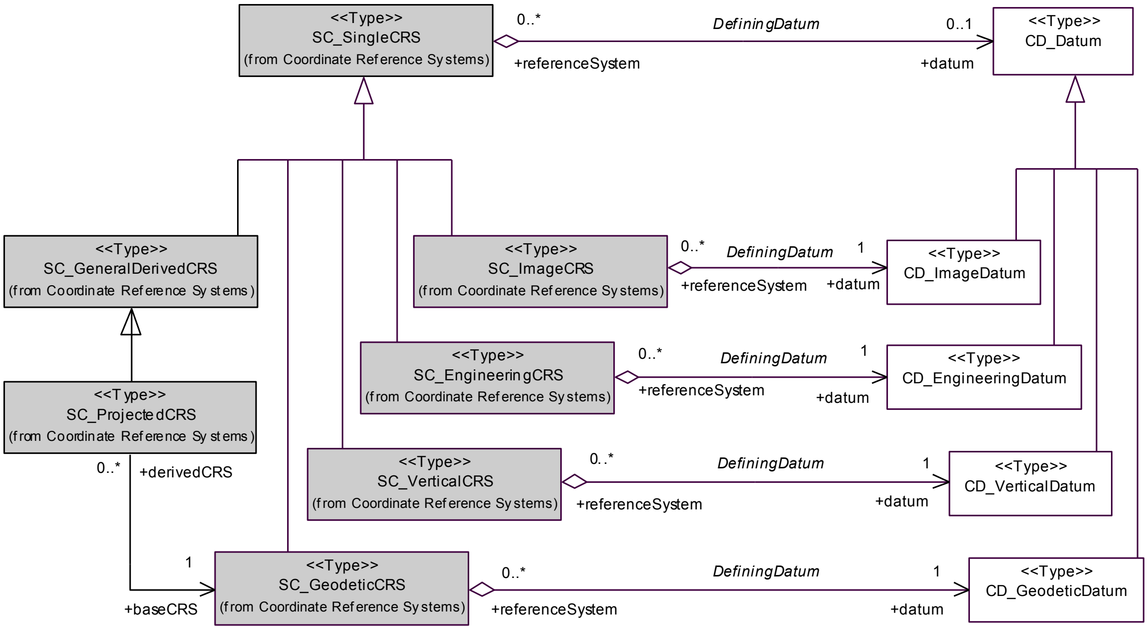


Figure 10 — Datum type associations with Coordinate Reference System type

Table 33 — Defining elements of CD_Datum class

Description:	A datum specifies the relationship of a coordinate system to an object, thus creating a coordinate reference system. For geodetic and vertical coordinate reference systems, the datum relates the coordinate system to the Earth. With other types of coordinate reference systems, the datum may relate the coordinate system to another physical or virtual object. 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:	Type
Class attribute:	Abstract
Inheritance from:	IO_IdentifiedObject
Association roles:	(aggregation) datum from SC_SingleCRS [0..1], association named *DefiningDatum* *(reverse: referenceSystem to SC_SingleCRS [0..*] navigable only from SC_SingleCRS – see Table 5)*
Public attributes:	4 attributes (datum name, datum alias, datum identifier and datum remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Datum anchor	anchorDefinition	CharacterString	O	1	The datum definition – a description, possibly including coordinates of an identified point or points, of the relationship used to anchor the coordinate system to the Earth or alternate object. - For a geodetic datum, this anchor may be a point known as the fundamental point, which is traditionally the point where the relationship between geoid and ellipsoid is defined, together with a direction from that point. In other cases, the anchor 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 coordinates of the points adopted as the datum definition. - For an engineering datum, the anchor may be an identified physical point with the orientation defined relative to the object. - For an image datum, the anchor is usually either the centre of the image or the corner of the image. The coordinate system orientation is defined through the CS_AxisDirection class.

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 time frame in which this datum is valid.
Datum scope	scope	CharacterString	M	N	Description of usage, or limitations of usage, for which this datum is valid. If unknown, enter "not known".

Table 34 — Defining elements of CD_GeodeticDatum class

Description:	A geodetic datum defines the location and precise orientation in three-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:	Type
Class attribute:	Concrete
Inheritance from:	CD_Datum
Association roles:	(aggregation) ellipsoid to CD_Ellipsoid [1] (aggregation) primeMeridian to CD_PrimeMeridian [1] (aggregation) datum from SC_GeodeticCRS [1], association named *DefiningDatum* *(reverse: referenceSystem to SC_GeodeticCRS [0..*] navigable only from SC_GeodeticCRS – see Table 10)*
Public attributes:	8 attributes (datum name, datum alias, datum identifier, datum remarks, datum anchor, datum realization epoch, datum validity and datum scope) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CD_Datum. See Tables 1, 2 and 33.

Table 35 — Defining elements of CD_PrimeMeridian class

Description:	A prime meridian defines the origin from which longitude values are determined. NOTE The default value for prime meridian name is "Greenwich". When the default applies, the value for the greenwichLongitude shall be 0 (degrees).				
Stereotype:	Type				
Class attribute:	Concrete				
Inheritance from:	IO_IdentifiedObject				
Association roles:	(aggregation) primeMeridian from CD_GeodeticDatum [1] *(reverse: datum to CD_GeodeticDatum [0..*] navigable only from CD_GeodeticDatum – see Table 34)*				
Public attributes:	4 attributes (prime meridian name, prime meridian alias, prime meridian identifier and prime meridian remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), 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.

Table 36 — 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:	Type				
Class attribute:	Concrete				
Inheritance from:	IO_IdentifiedObject				
Association roles:	(aggregation) ellipsoid from CD_GeodeticDatum [1] *(reverse: datum to CD_GeodeticDatum [0..*] navigable only from CD_GeodeticDatum – see Table 34)*				
Public attributes:	4 attributes (ellipsoid name, ellipsoid alias, ellipsoid identifier and ellipsoid remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), 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_SecondDefining Parameter	M	1	Definition of the second parameter that describes the shape of this ellipsoid.

Table 37 — 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: a semi-major axis and inverse flattening or a semi-major axis and a 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				
Inheritance 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	Boolean	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 value “true” if the figure is a sphere.
Condition:	One and only one of these three elements shall be supplied.				

Table 38 — 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:	Type
Class attribute:	Concrete
Inheritance from:	CD_Datum
Association roles:	(aggregation) datum from CD_EngineeringDatum [1], association named *DefiningDatum* *(reverse: referenceSystem to SC_EngineeringCRS [0..*] navigable only from SC_EngineeringCRS – see Table 12)*
Public attributes:	8 attributes (datum name, datum alias, datum identifier, datum remarks, datum anchor, datum realization epoch, datum validity and datum scope) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CD_Datum. See Tables 1, 2 and 33.

Table 39 — 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 is usually either the centre of the image or the corner of the image. NOTE The image datum definition applies regardless of whether or not the image is georeferenced. Georeferencing is performed through a transformation of image CRS to geodetic or projected CRS. The transformation plays no part in the image datum definition.				
Stereotype:	Type				
Class attribute:	Concrete				
Inheritance from:	CD_Datum				
Association roles:	(aggregation) datum from CD_ImagegDatum [1], association named *DefiningDatum* *(reverse: referenceSystem to SC_ImageCRS [0..*] navigable only from SC_ImageCRS – see Table 13)*				
Public attributes:	8 attributes (datum name, datum alias, datum identifier, datum remarks, datum anchor, datum realization epoch, datum validity and datum scope) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CD_Datum (see Tables 1, 2 and 33), 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 40 — Defining elements of CD_PixelinCell class

Description:	Specification of the way the image grid is associated with the image data attributes.				
Stereotype:	CodeList				
Inheritance 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 41 — 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.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CD_Datum
Association roles:	(aggregation) datum to CD_VerticalDatum [1], association named *DefiningDatum* *(reverse: referenceSystem to SC_VerticalCRS [0..*] navigable only from SC_VerticalCRS – see Table 14)*
Public attributes:	8 attributes (datum name, datum alias, datum identifier, datum remarks, datum anchor, datum realization epoch, datum validity and datum scope) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CD_Datum. See Tables 1, 2 and 33.

11 Coordinate Operation package

11.1 General characteristics of coordinate operations

In this Abstract Specification, the following subtypes of coordinate operation shall be recognized.

a) A *coordinate conversion* changes coordinates from one coordinate reference system to another based on the same datum.

b) A *coordinate transformation* changes coordinates from one coordinate reference system to another coordinate reference system which is based on a different datum.

c) A *concatenated coordinate operation* is a non-repeating sequence of coordinate conversions and/or coordinate transformations.

d) A *pass-through coordinate operation* allows a subset of a coordinate tuple to be subjected to a coordinate operation; coordinates in the coordinate tuple other than the subset remain unchanged.

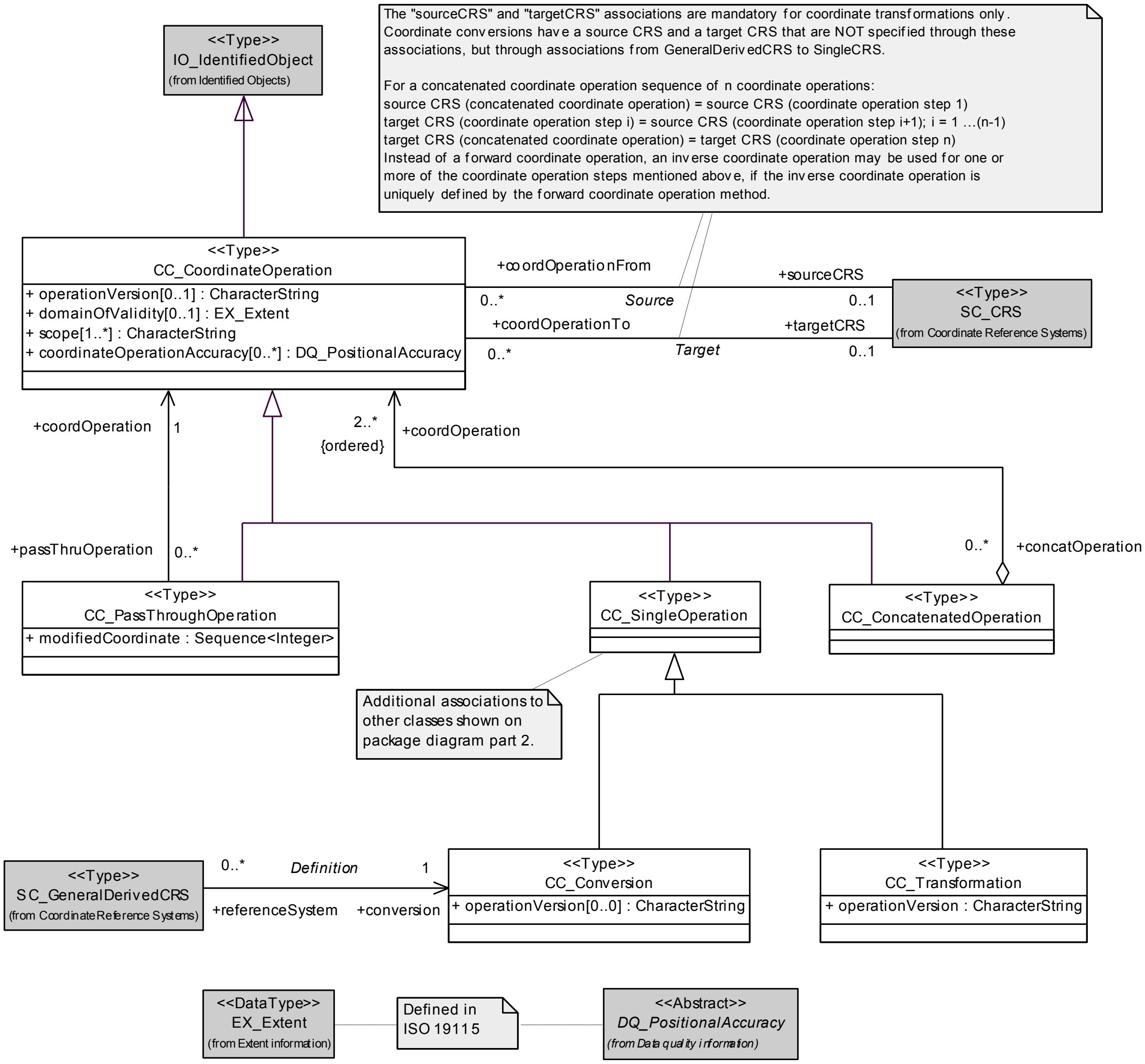
Coordinate operations are further described in B.4.

A coordinate operation may be time-varying, and shall be time-varying if the source and target CRS are moving relative to each other. When the coordinate operation is time-varying, the coordinate operation method used shall also be time-varying, and some of the parameters used by that coordinate operation method will involve time.

EXAMPLE Some of the parameters may have time, velocity, and/or acceleration values and units.

11.2 UML schema for the Coordinate Operation package

Figures 11 and 12 contain the two parts of the UML class diagram for the CC_CoordinateOperation package. As indicated by the note in Figure 11, Figure 12 shows additional classes and associations from the CC_SingleOperation class shown in Figure 11. The definition of the object classes of the CC_CoordinateOperation package is provided in Tables 42 through 56.



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 SingleCRS.

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.

Additional associations to other classes shown on package diagram part 2.

Defined in ISO 19115

Figure 11 — CC_CoordinateOperation package part 1

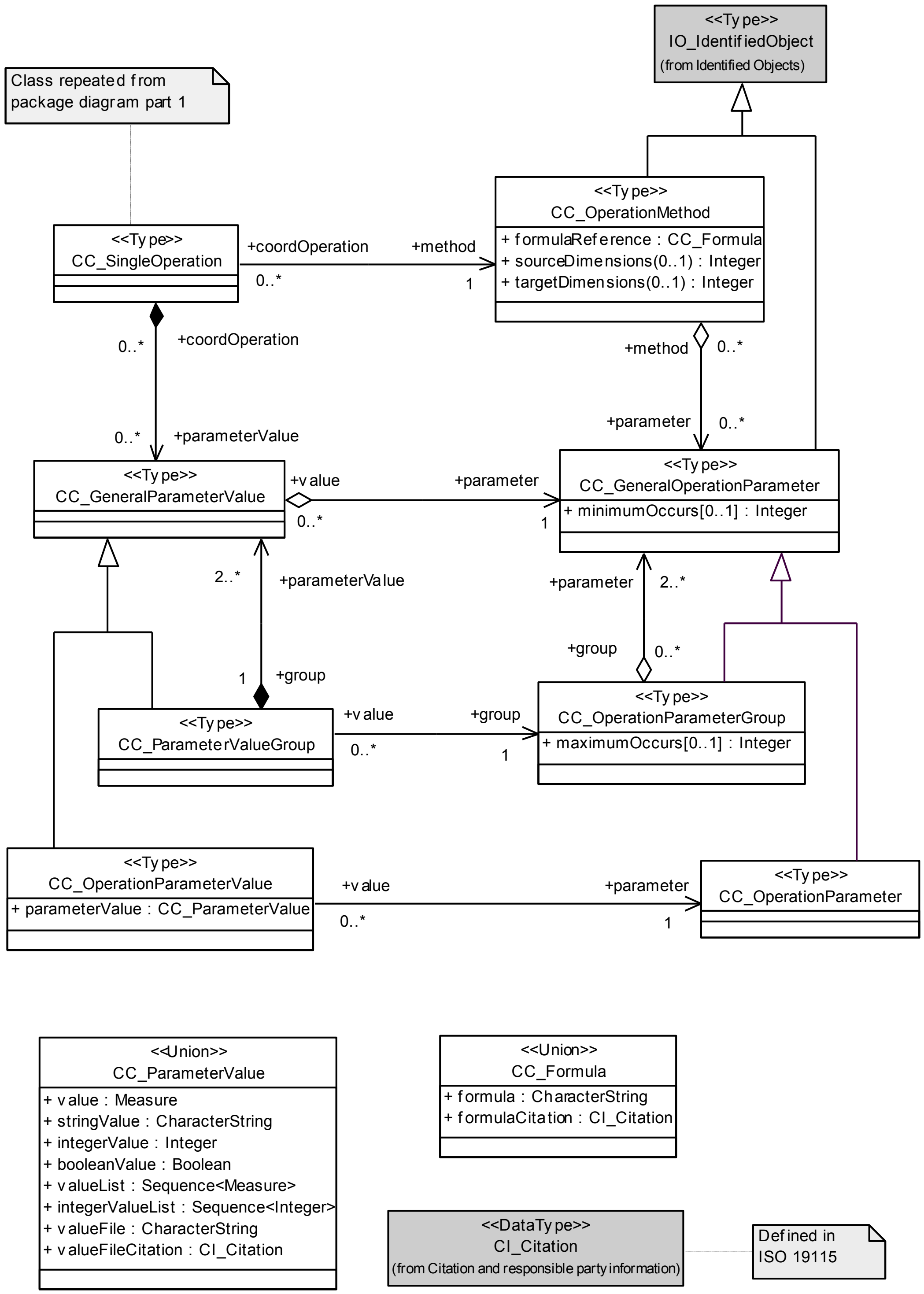

<<Type>>
IO_IdentifiedObject
(from Identified Objects)
Class repeated from package diagram part 1
<<Type>>
CC_SingleOperation
+coordOperation
0..*
+method
1
<<Type>>
CC_OperationMethod
+ formulaReference : CC_Formula
+ sourceDimensions(0..1) : Integer
+ targetDimensions(0..1) : Integer
0..*
+coordOperation
+method
0..*
0..*
+parameterValue
+parameter
0..*
<<Type>>
CC_GeneralParameterValue
+value
0..*
+parameter
1
<<Type>>
CC_GeneralOperationParameter
+ minimumOccurs[0..1] : Integer
2..*
+parameterValue
+parameter
2..*
+group
0..*
1
+group
<<Type>>
CC_ParameterValueGroup
+value
0..*
+group
1
<<Type>>
CC_OperationParameterGroup
+ maximumOccurs[0..1] : Integer
<<Type>>
CC_OperationParameterValue
+ parameterValue : CC_ParameterValue
+value
0..*
+parameter
1
<<Type>>
CC_OperationParameter
<<Union>>
CC_ParameterValue
+ value : Measure
+ stringValue : CharacterString
+ integerValue : Integer
+ booleanValue : Boolean
+ valueList : Sequence<Measure>
+ integerValueList : Sequence<Integer>
+ valueFile : CharacterString
+ valueFileCitation : CI_Citation
<<Union>>
CC_Formula
+ formula : CharacterString
+ formulaCitation : CI_Citation
<<DataType>>
CI_Citation
(from Citation and responsible party information)
Defined in ISO 19115

Figure 12 — CC_CoordinateOperation package part 2

Table 42 — Defining elements of CC_CoordinateOperation class

Description: A mathematical operation on coordinates that transforms or converts coordinates to another coordinate reference system. Many but not all coordinate operations (from CRS A to CRS B) also uniquely define the inverse 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: Type

Class attribute: Abstract

Inheritance from: IO_IdentifiedObject

Association roles: sourceCRS to SC_CRS [0..1], association named *Source*
targetCRS to SC_CRS [0..1], association named *Target*
(aggregation) coordOperation from CC_ConcatenatedOperation [2..*] {ordered}
(reverse: concatOperation to CC_ConcatenatedOperation [0..] navigable only from CC_ConcatenatedOperation – see Table 46)*
coordOperation from CC_PassThroughOperation [1]
(reverse: passThruOperation to CC_PassThroughOperation [0..] navigable only from CC_PassThroughOperation – see Table 47)*
(associations inherited from IO_IdentifiedObject)

Note attached to associations *Source* and *Target*:
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 SingleCRS.
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 (coordinate operation name, coordinate operation alias, coordinate operation identifier and coordinate operation remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), 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 time frame in which this coordinate operation is valid.
Coordinate operation scope	scope	CharacterString	M	N	Description of usage, or limitations of usage, for which this coordinate operation is valid. If unknown, enter "not known".
Coordinate operation accuracy	coordinateOperationAccuracy	DQ_Positional Accuracy	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 43 — Defining elements of CC_SingleOperation class

Description:	A single (not concatenated) coordinate operation.
Stereotype:	Type
Class attribute:	Abstract
Inheritance from:	CC_CoordinateOperation
Association roles:	method to CC_OperationMethod [1] (composition) parameterValue to CC_GeneralParameterValue [0..*] (associations inherited from CC_CoordinateOperation)
Public attributes:	8 attributes (coordinate operation name, coordinate operation alias, coordinate operation identifier, coordinate operation remarks, coordinate operation version, coordinate operation validity, coordinate operation scope and coordinate operation accuracy) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase and CC_CoordinateOperation. See Tables 1, 2 and 42.

Table 44 — Defining elements of CC_Transformation class

Description:	A coordinate operation through which the input and output coordinates are referenced to different datums. 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 coordinate 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:	Type				
Class attribute:	Concrete				
Inheritance from:	CC_SingleOpereration				
Association roles:	(associations inherited from CC_SingleOperation)				
Public attributes:	8 attributes (coordinate operation name, coordinate operation alias, coordinate operation identifier, coordinate operation remarks, coordinate operation version, coordinate operation validity, coordinate operation scope and, coordinate operation accuracy) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase and CC_CoordinateOperation (see Tables 1, 2 and 42), one of which is modified:				
Attribute name	**UML identifier**	**Data type**	**Obligation**	**Maximum Occurrence**	**Description**
Coordinate 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 45 — Defining elements of CC_Conversion class

<table>
<tr><td>Description:</td><td colspan="5">A coordinate operation through which the output coordinates are referenced to the same datum as are the input coordinates. The best-known example of a coordinate conversion is a map projection. The parameter values describing coordinate conversions are defined rather than empirically derived.</td></tr>
<tr><td>Stereotype:
Class attribute:
Inheritance from:
Association roles:

Public attributes:</td><td colspan="5">Type
Concrete
CC_SingleOperation
conversion from SC_GeneralDerivedCRS [1], association named <i>Definition</i>
<i>(reverse: referenceSystem to SC_GeneralDerivedCRS [0..*] navigable only from SC_GeneralDerivedCRS – see table 7)</i>
(associations inherited from CC_SingleOperation)
8 attributes (coordinate operation name, coordinate operation alias, coordinate operation identifier, coordinate operation remarks, coordinate operation version, coordinate operation validity, coordinate operation scope and coordinate operation accuracy) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase and CC_CoordinateOperation (see Tables 1, 2 and 42), one of which is modified:</td></tr>
<tr><th>Attribute name</th><th>UML identifier</th><th>Data type</th><th>Obligation</th><th>Maximum Occurrence</th><th>Description</th></tr>
<tr><td>Coordinate operation version</td><td>operationVersion</td><td>CharacterString</td><td>O</td><td>0</td><td>This attribute is not used in a coordinate conversion.</td></tr>
</table>

Table 46 — 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:	Type
Class attribute:	Concrete
Inheritance from:	CC_CoordinateOperation
Association roles:	(aggregation) coordOperation to CC_CoordinateOperation [2..*] {ordered} (associations inherited from CC_CoordinateOperation)
Public attributes:	8 attributes (coordinate operation name, coordinate operation alias, coordinate operation identifier, coordinate operation remarks, coordinate operation version, coordinate operation validity, coordinate operation scope, coordinate operation accuracy) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase and CC_CoordinateOperation. See Tables 1, 2 and 42.

Table 47 — Defining elements of CC_PassThroughOperation class

Description:	A pass-through coordinate operation specifies that a subset of a coordinate tuple is subject to a specific coordinate operation.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CC_SingleOperation
Association roles:	(aggregation) coordOperation to CC_CoordinateOperation [1] (associations inherited from CC_CoordinateOperation)
Public attributes:	8 attributes (coordinate operation name, coordinate operation alias, coordinate operation identifier, coordinate operation remarks, coordinate operation version, coordinate operation validity, coordinate operation scope and coordinate operation accuracy) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase and CC_CoordinateOperation (see Tables 1, 2 and 42), plus:

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

Table 48 — Defining elements of CC_OperationMethod class

Description:	The method (algorithm or procedure) used to perform the coordinate operation.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	IO_IdentifiedObject
Association roles:	(aggregation) parameter to CC_GeneralOperationParameter [0..*] method from CC_SingleOperation [1] *(reverse: coordOperation to CC_SingleOperation [0..*] navigable only from CC_SingleOperation – see Table 43)* (associations inherited from IO_IdentifiedObject)
Public attributes:	4 attributes (coordinate operation method name, coordinate operation method alias, coordinate operation method identifier and coordinate operation method remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate operation method formula reference	formulaReference	CC_Formula	M	1	Formula(s) or procedure used by this coordinate 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	O	1	Number of dimensions in the source CRS of this coordinate operation method.
Dimension of target CRS	targetDimensions	Integer	O	1	Number of dimensions in the target CRS of this coordinate operation method.

Table 49 — Defining elements of CC_Formula class

Description:	Specification of the coordinate operation method formula.
Stereotype:	CodeList
Inheritance from:	(none)
Association roles:	(none)
Used by:	CC_OperationMethod
Public attributes:	

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Coordinate operation method formula	formula	CharacterString	C	1	Formula(s) or procedure used by this operation method.
Coordinate operation method formula citation	formulaCitation	CI_Citation	C	1	Reference to a publication giving the formula(s) or procedure used by the coordinate operation method.

Condition: One and only one of the listed attributes shall be supplied.

Table 50 — Defining elements of CC_GeneralOperationParameter class

Description:	Definition of a parameter or group of parameters used by a coordinate operation method.
Stereotype:	Type
Class attribute:	Abstract
Inheritance from:	IO_IdentifiedObject
Association roles:	(aggregation) parameter from CC_OperationMethod [0..*] *(reverse: method to CC_OperationMethod [0..*] navigable only from CC_OperationMethod – see Table 48)* (aggregation) parameter from CC_OperationParameterGroup [2..*] *(reverse: group to CC_OperationParameterGroup [0..*] navigable only from CC_OperationParameterGroup – see Table 51)* (aggregation) parameter from CC_GeneralParameterValue [1] *(reverse: value to CC_GeneralParameterValue [0..*] navigable only from CC_ GeneralParameterValue – see Table 53)* (associations inherited from IO_IdentifiedObject)
Public attributes:	4 attributes (coordinate operation parameter name, coordinate operation parameter alias, coordinate operation parameter identifier and coordinate operation parameter remarks) inherited from IO_IdentifiedObject and IO_IdentifiedObjectBase (see Tables 1 and 2), 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 51 — Defining elements of CC_OperationParameterGroup class

Description:	The definition of a group of related parameters used by a coordinate operation method.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CC_GeneralOperationParameter
Association roles:	(aggregation) parameter to CC_GeneralOperationParameter [2..*] group from CC_ParameterValueGroup [1] *(reverse: value to CC_ParameterValueGroup [0..*] navigable only from CC_ParameterValueGroup – see Table 54)* (associations inherited from CC_GeneralOperationParameter)
Public attributes:	5 attributes (coordinate operation parameter name, coordinate operation parameter alias, coordinate operation parameter identifier, coordinate operation parameter remarks and minimum occurences) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CC_GeneralOperationParameter (see Tables 1, 2 and 50), 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 maximum number is one.

Table 52 — 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:	Type
Class attribute:	Concrete
Inheritance from:	CC_GeneralOperationParameter
Association roles:	parameter from CC_OperationParameterValue [1] *(reverse: value to CC_OperationParameterValue [0..*] navigable only from CC_OperationParameterValue – see Table 55)* (associations inherited from CC_GeneralOperationParameter)
Public attributes:	5 attributes (coordinate operation parameter name, coordinate operation parameter alias, coordinate operation parameter identifier, coordinate operation parameter remarks and minimum occurences) inherited from IO_IdentifiedObject, IO_IdentifiedObjectBase and CC_GeneralOperationParameter (see Tables 1, 2 and 50).

Table 53 — Defining elements of CC_GeneralParameterValue class

Description:	Parameter value or group of parameter values.
Stereotype:	Type
Class attribute:	Abstract
Inheritance from:	(none)
Association roles:	(composition) parameterValue from CC_SingleOperation [0..*] *(reverse: coordOperation to CC_SingleOperation [0..*] navigable only from CC_SingleOperation – see Table 43)* (composition) parameterValue from CC_ParameterValueGroup [2..*] *(reverse: group to CC_ParameterValueGroup [1] navigable only from CC_ParameterValueGroup – see Table 54)* (aggregation) parameter to CC_GeneralOperationParameter[1]
Public attributes:	(none)

Table 54 — 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 distinguish among those groups.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CC_GeneralParameterValue
Association roles:	(composition) parameterValue to CC_GeneralParameterValue [2..*] group to CC_OperationParameterGroup [1] (associations inherited from CC_GeneralParameterValue)
Public attributes:	(none)

Table 55 — Defining elements of CC_OperationParameterValue class

Description:	A parameter value, ordered sequence of values, or reference to a file of parameter values.
Stereotype:	Type
Class attribute:	Concrete
Inheritance from:	CC_GeneralParameterValue
Association roles:	(aggregation) parameter to CC_OperationParameter [1] (associations inherited from CC_GeneralParameterValue)
Public attributes:	0 attributes inherited from CC_GeneralParameterValue (see Table 53), plus:

Attribute name	UML identifier	Data type	Obligation	Maximum Occurrence	Attribute description
Parameter value	parameterValue	CC_ParameterValue	M	1	Value of the coordinate operation parameter.

Table 56 — Defining elements of CC_ParameterValue class

Description:	Value of the coordinate operation parameter.				
Stereotype: Inheritance from: Association roles: Used by: Public attributes:	Union (none) (none) CC_OperationParameterValue				
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.
Operation parameter string value	stringValue	CharacterString	C	1	String value of a coordinate operation parameter. A string value does not have an associated unit.
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.
Operation parameter Boolean value	booleanValue	Boolean	C	1	Boolean value of a coordinate operation parameter. A Boolean value does not have an associated unit.
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.
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.
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.
Operation parameter file reference citation	valueFileCitation	CI_Citation	C	1	Citation for a 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)

Abstract test suite

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

A.1.1 Abstract test suite for CRS

To check that a coordinate reference system is in conformance with this Abstract Specification, check that it satisfies the requirements given in A.1.2 to A.1.4. 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 6 to 10. 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 11.

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 41 and, in the case of projected coordinate reference systems, additionally Tables 42 to 56.

c) Reference: Clauses 6 to 10 and, in the case of projected coordinate reference systems, also Clause 11.

d) Test type: capability.

A.1.3 Test case identifier: Maximum occurrence test

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

b) 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 6 to 10 and, in the case of projected coordinate reference systems, additionally Clause 11.

c) Reference: Clauses 6 to 10 and, in the case of projected coordinate reference systems, also Clause 11.

d) Test type: capability.

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 6 to 10 and, in the case of projected coordinate reference systems, additionally Clause 11.

c) Reference: Clauses 6 to 10 and, in the case of projected coordinate reference systems, also Clause 11.

d) Test type: capability.

A.2 Class B — Conformance of a coordinate operation

A.2.1 Abstract test suite for coordinate operation

To check that a coordinate operation is in conformance with this Abstract Specification, check that it satisfies the requirements given in A.2.2 to A.2.4.

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 42 to 56.

c) Reference: Clause 11.

d) Test type: capability.

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 42 to 56.

c) Reference: Clause 11.

d) Test type: capability.

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 42 to 56.

c) Reference: Clause 11.

d) Test type: capability.

Annex B (informative)

Context for modelling of spatial referencing by coordinates

B.1 Coordinate reference system

B.1.1 Coordinates

The geometry of spatial features can 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 and the orientations of the axes. This choice underlines the fact that coordinates are human-defined quantities and **not** natural phenomena. Although this may seem self-evident, it is often overlooked and has consequences for the interpretation of coordinates and their error characteristics.

The 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 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.

B.1.2 Coordinate reference system — Details

B.1.2.1 Principal subtypes of coordinate reference system

Subtypes of coordinate reference system are defined in 8.2.

The classification criterion for sub-typing of coordinate reference systems is by reference to the type of datum associated with the coordinate reference system. The following principal subtypes of coordinate reference system are distinguished.

a) **Geodetic**. A coordinate reference system that is associated with a geodetic datum. Geodetic coordinate reference systems can be two- or three-dimensional. They are associated with ellipsoidal and 3D Cartesian coordinate systems. A geodetic CRS using 2D ellipsoidal coordinates (latitude and longitude) is used when positions of features are described on the surface of the ellipsoid; a geodetic CRS using 3D ellipsoidal coordinates [latitude, longitude and ellipsoidal height (*h*)] is used when positions are described on, above or below the ellipsoid. A geodetic 3D CRS using three-dimensional Cartesian coordinates is used when describing positions relative to the centre of the Earth.

b) **Vertical**. A coordinate reference system that is associated with a vertical datum. Vertical CRSs make use of the direction of gravity to define the concept of height or depth. 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 geodetic 3D coordinate reference system.

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”.

c) **Engineering**. A coordinate reference system that is associated with an engineering datum, used only in a contextually local sense. This subtype 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 geodetic 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. 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.

d) **Image**. An Image CRS is an Engineering CRS applied to images. The definition of the associated Image Datum contains two data attributes not relevant for other engineering datums.

In addition to these principal subtypes of coordinate reference systems, to permit modelling of certain relationships and constraints, three more subtypes are distinguished. These additional subtypes are

1. derived coordinate reference system,
2. projected coordinate reference system, and
3. compound coordinate reference system.

B.1.2.2 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. A Derived CRS inherits its datum from its Base CRS.

In principle, all subtypes of single coordinate reference system may take on the role of either Base or Derived CRS with the exception of a Projected CRS.

An example of a Derived CRS of *derivedCRStype*: “geodetic” is one of which the unit has been modified with respect to an earlier defined Geodetic CRS, which then takes the role of Base CRS.

B.1.2.3 Projected coordinate reference system

A coordinate reference system that is derived from a base geodetic CRS by applying to latitude and longitude ellipsoidal coordinate values the coordinate conversion is known as a map projection. Projected CRS is modelled as an object class under its own name, rather than as a general Derived CRS of type “projected”, to honour common practice which acknowledges Projected CRSs as one of the most frequently encountered types of coordinate reference systems.

B.1.2.4 Compound coordinate reference system

The traditional separation of horizontal and vertical position has resulted in coordinate reference systems that are horizontal (2D) and vertical (1D) in nature, as opposed to truly three-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 should follow the order of coordinates within the coordinate tuples for each of those component single CRSs, in the order of the component single CRSs.

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 B.1 shows examples of the possible composition of spatial and spatio-temporal compound coordinate reference systems.

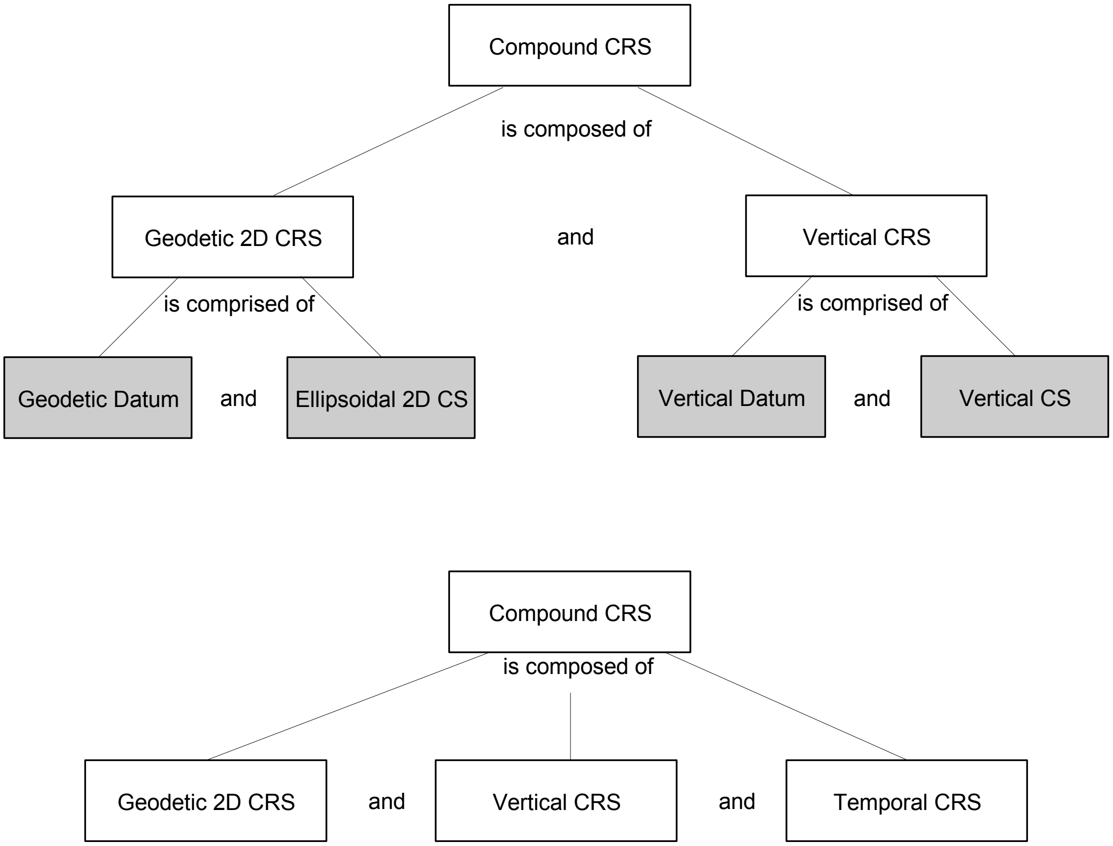


Figure B.1 — Conceptual model of spatial and spatio-temporal compound CRSs

B.2 Coordinate system

B.2.1 General

Coordinate systems are defined in 9.2.

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 The word "distance" is used loosely in the above description. Strictly speaking distances are not invariant quantities, as they are expressed in the unit defined for the coordinate system; ratios of distances are invariant.

B.2.2 Coordinate system axis

Coordinate system axes are defined in 9.3.

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 prime meridian and the longitude axis would be the equator, 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 1 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. This may lead to the two uses of the coordinate system being slightly rotated with respect to each other.

EXAMPLE 2 Two geodetic coordinate reference systems that make use of the same ellipsoidal coordinate system will usually be associated with the Earth through two different geodetic datums.

B.3 Datum

B.3.1 General

Datums are defined in Clause 10.

A datum specifies the relationship of a coordinate system to an object thus creating a coordinate reference system. The datum implicitly (occasionally explicitly) contains the values chosen for the set of parameters that represents the degrees of freedom of the coordinate system, as described in B.1.1. A datum therefore implies a choice regarding the approximate origin and orientation of the coordinate system.

B.3.2 Geodetic datum

B.3.2.1 General

A geodetic datum is used with three-dimensional or horizontal (two-dimensional) coordinate reference systems. It is used to describe large portions of the Earth's surface up to the entire Earth's surface. It requires a prime meridian definition and an ellipsoid definition.

B.3.2.2 Prime meridian

A prime meridian defines the origin from which longitude values are specified. Most geodetic datums use Greenwich as their prime meridian.

B.3.3.3 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 Geodetic and, indirectly, Projected CRSs.

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 Geodetic CRS is used for example in the calculation of satellite orbit and ground positions from satellite observations. Although use of a Geodetic CRS using a geocentric Cartesian coordinate system 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 Geodetic 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.

B.3.3 Vertical datum

Although subtyping of vertical datum is not modelled in this Abstract Specification, the following types of vertical datum may be 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 most commonly encountered type of vertical datum.

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.

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.

B.3.4 Engineering datum

An engineering datum is used in a local context only. It describes the origin of an engineering (or local) coordinate reference system. It is stressed that the engineering datum does not necessarily describe the origin of the engineering CRS with respect to the Earth, but only relative to other points in its domain of validity, be that a moving platform or an area on or near the surface of the Earth. The relationship of the engineering CRS with any geodetic or projected CRS can only be described by means of a coordinate operation.

B.3.5 Image datum

An image datum relates a coordinate system to an image. The image datum definition applies regardless of whether or not the image is georeferenced. Georeferencing is performed through a coordinate transformation. The coordinate transformation plays no part in the image datum definition. Image datums include an implication that the coordinate system is in the image plane. They define the origin and orientation of the coordinate system within the image plane.

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 [6]). 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.

B.4 Coordinate operation

B.4.1 General characteristics of coordinate operations

Coordinate operations are defined in Clause 11.

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 realized 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 exist.

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 B.4.2.

In this Abstract Specification, two subtypes of single coordinate operations are recognized.

- *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.

Once the parameter values are obtained, both coordinate conversion and coordinate transformation use similar mathematical processes.

B.4.2 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. One of the two coordinate tuples cannot exist without specification of the “source” or “base” coordinate reference system for the coordinate conversion.

The best-known example of this source-derived relationship is a projected coordinate reference system, which is always related to a base geodetic coordinate reference system. The associated map projection effectively **defines** the projected coordinate reference system from the geodetic coordinate reference system. This concept is modelled as a direct link between (derived) coordinate reference system and coordinate conversion, as illustrated in Figure 6 and Figure 11.

B.4.3 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.

B.4.4 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 two-dimensional CRSs to (2 + 1) = three-dimensional coordinate tuples.

B.4.5 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. It is critical that the parameters and their values are consistent with the method's formula. Several superficially similar methods are in detail distinctly different. Different parameter values may then be required.

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 recognize, 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.

B.4.6 Parameter groups

Some coordinate operation methods require that groups of coordinate operation parameters be repeatable as a group. Also, some coordinate operation methods may utilize 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.

B.4.7 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 1927 coordinates to Australian Geodetic Datum of 1966 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.

Annex C (informative)

Spatial referencing by coordinates – Geodetic concepts

C.1 Some geodetic concepts

Coordinates are the object of this Abstract Specification. Point positioning is a central technological element for this. The creation and maintenance of hierarchically ordered geodetic reference systems makes available a consistent stable base for positioning and navigation.

Geodesy is the geoscience which deals with the measurement of the size and shape of the Earth, the Earth's rotation and its gravitational field, as well as with mapping its surface. The determination of the size and shape (or “figure”) of the Earth includes the study of the solid and fluid Earth surfaces, their changes and deformations through Earth tides and crustal motion. Earth rotation and its temporal variations is the transformation between terrestrial and celestial reference systems. Earth gravity field determination is related to the geo-centre, the outer gravity field and its temporal variations.

Spatial terrestrial reference systems are sustainable central elements against which changes are measurable. In the terminology of this Abstract Specification, these systems are *coordinate reference systems*.

C.2 Geodetic reference surfaces

The locations of points in three-dimensional space are most conveniently described by three Cartesian or rectangular coordinates, *X*, *Y* and *Z*. Since the advent of satellite positioning, such coordinate systems are typically *geocentric*: the *Z*-axis is aligned with the Earth's (conventional or instantaneous) rotation axis, the *X*-axis lies within the equatorial plane and the Greenwich observatory's meridian plane, whilst the *Y*-axis forms a right-handed coordinate system.

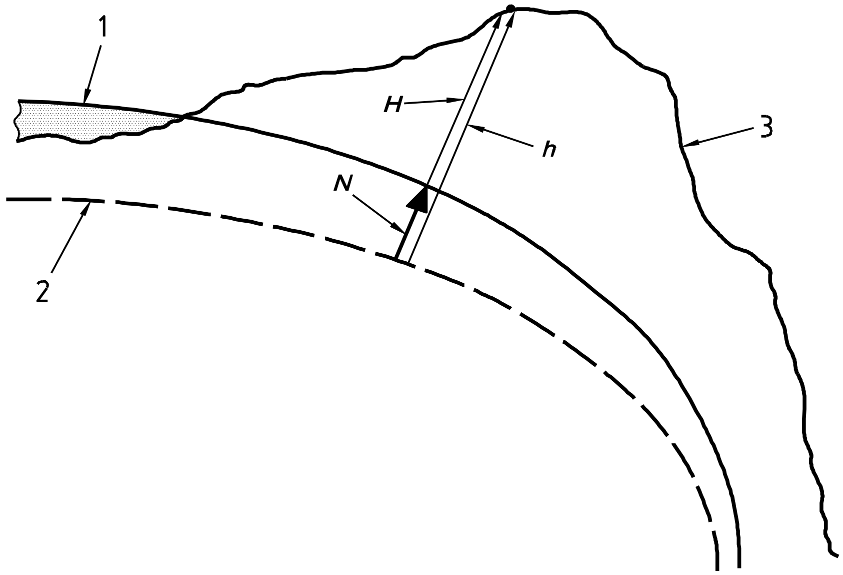
Before the advent of satellite positioning, a more practical reference was the surface of the Earth. The shape best approximating that of the Earth is the *geoid*. In essence, the geoid is the surface of the Earth from which topographic features are removed. It is an idealized surface of sea water in equilibrium – the mean sea level surface in the absence of currents, air pressure variations, etc. It is continued under the continental masses.

Vertical reference surfaces are based on the geoid. Typically, they will be defined as mean sea level at one or more locations over a particular period of time. Heights and depths are measured along the direction of gravity and related to such vertical reference surfaces. Gravity-related *heights* (*H*),are “above sea level”, an irregular, physically defined surface. Strictly, a gravity-related height should *not* be referred to as a coordinate. It is more like a physical quantity, and though it can be tempting to treat height as the vertical coordinate *z*, in addition to the horizontal coordinates *x* and *y*, and though this actually is a good approximation of physical reality in small areas, it becomes quickly invalid over larger areas. Geodetic science distinguishes several different types of gravity-related heights, 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 Abstract Specification.

The geoid is affected by anomalies in the distribution of mass inside the Earth and hence has an irregular surface. These irregularities cause the shape of the geoid to be too complicated to serve as the computational surface for geometrical problems such as point positioning. To facilitate easier spatial calculations the geoid is approximated by the nearest regular body, an oblate ellipsoid. The ellipsoid is a reasonably accurate approximation of the geoid, the geoid undulating around the ellipsoid’s surface with variations globally of ± 110 m. The geometrical separation between the geoid and the reference ellipsoid is called the geoidal undulation.

There is not just one ellipsoid. The size, shape, position and orientation of an ellipsoid are a matter of choice, and therefore many choices are possible. This choice of ellipsoid size, shape, position and orientation with respect to the Earth is captured by the concept of *geodetic datum*. Geodetic datums were traditionally defined such that the ellipsoid matched the surface of the geoid as closely as possible locally, e.g. in a country. Before the satellite geodesy era, the coordinate systems associated with geodetic datums attempted to be geocentric, but their origins differed from the geocentre by hundreds of metres, due to local deviations in the direction of the (vertical) plumbline. These regional geodetic datums, such as ED50 (European Datum 1950) or NAD27 (North American Datum 1927) have ellipsoids associated with them that are regional “best fits”" to the geoid within their areas of determination.

The position of a point relative to an ellipsoid is expressed by means of ellipsoidal coordinates: geodetic latitude (□) and geodetic longitude (*l*). The height above the ellipsoid (*h*) is an inseparable element of a geodetic 3D coordinate tuple. Note however that ellipsoidal height (*h*) differs from heights related to the geoid (*H*) by the amount by which the geoid undulates relative to the ellipsoid; see Figure C.1



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 geoid

N = geoid height, height of geoid above ellipsoid

Figure C.1 — Ellipsoidal and gravity-related heights

A change of size, shape, position or orientation of an ellipsoid will result in a change of geodetic coordinates of a point and the point will be described as being referenced to a different geodetic datum. Conversely, geodetic coordinates – latitude and longitude – are only unambiguous when the geodetic datum and coordinate system are identified.

Historically, it has been common to describe location in 3D space through the combination of horizontal geodetic coordinates for horizontal position together with gravity-related height for vertical position – together, an example of a compound coordinate reference system.

C.3 Map projections

Spatial calculations on the surface of an ellipsoid are not straightforward. It is considerably easier to work in plane rectangular coordinates. More formally, such coordinates can be obtained from ellipsoidal coordinates using the artifice of a map projection. It is *not* possible to map the curved surface of an ellipsoid onto a plane map surface without deformation. The compromise most frequently chosen is to preserve angles and length ratios, so small spheres are mapped as small spheres and small squares as squares. This is known as a conformal projection. One example of a conformal map projection method is Transverse Mercator. Properties other then those preserved, for example scale, contain errors and the projected coordinate reference system can only be used over areas where the errors can be tolerated. Other projection methods preserve different properties, for example area.

Within the map plane, we have rectangular coordinates *x* and *y*. In this case, the north direction used for reference is the *map* north, not the *local* geodetic north. The difference between the two is called the *meridian convergence*.

C.4 Transformation of coordinates

Changing the coordinates of a point or set of points referenced to a coordinate reference system associated with one datum to make them refer to another a coordinate reference system associated with a different datum is called a *datum transformation*. (Strictly, this is a misnomer: it is the *coordinates* that are being transformed). In the case of vertical datums, the transformation consists of simply adding a shift to all height values – often the shift is constant. In the case of plane or spatial coordinates, a datum transformation often takes the form of a similarity or *Helmert transformation*, consisting of a rotation and scaling operation in addition to a simple translation. In the plane, a Helmert transformation has four parameters; in space, seven.

C.5 Point positioning

Point positioning is the determination of the coordinates of a point on land, at sea, or in space with respect to a coordinate reference system. Point position is solved by computation from measurements linking the known positions of terrestrial or extraterrestrial points with the unknown terrestrial position. This may involve transformations between or among astronomical and terrestrial coordinate systems.

Traditionally, a hierarchy of networks has been built to allow point positioning within a country. Highest in the hierarchy were triangulation networks. These were densified into networks of polygons, into which local mapping surveying measurements, usually with measuring tape, corner prism and the familiar red and white poles, are tied.

Nowadays, all but special measurements (e.g. underground or high precision engineering measurements) are performed with GPS. The higher order networks are measured with static GPS, using differential measurement to determine vectors between terrestrial points. These vectors are then adjusted in traditional network fashion. A global polyhedron of permanently operating GPS stations under the auspices of the IERS is used to define a single global, geocentric reference frame which serves as the “zero order” global reference to which national measurements are attached.

One purpose of point positioning is the provision of known points for mapping measurements, also known as (horizontal and vertical) control. In every country, thousands of such known points exist in the terrain and are documented by the national mapping agencies. Constructors and surveyors involved in real estate will use these to tie their local measurements.

Annex D (informative)

Examples

Several examples are given below to illustrate how this Abstract Specification can be applied when defining a coordinate reference system or coordinate transformation. The examples give both UML identifier and attribute name. For digital data processing purposes, the UML identifier should be used. When presenting coordinate reference system metadata to human beings, the attribute name should be given.

The following examples are given:

D.1 Coordinate reference system with all required attribute values referenced through a citation.

D.2 Vertical coordinate reference system.

D.3 Geodetic two-dimensional coordinate reference system (latitude and longitude).

D.4 Geodetic three-dimensional coordinate reference system (geocentric Cartesian *X, Y, Z*).

D.5 Projected coordinate reference system.

D.6 Compound coordinate reference system formed from a projected CRS with a vertical CRS.

D.7 Coordinate transformation.

D.8 Geoid height model (another coordinate transformation).

D.9 Concatenated operation.

Example D.1: Coordinate reference system with all required attribute values referenced through a citation.

This citation defines all of the coordinate reference system, datum, coordinate system and coordinate conversion information for this projected coordinate reference system. This CRS is defined in full in Example D.5. Citations are described in ISO 19115.

UML identifier	Attribute	Entry	Comment
SC_CRS			
CI_Citation			Citation is documented in ISO 19115.
title:	Citation title	EPSG v6.6	
dateType:	Citation date type	003	This is a revision date.
date:	Citation date	20041023	
identifier:	Citation identifier	26734	This is the unique identifier (code) for the system as given within the citation.

Example D.2: Vertical coordinate reference system.

UML identifier	Attribute	Entry	Comment
SC_VerticalCRS			
name:	Vertical CRS name	ODN	
domainOfValidity:	CRS validity	British mainland	This attribute has been made mandatory in this revision of the Abstract Specification. This example shows a character string entry: refer to ISO 19115.
scope:	CRS scope	National height system	This attribute has been made mandatory in this revision of the Abstract Specification.
CS_VerticalCS			
name:	Vertical coordinate system name	ODN heights	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	height	
axisAbbrev:	Coordinate system axis abbreviation	H	
axisDirection:	Coordinate system axis direction	up	
axisUnitID:	Coordinate system axis unit identifier	metre	
CD_VerticalDatum			
name:	Vertical datum name	Ordnance Datum Newlyn	
alias:	Datum alias	ODN	This is an optional attribute.
anchorDefinition:	Datum anchor	Mean Sea Level at Newlyn between 1915 and 1921	This is an optional attribute.

Example D.3: Geodetic coordinate reference system to which latitude and longitude are referenced.

UML identifier	Attribute	Entry	Comment
SC_GeodeticCRS			
name:	Geodetic CRS name	NAD83(CSRS)	
domainOfValidity:	CRS validity	EX_GeographicBoundingBox westBL: -120 eastBL: -57.1 southBL: 43.46 northBL: 62.56	This attribute is optional. This example shows geographic bounding box entries: refer to ISO 19115.
scope:	CRS scope	Geodetic surveying and other high accuracy applications.	This attribute has been made mandatory in this revision.
remarks:	CRS remarks	Supersedes NAD83. See datum remarks.	This attribute is optional.
CS_EllipsoidalCS			An ellipsoidal CS may be 2- or 3-dimensional. The axes descriptions will be given 2 or 3 times, as appropriate. In this example, although the CRS is 3-dimensional it is assumed that the coordinate tuple contains only latitude and longitude, and therefore, no description of a third, vertical CS axis is required.

UML identifier	Attribute	Entry	Comment
name:	Ellipsoidal coordinate system name	Latitude/longitude in degrees	Finding a suitable entry for the mandatory CS name is often a challenge as there is no established practice for naming coordinate systems.
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	geodetic latitude	
axisAbbrev:	Coordinate system axis abbreviation	*j*	
axisDirection:	Coordinate system axis direction	north	
axisUnitID:	Coordinate system axis unit identifier	degree	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	geodetic longitude	
axisAbbrev:	Coordinate system axis abbreviation	*l*	
axisDirection:	Coordinate system axis direction	east	
axisUnitID:	Coordinate system axis unit identifier	degree	
CD_GeodeticDatum			
name:	Geodetic datum name	NAD83 Canadian Spatial Reference System	
alias:	Datum alias	NAD83 Système canadien de référence spatiale	An optional entry.
alias:	Datum alias	NAD83(CSRS)	An optional entry.
alias:	Datum alias	NAD83(SCRS)	An optional entry.
remarks:	Datum remarks	NAD83(CSRS) is a locally improved version of the original (1986) NAD83. The difference between the NAD83(CSRS) and the NAD83 coordinates varies irregularly, depending on the geographic location over the Canadian territory.	An optional entry.
anchorDefinition:	Datum anchor	Geocentre	An optional entry.
realizationEpoch:	Datum realization epoch	1998	An optional entry.
CD_PrimeMeridian			Because the datum class is CD_GeodeticDatum, if this CD_PrimeMeridian class had been absent, the attributes name and Greenwich longitude would have taken their default values.
name:	Prime meridian name	Greenwich	Because the value for this attribute is “Greenwich”, it is not essential to provide this attribute information.
GreenwichLongitude:	Prime meridian Greenwich longitude	0 degrees	Because the value for the prime meridian name is “Greenwich”, it is not essential to provide the prime meridian Greenwich longitude information.
CD_Ellipsoid			
name:	Ellipsoid name	GRS 1980	
semiMajorAxis:	Length of semi-major axis	6378137.0 m	
secondDefiningParameter:	Second defining parameter	inverseFlattening	
inverseFlattening:	Inverse flattening	298.2572221	

Example D.4: Geodetic coordinate reference system with three-dimensional Cartesian coordinate system.

UML identifier	Attribute	Entry	Comment
SC_GeodeticCRS			
name:	Geodetic CRS name	WGS 84	
domainOfValidity:	CRS validity	World	This attribute is optional. This example shows a character string: refer to ISO 19115.
scope:	CRS scope	Geodetic applications	This attribute has been made mandatory in this revision.
CS_CartesianCS			A Cartesian CS may be 2- or 3-dimensional. The axes descriptions will be given 2 or 3 times, as appropriate. In this example, the system is 3-dimensional.
name:	Cartesian coordinate system name	ECR geocentric	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	Geocentric X	
axisAbbrev:	Coordinate system axis abbreviation	X	
axisDirection:	Coordinate system axis direction	In the equatorial plane from the centre of the Earth towards the intersection of the equator with the prime meridian.	
axisUnitID:	Coordinate system axis unit identifier	metre	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	Geocentric Y	
axisAbbrev:	Coordinate system axis abbreviation	Y	
axisDirection:	Coordinate system axis direction	In the equatorial plane from the centre of the Earth towards the intersection of the equator and the meridian □/2 radians eastwards from the prime meridian.	
axisUnitID:	Coordinate system axis unit identifier	metre	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	Geocentric Z	
axisAbbrev:	Coordinate system axis abbreviation	Z	
axisDirection:	Coordinate system axis direction	From the centre of the Earth parallel to its rotation axis and towards its north pole.	
axisUnitID:	Coordinate system axis unit identifier	metre	
CD_GeodeticDatum			Because the datum class is CD_GeodeticDatum, and because the CD_PrimeMeridian class is absent, the attributes name and Greenwich longitude take their default values of “Greenwich” and “0 degrees” respectively.
name:	Geodetic datum name	World Geodetic System of 1984	
CD_Ellipsoid			Although a geocentric Cartesian coordinate system may not use an ellipsoid because the datum type is geodetic, an ellipsoid definition is mandatory.
name:	Ellipsoid name	WGS 84	
semiMajorAxis:	Length of semi-major axis	6378137.0 m	
secondDefiningParameter:	Second defining parameter	inverseFlattening	

UML identifier	Attribute	Entry	Comment
inverseFlattening:	Inverse flattening	298.257223563	

Example D.5: Projected coordinate reference system with all mandatory defining data given in full.

UML identifier	Attribute	Entry	Comment
SC_ProjectedCRS			
name:	Projected CRS name	NAD27 / Alaska zone 4	
domainOfValidity:	CRS validity	Alaska between 148 and 152 degrees west	This attribute is optional.
scope:	CRS scope	Topographic mapping. After 1986 superseded by NAD83.	This attribute has been made mandatory in this revision.
CS_CartesianCS			A Cartesian CS may be 2- or 3-dimensional. The axes descriptions will be given 2 or 3 times, as appropriate. In this example, the system is 2-dimensional.
name:	Cartesian coordinate system name	State Plane Coordinate System	
CS_CoordinateSystemAxis			These are the attributes for the first axis, used by the first coordinate in a coordinate tuple.
name:	Coordinate system axis name	easting	
axisAbbrev:	Coordinate system axis abbreviation	X	
axisDirection:	Coordinate system axis direction	east	
axisUnitID:	Coordinate system axis unit identifier	US survey foot	
CS_CoordinateSystemAxis			These are the attributes for the second axis, used by the second coordinate in a coordinate tuple.
name:	Coordinate system axis name	northing	
axisAbbrev:	Coordinate system axis abbreviation	Y	
axisDirection:	Coordinate system axis direction	north	
axisUnitID:	Coordinate system axis unit identifier	US survey foot	
CD_GeodeticDatum			Because the datum class is CD_GeodeticDatum, and because the CD_PrimeMeridian class is absent, the attributes name and Greenwich longitude take their default values of "Greenwich" and "0 degrees" respectively.
name:	Geodetic datum name	North American Datum of 1927	
alias:	Datum alias	NAD27	This is an optional attribute.
CD_Ellipsoid			
name:	Ellipsoid name	Clarke 1866	
semiMajorAxis:	Length of semi-major axis	6378206.4 m	
secondDefiningParameter:	Second defining parameter	semiMinorAxis	
semiMinorAxis:	Length of semi-minor axis	6356583.8 m	
remarks:	Ellipsoid remarks	inverse flattening derived from semi-major and semi-minor axes is 294.9786982	Remarks is an optional attribute.
CC_Conversion			
name:	Coordinate operation name	Alaska SPCS27 zone 4	

UML identifier	Attribute	Entry	Comment
domainOfValidity:	Coordinate operation validity	Alaska between 148 and 152 degrees west	Coordinate conversion validity is an optional attribute.
scope:	Coordinate operation scope	Topographic mapping	
CC_OperationMethod			
name:	Coordinate operation method name	Transverse Mercator	
formula:	Coordinate operation method formula	See USGS professional paper 1395 [11].	
sourceDimensions:	Dimension of source CRS	2	This attribute is optional.
targetDimensions:	Dimension of target CRS	2	This attribute is optional.
CC_OperationParameter			The number of parameters (*n*) is dictated by the formula of the operation method. Parameter names, values (and, if required, optional attributes) will be given *n* times, as appropriate.
name:	Operation parameter name	latitude of origin	
CC_ParameterValue			
value:	Operation parameter numeric value	54 degrees	
CC_OperationParameter			
name:	Operation parameter name	longitude of origin	
CC_ParameterValue			
value:	Operation parameter numeric value	□150 degrees	
CC_OperationParameter			
name:	Operation parameter name	scale factor	
CC_ParameterValue			
stringValue:	Operation parameter string value	0.9999	This is a ratio and is unitless.
CC_OperationParameter			
name:	Operation parameter name	false easting	
CC_ParameterValue			
value:	Operation parameter numeric value	500 000 US Survey foot	
CC_OperationParameter			
name:	Operation parameter name	false northing	
CC_ParameterValue			
value:	Operation parameter numeric value	0 US Survey foot	

Example D.6: Compound coordinate reference system formed from a projected CRS with a vertical CRS.

UML identifier	Attribute	Entry	Comment
SC_CompoundCRS			This example supports a coordinate tuple of easting, northing, gravity-related height.
name:	Compound CRS name	British National Grid + ODN	
domainOfValidity:	CRS validity	Great Britain mainland.	
scope:	CRS scope	National mapping including heights related to mean sea level.	

UML identifier	Attribute	Entry	Comment
			The individual CRSs forming the compound CRS are next described. The sequence is significant as it implies the order of coordinates in the coordinate tuple.
SC_ProjectedCRS			The projected CRS is then described in a similar manner to that in Example 5.
name:	Projected CRS name	British National Grid	
domainOfValidity:	CRS validity	England, Wales, Scotland, Isle of Man.	
scope:	CRS scope	Large, medium and small scale topographic mapping, engineering survey and GIS.	
CS_CartesianCS			
name:	Cartesian coordinate system name	National grid	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	easting	
axisAbbrev:	Coordinate system axis abbreviation	E	
axisDirection:	Coordinate system axis direction	east	
axisUnitID:	Coordinate system axis unit identifier	metre	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	northing	
axisAbbrev:	Coordinate system axis abbreviation	N	
axisDirection:	Coordinate system axis direction	north	
axisUnitID:	Coordinate system axis unit identifier	metre	
CD_GeodeticDatum			
name:	Geodetic datum name	Ordnance Survey of Great Britain 1936	
CD_Ellipsoid			
name:	Ellipsoid name	Airy 1830	
semiMajorAxis:	Length of semi-major axis	6377563.396 m	
secondDefiningParameter:	Second defining parameter	inverseFlattening	
inverseFlattening:	Inverse flattening	299.3249646	
CC_Conversion			
name:	Coordinate operation name	British National Grid	
scope:	Coordinate operation scope	Topographic mapping	
CC_OperationMethod			
name:	Coordinate operation method name	Transverse Mercator	
formula:	Coordinate operation method formula	(Metadata describing the formula should be given here and is not detailed in this example.)	
CC_OperationParameter			
name:	Operation parameter name	latitude of origin	
CC_ParameterValue			
value:	Operation parameter numeric value	49 degrees	
CC_OperationParameter			
name:	Operation parameter name	longitude of origin	
CC_ParameterValue			
value:	Operation parameter numeric value	□2 degrees	

UML identifier	Attribute	Entry	Comment
CC_OperationParameter			
name:	Operation parameter name	scale factor	
CC_ParameterValue			
stringValue:	Operation parameter string value	0.9996012717	
CC_OperationParameter			
name:	Operation parameter name	false easting	
CC_ParameterValue			
value:	Operation parameter numeric value	400 000 m	
CC_OperationParameter			
name:	Operation parameter name	false northing	
CC_ParameterValue			
value:	Operation parameter numeric value	□100 000 m	
SC_VerticalCRS			The vertical CRS is then described in a similar manner to that in Example 2.
name:	Vertical CRS name	ODN	
domainOfValidity:	CRS validity	British mainland	
scope:	CRS scope	National height system	
CS_VerticalCS			
name:	Vertical coordinate system name	ODN heights	
CS_CoordinateSystemAxis			
name:	Coordinate system axis name	height	
axisAbbrev:	Coordinate system axis abbreviation	H	
axisDirection:	Coordinate system axis direction	up	
axisUnitID:	Coordinate system axis unit identifier	metre	
CD_VerticalDatum			
name:	Vertical datum name	Ordnance Datum Newlyn	
			The order of coordinates in a coordinate tuple referenced to the compound CRS is then implied as E,N,H.

Example D.7: Coordinate transformation.

This example shows a coordinate transformation from WGS 84 to ED50.

UML identifier	Attribute	Entry	Comment
CC_Transformation			
name:	Coordinate operation name	WGS 84 to ED50 NIMA 1993 mean Europe	
operationVersion:	Coordinate operation version	NIMA mean for Europe	
domainOfValidity:	Coordinate operation validity	Austria; Belgium; Denmark; Finland; France; Germany (west); Gibraltar; Greece; Italy; Luxembourg; Netherlands; Norway; Portugal; Spain; Sweden; Switzerland	
scope:	Coordinate operation scope	military operations	
remarks:	Coordinate operation remarks	Not used for civilian purposes: consult EuroGeographics or national mapping authorities.	This field is optional.

UML identifier	Attribute	Entry	Comment
coordinateOperationAccuracy:	Coordinate operation accuracy	3 m, 8 m and 5 m in *X*, *Y* and *Z* axes.	This field is optional.
SC_GeodeticCRS		(Metadata defining the source CRS should be given here and is not detailed in this example.)	This first CRS is by implication the source CRS for the transformation, in this example WGS 84.
SC_GeodeticCRS		(Metadata defining the target CRS for should be given here and is not detailed in this example.)	This second CRS is by implication the target CRS for the transformation, in this example ED50.
CC_OperationMethod			
name:	Coordinate operation method name	geocentric translations	
formula:	Coordinate operation method formula	$X_t = X_s + dX$; $Y_t = Y_s + dY$; $Z_t = Z_s + dZ$ where d*X*, d*Y* and d*Z* are translations along *X*, *Y* and *Z* axes, respectively. (The subscripts "t" and "s" refer to target and source.)	
sourceDimensions:	Dimension of source CRS	3	
targetDimensions:	Dimension of target CRS	3	
CC_OperationParameter			The number of parameters (*n*) is dictated by the formula of the operation method. Parameter names, values (and, if required, optional attributes) will be given *n* times, as appropriate. In this example, *n* = 3.
name:	Operation parameter name	*X*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	87 m	
CC_OperationParameter			
name:	Operation parameter name	*Y*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	98 m	
CC_OperationParameter			
name:	Operation parameter name	*Z*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	121 m	

Example D.8: Geoid height model (coordinate transformation).

This example describes a model which transforms gravity-related heights referenced to the United European Levelling Network (UELN) to ellipsoid heights which are referenced to the European Terrestrial Reference System (ETRS) as part of a 3D CRS.

UML identifier	Attribute	Entry	Comment
CC_Transformation			
name:	Coordinate operation name	EGG97	
alias:	Coordinate operation alias	European Gravimetric Geoid 1997	
operationVersion:	Coordinate operation version	1997	
domainOfValidity:	Coordinate operation validity	Europe	

UML identifier	Attribute	Entry	Comment
scope:	Coordinate operation scope	Coordinate transformation of the ellipsoidal height component of a 3D geodetic CRS to gravity-related heights.	
remarks:	Coordinate operation remarks	Source: University of Hanover Institute for Earth Measurement.	This attribute is optional.
SC_GeodeticCRS		(Metadata defining the source CRS should be given here and is not detailed in this example.)	This first CRS is by implication the source CRS for the transformation, in this example ETRS. Transformation applications need to extract the height component
SC_VerticalCRS		(Metadata defining the target CRS should be given here and is not detailed in this example.)	This second CRS is by implication the target CRS for the transformation, in this example UELN.
CC_OperationMethod			
name:	Coordinate operation method name	EGG geoid model	
formula:	Coordinate operation method formula	$h_{\mathrm{ETRS}} = H_{\mathrm{UELN}} + N_{\mathrm{EGG97}}$	
remarks:	Coordinate operation method remarks	The method requires interpolation of geoid height (*N*) within the geoid model, using latitude and longitude components of the source CRS as arguments for the interpolation.	This attribute is optional.
sourceDimensions:	Dimension of source CRS	3	
targetDimensions:	Dimension of target CRS	1	
CC_OperationParameter			The number of parameters (*n*) is dictated by the formula of the operation method. Parameter names, values (and, if required, optional attributes) will be given *n* times, as appropriate. In this example, *n* is the value of each grid node in the geoid model and is too large to be conveniently described directly. It is therefore given indirectly through a file reference. The format of the file will be dictated by the operation method.
name:	Operation parameter name	geoid model file	
remarks:	Operation parameter remarks	1567890 nodes	
CC_ParameterValue		CC_ParameterValue	
valueFile:	Operation parameter file reference	filename	Filename might be a URI.

Example D.9: Concatenated operation.

This example demonstrates the concatenation of a transformation between Egypt 1907 to WGS 72 with one between WGS 72 and WGS 84 to form a concatenated operation between Egypt 1907 and WGS 84.

UML identifier	Attribute	Entry	Comment
CC_ConcatenatedOperation			
name:	Concatenated coordinate operation name	ED50 to WGS 84 Egypt	

UML identifier	Attribute	Entry	Comment
operationVersion:	Coordinate operation version	MCE and DMA concatenation	
domainOfValidity:	Coordinate operation validity	Egypt - Western Desert.	
scope:	Coordinate operation scope	Oil exploration.	
SC_GeodeticCRS		(Metadata defining the source CRS should be given here and is not detailed in this example.)	This is the source CRS for the concatenated operation, in this example ED50.
SC_GeodeticCRS		(Metadata defining the target CRS should be given here and is not detailed in this example.)	This is the target CRS for the concatenated operation, in this example WGS 84.
			Then each of the single coordinate operations forming the concatenated operation are given in turn. The order is that in which the operations are to be made. In this example, only selected attributes are shown – see Example E.7 for a full example of a single coordinate operation.
			The first step of the concatenated transformation is described next.
CC_Transformation			
name:	Concatenated coordinate operation name	ED50 to WGS 72 Egypt	
operationVersion:	Coordinate operation version	MCE 1974	
domainOfValidity:	Coordinate operation validity	Egypt.	
scope:	Coordinate operation scope	Geodetic survey.	
SC_GeodeticCRS		(Metadata defining the source CRS should be given here and is not detailed in this example.)	This is the source CRS for the first step of the concatenated operation, in this example ED50.
SC_GeodeticCRS		(Metadata defining the target CRS should be given here and is not detailed in this example.)	This is the target CRS for the first step of the concatenated operation, in this example WGS 84.
CC_OperationMethod			
name:	Coordinate operation method name	geocentric translations	
formula:	Coordinate operation method formula	$X_t = X_s + \mathrm{d}X$; $Y_t = Y_s + \mathrm{d}Y$; $Z_t = Z_s + \mathrm{d}Z$ where d*X*, d*Y* and d*Z* are translations along *X*, *Y* and *Z* axes respectively. (The subscripts "t" and "s" refer to target and source.)	
sourceDimensions:	Dimension of source CRS	3	
targetDimensions:	Dimension of target CRS	3	
CC_OperationParameter			The number of parameters (*n*) is dictated by the formula of the operation method. Parameter names, values (and, if required, optional attributes) will be given *n* times, as appropriate. In this example, first step, *n* = 3.
name:	Operation parameter name	*X*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	□121.8 m	
CC_OperationParameter			
name:	Operation parameter name	*Y*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	98.1 m	

UML identifier	Attribute	Entry	Comment
CC_OperationParameter			
name:	Operation parameter name	*Z*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	□15.2 m	
CC_OperationParameter			
name:	Operation parameter name	Longitude coefficient v^4	
CC_ParameterValue			
value:	Operation parameter numeric value	7.62236E-09	
			The next step of the concatenated transformation is described.
CC_Transformation			
name:	Concatenated coordinate operation name	WGS 72 to WGS 84 DMA	
operationVersion:	Coordinate operation version	DMA 1987	
domainOfValidity:	Coordinate operation validity	World.	
scope:	Coordinate operation scope	Geodetic survey.	
SC_GeodeticCRS		(Metadata defining the source CRS should be given here and is not detailed in this example.)	This is the source CRS for the second step of the concatenated operation, in this example WGS 72.
SC_GeodeticCRS		(Metadata defining the target CRS should be given here and is not detailed in this example.)	This is the target CRS for the second step of the concatenated operation, in this example WGS 84.
CC_OperationMethod			
name:	Coordinate operation method name	Helmert similarity transform (position vector rotation convention)	
formula:	Coordinate operation method formula	(The method formula or a citation for it should be given here and is not detailed in this example.)	
sourceDimensions:	Dimension of source CRS	3	
targetDimensions:	Dimension of target CRS	3	
CC_OperationParameter			The number of parameters (*n*) is dictated by the formula of the operation method. Parameter names, values (and, if required, optional attributes) will be given *n* times, as appropriate. In the second step of this example, *n* = 7.
name:	Operation parameter name	*X*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	0 m	
CC_OperationParameter			
name:	Operation parameter name	*Y*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	0 m	
CC_OperationParameter			
name:	Operation parameter name	*Z*-axis translation	
CC_ParameterValue			
value:	Operation parameter numeric value	4.5 m	
CC_OperationParameter			

UML identifier	Attribute	Entry	Comment
name:	Operation parameter name	*X*-axis rotation	
CC_ParameterValue			
value:	Operation parameter numeric value	0 s	
CC_OperationParameter			
name:	Operation parameter name	*Y*-axis rotation	
CC_ParameterValue			
value:	Operation parameter numeric value	0 s	
CC_OperationParameter			
name:	Operation parameter name	*Z*-axis rotation	
CC_ParameterValue			
value:	Operation parameter numeric value	0.554 s	
CC_OperationParameter			
name:	Operation parameter name	Scale difference	
CC_ParameterValue			
value:	Operation parameter numeric value	0.226 3 parts per million	

Annex E (informative)

Recommended best practice for interfacing to ISO 19111

Standards which reference ISO 19111 can minimize dependencies by only referencing to the following.

a) An interface to the ISO 19111 model which requires coordinate reference system should be only to the SC_CRS class or any one of its concrete subclasses SC_GeodeticCRS, SC_ProjectedCRS, SC_VerticalCRS, SC_EngineeringCRS, SC_ImageCRS and SC_CompoundCRS.

   Interfaces to CD_Datum (including datum subclasses) or to CS_CoordinateSystem will not provide for a complete coordinate reference system definition and should not be made.

b) If a coordinate operation is required, interfacing should be made through the SC_CRS class from where navigation to the CC_Operation class will provide the necessary metadata for the coordinate operation.

Bibliography

ISO 31 (all parts), *Quantities and units*

ISO 8601, *Data elements and interchange formats — Information interchange — Representation of dates and times*

ISO 19107:2003, *Geographic information — Spatial schema*

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ISO 19113, *Geographic information — Quality principles*

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HOOIJBERG, M. *Practical Geodesy*, Springer, 1997 [1)]

SNYDER, JOHN P. *Map Projections: A Working Manual*, USGS Professional Paper 1395, 1987, 383 pp

[1)] This and similar literature describing the geodetic concepts incorporated within this Abstract Specification may use different terminology to that defined herein. Some terms may be common to both documents but have different meanings.