Open Geospatial Consortium Inc.

Date: 2009-09-14

Reference number of this document: 09-076r3

Version: 0.3.0

Category: OGC Public Discussion Paper

Editor: Arliss Whiteside

Uses and summary of Topic 2: Spatial referencing by coordinates

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Document type:	**OpenGIS® Discussion Paper**
Document subtype:	**NA**
Document stage:	**Approved for Public Release**
Document language:	**English**

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1. Introduction

This document first discusses the uses for data sharing, and then provides a brief summary, of OGC Abstract Specification Topic 2: Spatial referencing by coordinates. Topic 2 is almost the same as ISO 19111:2007, but includes some corrections. This document includes some best practices for using Coordinate Reference Systems (CRSs).

Abstract Specification Topic 2 specifies the concepts, definitions, and data model of a coordinate reference system (CRS) and its various parts. Readers of this document are encouraged to reference the UML diagrams in Topic 2, especially Figures 2, 3, 6, 7, 9, 11, and 12. A CRS definition provides the meaning of position coordinates using that CRS, and includes an identifier and a somewhat detailed description of that CRS. A CRS is thus essential (meta) data for sharing most geospatial data, in which spatial positions are represented by coordinates.

2. CRS uses for data sharing

A CRS definition provides the meaning for position coordinates that use that CRS. Topic 2 does not discuss the uses of a CRS, but understanding CRS use cases is essential for sharing geospatial data in which positions are represented by coordinates. In this data sharing, the data represented by coordinates will reference the appropriate CRS(s), and CRS definitions are shared when needed.

The current uses of CRS definitions in sharing geospatial data include:

a) A CRS definition provides human-understandable name, aliases, units, direction, and origin for each coordinate axis (ordinate from a coordinate tuple), and a name and aliases for the CRS, for data that references (or includes) this CRS definition.

b) A CRS definition (encoded in GML) provides software-useable CRS, datum, and coordinate system identifiers, names, and aliases, plus each coordinate axis identifier, name, aliases, and units, for data that references (or includes) this CRS definition.

NOTE 1 The above use has been rare, except for requirements in Sensor Web Enablement (SWE). Discussion with the SWE community indicates they require more definition information to be separately encoded, especially datum information. Some persons have thus suggested that they propose extending Topic 2 and the corresponding GML encoding.

c) The source and target CRS identifiers explicitly referenced in a coordinate Transformation indicate the intended use of that Transformation, to transform data using the source CRS into the corresponding data using the target CRS (or in the opposite direction). These CRS identifiers are also clear when a coordinate transformation or equivalent is required by an OGC Web Service operation (e.g., in WMS, WFS, WCS).

NOTE 2 The following use might be interpreted as either a precondition or consequence of the above use.

d) The CRS identifiers provided for different data sets should indicate if that data is directly comparable. That is, providing the same CRS identifiers for different data should indicate that the data is directly comparable, while providing different CRS identifiers should indicate that the data is not directly comparable (without transformation). Directly comparable here means that different data with the same position coordinates is for (approximately) the same spatial position. Directly comparable means that this data can be meaningfully overlaid or merged. (That is, geographic properties such as distances, bearings, and areas can be calculated using data from the comparable data sets.) Of course, the different data is likely to be for different times or different feature types. [Best Practice]

Uses c) and d) listed above refer to CRS identifiers since shared data users are expected to compare CRS identifiers (not complete definitions) for these purposes. That is, the CRS identifiers provided with different data sets are expected to be compared to determine if that data is directly comparable [use d)]. Similarly, the CRS identifiers provided with different data sets are expected to be used to select a coordinate transformation that could be applied to make different data sets directly comparable [use c)].

3. CRS identifiers for interoperability

Use d) listed above in Clause 2 uses the word “should” since nothing is said in Topic 2 that promotes (or ensures) assignment of CRS identifiers for this use. However, good assignment of CRS identifiers is essential for interoperability among multiple data sources and data users. If one data source produces multiple data sets, it should assign CRSs to those sets so that the CRS identifiers indicate if that data is directly comparable. Similarly, if multiple interoperating data sources produce multiple data sets, they should assign CRSs to those sets so that the CRS identifiers indicate if that data is directly comparable. [Best Practice]

Good assignment of CRS identifiers may take the form of using widely known CRSs with standardized CRS identifiers and definitions. Geographic CRSs and Projected CRSs based on those geographic CRSs are often widely known, and use of standardized CRS identifiers and definitions is highly desirable for interoperability. Such standardization is a major purpose of the EPSG database: to define standard CRSs and assign standard identifiers to them. [Best Practice]

Good assignment of CRS identifiers may take the form of assigning unique CRS identifiers for each image and for each object to which an Engineering CRS is applied. Each different image requires a different CRS, because it uses a different datum that references the specific image. Similarly, each different object to which an Engineering CRS is applied requires a different CRS, using a different datum. [Best Practice]

The assignment of CRS identifiers for interoperability is harder in many other cases. One such case is a georectified grid, even a grid in a standard Projected CRS or geographic CRS. There are many possible rectified grids in one Projected CRS or geographic CRS, and work on defining standardized rectified grids is either non-existent or not widely known.

In many of these other cases, assigning CRS identifiers to indicate if data is directly comparable seems to require coordination between multiple interoperating data sources. Such coordination might be obtained by using one or more central registry(ies) of these CRS identifiers and definitions. The degree to which this is achieved is then one measure of the interoperability of multiple data sources.

4. XML encoding

Clause 12 “Coordinate reference systems schemas” of GML 3.2.1 specifies how to XML encode the definition of a coordinate reference system (CRS), a coordinate system (CS), a coordinate axis, a datum, a coordinate operation (including coordinate transformations and conversions), an operation method, and an operation parameter. Such GML encoding of these definitions should be used for uses a) and b) listed above in Clause 2. [Best Practice]

On the other hand, XML encoding of CRS references, using CRS identifiers, is usually used for uses c) and d) listed above. In most cases, CRS references use the XML Schema data type anyURI, to encode a reference to a CRS using its identifier. This is done by all geometries encoded in GML 3, where the gml:SRSReferenceGroup attribute group is included in each direct position (gml:pos) or higher-level geometry element. Use of the XML Schema data type anyURI is also specified in Clause 10.3 of OWS Common 1.2.

NOTE 1 In addition to the CRS identifier, the gml:SRSReferenceGroup attribute group allows inclusion of copies of some CRS definition data. That optional definition data is an ordered list of coordinate axis names, and an ordered list of coordinate axis units, both the same as specified in the definition of the referenced CRS.

NOTE 2 OWS Common 1 does not use the gml:SRSReferenceGroup attribute group, or any equivalent, since it does not use GML, and it usually encodes CRS references as XML elements (not XML attributes).

Clause 10.3 of OWS Common 1.2 specifies, and GML 3 allows, an anyURI to reference a CRS (or a CRS component) using either of two alternative URI formats: [Best Practice]

a) Universal Resource Locator (URL), using the standard forms. The URL format **shall** be used when the referenced definition is known to be electronically available using this standard URL. When not in the same XML document, those definitions **shall** be electronically available over the Internet using this URL. The available definitions **shall** be encoded in GML, perhaps using one or more GML Application Schemas.

b) Universal Resource Name (URN), with a specified form. The URN format **shall** be used whenever the referenced definition is not, or might not be, available using a URL. This URN **shall** reference data that is specified by some “authority” and is “well-known” to both client and server software, including multiple clients and multiple servers. A URN value in the “ogc” URN namespace may be used to reference a definition specified in that “ogc” URN namespace. The format of those URNs **shall** be as specified in OGC Policy documents OGC 09-048, 09-054, and 09-055.

NOTE The OGC is currently in the process of setting up a URN resolver service for assigned URN values in the “ogc” URN namespace, as discussed in OGC Policy document OGC 09-046.

5. Topic 2 summary

Topic 2 specifies the concepts, and the data required to define, a coordinate reference system (CRS), a coordinate system (CS), a coordinate axis, a datum, a coordinate operation (including coordinate transformations and conversions), an operation method, and an operation parameter. In more detail:

a) A CRS specifies the meaning for point position coordinates.

NOTE Without a CRS, point position coordinates are essentially meaningless.

b) Topic 2 does not specify how to encode position coordinates.

NOTE Topic 3 (ISO 19107) and GML specify how to encode position coordinates for “direct positions” used in a geometry. OWS Common, WMS, WCS, and other OGC standards specify how to encode position coordinates for service input-output positions not in any geometry.

c) A coordinate reference system relates a coordinate system to a specific object by a datum.

NOTE The specific object is often a physical object, such as the earth or a specific moving platform. However, the object may be a specific grid coverage.

d) A CRS definition combines a coordinate system (CS) with a datum, and includes unique identifiers for that CRS, CS, datum, and each coordinate axes in that CS.

NOTE One CS will often be used with many different datums. One datum may be used with several different CSs.

e) A datum identifies the location of the origin of the CRS-associated CS.

NOTE A datum may identify the location of the origin by means other than identifying the origin point. For example, a GeodeticDatum often identifies the location of the origin by specifying the geographic coordinates of an identified "fundamental point".

f) A datum also (sometimes implicitly) identifies one or more sets of orientation directions that are referenced by the coordinate axes in that CS.

NOTE This interpretation of a datum is not always fully understood. If a datum has more than one alternate set of orientation directions, as a geodetic datum does, the type of the associated CS selects the proper set of datum orientation directions.

g) A datum (usually) does NOT numerically specify the location of the origin of the associated CS, or the set of orientation directions, in any other CRS or CS, and a datum should NOT numerically specify these. [Best Practice]

h) The location of the origin of the datum should be an identified point on some identified object, where an image or other grid coverage is considered such an object. [Best Practice]

i) The anchorDefinition in the definition of an EngineeringDatum should identify a specific origin point and the orientation directions for coordinate axes, relative to the identified object. [Best Practice]

NOTE The anchorDefinition was previously called the anchorPoint, in GML 3.1.1 and ISO 19111:2003. (The reason for this change was that the relationship of a datum with the physical object is sometimes defined through multiple points, not just one.)

j) The anchorDefinition in the definition of an ImageDatum should identify a pixel in the image as the position of the origin. [Best Practice]

k) The anchorDefinition in the definition of an ImageDatum also (perhaps implicitly) defines the orientation set of directions in the image object, which are parallel to the image pixel rows and columns. The CS axes are then defined to be in the directions of the (perhaps implicit) datum orientation directions. [Best Practice]

NOTE 1 As stated in Clause B.3.5 of Topic 2, the anchorDefinition pixel is usually either the centre or a corner of the image. Notice that the anchorDefinition is different from the pixelInCell, which specifies whether the origin is centered on a pixel or is halfway between pixel centers

NOTE 2 Although the anchorDefinition is optional, it should be included in an engineering or image datum. Because the image IS the object, different anchorDefinitions and ImageDatums are needed by different images, and the ImageCRS thus must be different for each image. [Best Practice]

l) A coordinate system (CS) specifies an ordered sequence of the position coordinate axes (ordinates from a coordinate tuple) in that CS. The specified axis order **shall** be used by the coordinates (ordinates) in recorded coordinate tuples.

m) Each coordinate axis specifies the name(s) of that axis (ordinate), the axis direction, and the units that **shall** be used for recording positions along that axis.

n) Each axis direction (informally) references a direction of the orientation of the datum with which this CS is used by a CRS. [Best Practice]

NOTE This meaning of the axis direction is not explicitly stated in Topic 2, and thus not always understood. The purpose of the axis direction is to prevent ambiguity in associating the axes of a coordinate system with the directions defined by the datum. The exact direction of a coordinate axis can never be defined in absolute terms, since absolute directions do not exist.

o) A coordinate axis may be straight or curved, or may be an angle.

NOTE Some persons prefer to think of a coordinate axis as always straight, with a coordinate conversion to a curve. However, this terminology is not now supported in Topic 2. Topic 2 deliberately and explicitly supports curved spaces, such as the surface of an ellipsoid, or the curved axis of a gravity-related Vertical CRS. The conversion between curved and straight axes does not take place at the axis or coordinate system level, but in coordinate operations between coordinate reference systems.

p) A coordinate operation defines how to change coordinates from one coordinate reference system to another.

NOTE A coordinate operation is often based on a one-to-one relationship between corresponding coordinates. However, a coordinate operation may be based on other relationships between corresponding coordinates. For example, a many-to-one relationship usually exists, and is used, from 3D ground coordinates to unrectified 2D image coordinates.

q) A coordinate operation contains values for the operation parameters needed to perform this operation, and is associated to one operation method, which describes how to perform that operation using values of zero or more parameters.

NOTE One operation method will often be used by many different coordinate operations with different source and target CRSs, which may use different coordinate axis names.

r) The CRS, datum, and coordinate operation definitions each contain one or more “scope” parameters, to identify expected usage or restrictions and limitations of usage.

NOTE The “scope” parameter is required, so it must have the value “not known” when the “scope” in unknown. The “scope” may be repeated, but repetition is rare.

s) Although a CRS, CS, or datum might be used for more than position coordinates, such as velocities and accelerations, Topic 2 does not mention these possible uses, and thus does not suggest how this should be done.

NOTE This (current) limitation of the scope of Topic 2 is not always understood. (Topic 2 supports the DirectPosition specified in ISO 19107, providing the reference information required to interpret the position coordinates in the DirectPosition class.) However, extensions and modifications of Topic 2 are now being considered to increase its scope. Indeed, a new Topic 19 that extends Topic 2 has been drafted. Persons are encouraged to propose extensions to Topic 2 as may be needed to meet their needs.

t) Topic 2 specifies 7 concrete types of CRS, namely GeodeticCRS, VerticalCRS, ImageCRS, EngineeringCRS, ProjectedCRS, DerivedCRS, and CompoundCRS.

u) Topic 2 specifies 4 concrete types of datum, namely GeodeticDatum, VerticalDatum, ImageDatum, and EngineeringDatum.

v) Topic 2 specifies 9 concrete types of CS, namely EllipsoidalCS, CartesianCS, VerticalCS, LinearCS, CylindricalCS, PolarCS, AffineCS, and UserDefinedCS.

NOTE The LinearCS, CylindricalCS, PolarCS, AffineCS, and UserDefinedCS are rarely used.

w) Topic 2 specifies 4 concrete types of coordinate operation, namely Transformation, Conversion, PassThroughOperation, and ConcatenatedOperation.

x) A ProjectedCRS or DerivedCRS inherits its datum through its baseCRS, and just changes the CS using a coordinate Conversion between the old and new CSs.

6. Definitions copied from Topic 2

The following definitions from Topic 2 are ordered for top-down understanding.

6.1 General concepts

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.

4.46
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.

4.8
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.

EDITOR'S NOTE Restating this definition: A coordinate reference system relates its coordinate system to a specific object by a datum. The object is often a physical object, such as the earth or a moving platform.

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

EDITOR'S NOTE The words "the scale" in the above definition apply primarily to geodetic datums, and this scale reflects very small errors in the geodetic datum.

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

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.

6.2 Coordinate reference system types

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

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

4.30
image coordinate reference system
coordinate reference system based on an image datum

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.

4.3
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.

6.3 Datum types

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

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.

4.31
image datum
engineering datum which defines the relationship of a **coordinate system** to an image

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.

6.4 Coordinate system types

4.18
ellipsoidal coordinate system
coordinate system in which position is specified by **geodetic latitude**, **geodetic longitude** and (in the three-dimensional case) **ellipsoidal height**

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.

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

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.

4.44
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

[ISO 19136]
NOTE Not to be confused with an ellipsoidal coordinate system based on an ellipsoid 'degenerated' into a sphere.

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)**.

4.13
cylindrical coordinate system

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

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

6.5 Coordinate operation types

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.

4.6
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.

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

6.6 Geodetic CRS terms

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

4.19
ellipsoidal height
geodetic height

distance of a point from the **ellipsoid** measured along the perpendicular from the **ellipsoid** to this point, positive if upwards or outside of the **ellipsoid**

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

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.

4.40
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.

4.22
flattening
ratio of the difference between the **semi-major** (a) and **semi-minor axis** (b) of an **ellipsoid** to the **semi-major axis**; $f = (a - b)/a$

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

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.

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

6.7 Projected CRS terms

4.39
projected coordinate reference system

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

4.33
map projection
coordinate conversion from an **ellipsoidal coordinate system** to a plane

4.16
easting
E
distance in a **coordinate system**, eastwards (positive) or westwards (negative) from a north-south reference line

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

6.8 Vertical CRS terms

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.

4.15
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.

4.27
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.

4.34
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.

6.9 Other terms

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.

4.42
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.

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

4.45
tuple
ordered list of values

7. References

[1] OGC 08-015, The OpenGIS® Abstract Specification Topic 2: Spatial referencing by coordinates

[2] OGC 08-010r1, Topic 2 change request - Correct grid cell terms”

[3] OGC 08-089r3, Topic 2 change request - Correct inconsistencies ”

[4] OGC 08-149, Topic 2 change request - Change associations to GeneralParameterValue”

NOTE The three Topic 2 change requests listed above were accepted by the OGC Technical Committee in their September 2008 meeting.

[5] OGC 07-011, The OpenGIS® Abstract Specification Topic 6: Schema for coverage geometry and functions

[6] OGC 07-036, Geography Markup Language (GML), version 3.2.1

[7] OGC 06-121r7, OGC Web Services Common, version 1.2

[8] OGC 04-107, The OpenGIS® Abstract Specification Topic 7: The Earth Imagery Case