Volume 8

OGC CDB Spatial Reference System Guidance (Best Practice)

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i. Abstract

Volume 8 of the CDB standard defines the conceptual model and the methodologies that allow the description, and transformation or conversion, of geometric properties within a set of spatial reference frames supported by the CDB standard. The CDB Spatial Reference Model (SRM) supports an unambiguous specification of the positions, directions, and distances associated with spatial information. This document also defines algorithms for precise transformation of positions, directions and distances among different spatial reference frames.

In previous versions of the CDB standard, this CDB volume was Appendix K in CDB Version 3.2 as submitted to the OGC.

ii. Keywords

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, ogcdoc, cdb, spatial reference model, srm, coordinate systems, crs, srs

iii. Preface

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

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

Organization name(s)

- CAE Inc.
- Carl Reed, OGC Individual Member
- Envitia, Ltd
- Glen Johnson, OGC Individual Member
- KaDSci, LLC
- Laval University
- Open Site Plan
- University of Calgary
- UK Met Office

The OGC CDB standard is based on and derived from an industry developed and maintained specification, which has been approved and published as OGC Document 15-003: OGC Common

DataBase Volume 1 Main Body. An extensive listing of contributors to the legacy industry-led CDB specification is at Chapter 11, pp 475-476 in that OGC Best Practices Document (https://portal.opengeospatial.org/files/?artifact_id=61935).

v. Submitters

All questions regarding this submission should be directed to the editor or the submitters:

Name	Affiliation
Carl Reed	Carl Reed & Associates
David Graham	CAE Inc.

vi. Document Organization

For ease of editing and review, the standard has been separated into 16 Volumes, one being a schema repository.

- Volume 0: OGC CDB Companion Primer for the CDB standard (Best Practice).

- Volume 1: OGC CDB Core Standard: Model and Physical Data Store Structure. The main body (core) of the CDB standard (Normative).

- Volume 2: OGC CDB Core Model and Physical Structure Annexes (Best Practice).

- Volume 3: OGC CDB Terms and Definitions (Normative).

- Volume 4: OGC CDB Rules for Encoding CDB Vector Data using Shapefiles (Best Practice).

- Volume 5: OGC CDB Radar Cross Section (RCS) Models (Best Practice).

- Volume 6: OGC CDB Rules for Encoding CDB Models using OpenFlight (Best Practice).

- Volume 7: OGC CDB Data Model Guidance (Best Practice).

- Volume 8: OGC CDB Spatial Reference System Guidance (Best Practice).

- Volume 9: OGC CDB Schema Package: http://schemas.opengis.net/cdb/ provides the normative schemas for key features types required in the synthetic modelling environment. Essentially, these schemas are designed to enable semantic interoperability within the simulation context (Normative).

- Volume 10: OGC CDB Implementation Guidance (Best Practice).

- Volume 11: OGC CDB Core Standard Conceptual Model (Normative).

- Volume 12: OGC CDB Navaids Attribution and Navaids Attribution Enumeration Values (Best Practice).

- Volume 13: OGC CDB Rules for Encoding CDB Vector Data using GeoPackage (Normative, Optional Extension).

- Volume 14: OGC CDB Guidance on Conversion of CDB Shapefiles into CDB GeoPackages (Best Practice).

- Volume 15: OGC CDB Optional Multi-Spectral Imagery Extension (Normative).

Chapter 1. Scope

The handling of spatial data requires a good deal of rigor to accurately describe the position of points in space. Furthermore, it requires the ability to define directions and distances. Generally, this is accomplished through the use of coordinate systems.

A coordinate system (also called a spatial reference system) is a means of assigning coordinates to a location and establishing relationships between sets of such coordinates. Specifying a coordinate reference system enables the interpretation of a set of coordinates as a representation of a position in a real world space.

In the CDB standard, these terms can be used interchangeably. However, for consistency with previous versions of the CDB standard, the term spatial reference system (SRS) is used.

There is often the requirement to represent position in several different spatial reference systems. Each spatial reference system provides a particular way of defining positions within its domain. This level of abstraction also permits spatial reference systems to be decomposed into a series of, or even a hierarchy of reference, each relative to another reference system. This mechanism permits objects to be independently defined (positioned, oriented, and scaled) with respect to a local SRS and then be later incorporated into other reference systems. The reference systems can be abstract mathematical constructs or they can be bound to real world objects (e.g., a flap located defined in a flap reference system which in turn is bound to an aircraft wing reference system).

[1] There are many excellent references. A recent one is: http://www.oc.nps.edu/oc2902w/coord/coordcvt.pdf

Chapter 2. Conformance

There are no conformance classes in this document

Chapter 3. References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

ISO: ISO 19111:2007, *Geographic information — Spatial referencing by coordinates*, 2007

Chapter 4. Terms and Definitions

This document uses the terms defined in Sub-clause 5.3 of [OGC 06-121r8], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word "shall" (not "must") is the verb form used to indicate a requirement to be strictly followed to conform to this standard. Any terms and definitions for this CDB document may be found in Volume 3: CDB Terms and Definitions (Normative).

Chapter 5. Conventions

This sections provides details and examples for any conventions used in the document. Examples of conventions are symbols, abbreviations, use of XML schema, or special notes regarding how to read the document.

5.1. Identifiers

There are no normative provisions in this document.

Chapter 6. CDB Approach

One of the primary objectives of the CDB standard is to provide the means to represent the entire earth. As such, a CDB compliant data store must handle spatial data with a good deal of rigor to accurately describe the position of points in space and must do so at the level of fidelity commensurate with the precision that is now possible in modern simulators.
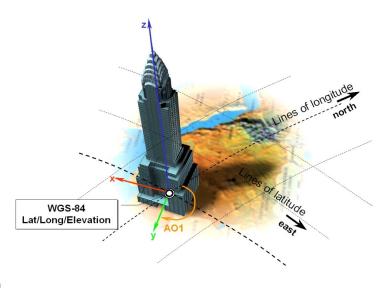
The size, content, fidelity and precision of synthetic environments now warrant a different approach, an approach that entirely avoids the "problem with projections" and other approximations used in the past. To this end, the CDB standard mandates the use a **geographic coordinate system** (GCS). A GCS uses a three-dimensional spherical surface to define locations on the earth. Since no projections are involved, full geometric coherence is assured without compromise and all four key spatial properties can be achieved simultaneously:

1. Preservation of distance
2. Preservation of direction
3. Preservation of area
4. Preservation of shape

6.1. CDB Spatial Reference Systems

The CDB standard is based on a surface geodetic coordinate system, i.e., points on the earth surface are specified as geographic latitude -longitude and elevation coordinates. More specifically, geodetic coordinates (sometimes called geographic coordinates) are angular coordinates (longitude and latitude), closely related to spherical polar coordinates, and are defined relative to a particular Earth geodetic datum. For the CDB, this is the WGS 84 datum. The WGS 84 datum surface is an oblate spheroid (ellipsoid) with major (equatorial) radius a = 6378137 m at the equator and flattening f = 1/298.257223563 [1]. The polar semi-minor axis b then equals a times (1−f), or 6356752.3142 m.

The CDB data store embeds modeled point features (e.g., the representation of 3-D objects, moving and/or static) within a Cartesian Coordinate System [2]. Its use is generally constrained to objects that are small in comparison to the earth. As shown below, a modeled point feature can be referenced anywhere on the earth by providing the model's orientation (the AO1 attribute specified in Chapter 5 of Volume 1: OGC CDB Core Standard: Model and Physical Database Structure) and the model's origin using a set of latitude/longitude/elevation coordinates. Note that the model's z-axis implicitly points upward with respect to the earth surface.

Figure 1: Cartesian Model positioned to WGS-84 Coordinates

The earth shape is described by the WGS-84 reference ellipsoid. The CDB standard also defines three related set of Spatial Reference Systems (and associated coordinate systems) for use in conjunction with the surface geodetic coordinate system; they are:

1. Earth-centered Cartesian (Geocentric)

2. Generic Cartesian

3. Local Vertical (LVCS)

[1] https://en.wikipedia.org/wiki/World_Geodetic_System#cite_note-Third_Edition_2000-6

[2] A Cartesian coordinate system is a coordinate system that specifies each point uniquely in a plane by a pair of numerical **coordinates**, which are the signed distances to the point from two fixed perpendicular directed lines, measured in the same unit of length

Chapter 7. The Three Systems

The following sections detail the normative aspects of the three Spatial Reference Systems (SRS) supported in the CDB model. We start with a general discussion of the Geographical Coordinate System before addressing the Spatial Reference Systems.

7.1. Geographic Coordinate System (Geodetic)

A geographic coordinate system (also called the geodetic coordinate system) is one in which the coordinates are expressed as latitude, longitude, and altitude relative to the reference ellipsoid. Geographical latitude φ and longitude λ are the angles of the normal on the reference ellipsoid along the point to the equator and zero meridian. The angles are normally given as degrees, minutes and seconds. Altitude is the distance above and normal to the reference ellipsoid in meters. The WGS 84 ellipsoid represents the actual geoid within an accuracy of 100 meters. The prime meridian and the equator are the reference planes used to define latitude and longitude.

In other terms, the geographic latitude – there are many other defined latitudes – of a point is the angle between the equatorial plane and a line normal to the reference ellipsoid's surface. The geographic longitude of a point is the angle between a reference plane, Greenwich, and a plane passing through the point, both planes being perpendicular to the equatorial plane. The geographic height at a point is the distance from the reference ellipsoid to the point in a direction normal to the reference ellipsoid.

Table 1: Geographic Coordinate System (Geodetic)

Field	Specification
Properties	Orthogonal.
CS parameters and constraints	a: major semi-axis length b: minor semi-axis length Constraints: $a > b$: (oblate ellipsoid)
Coordinate components	λ : longitude in radians, and φ : geodetic latitude in radians.
Domain of the generating function or mapping equations	$$-\pi/2 < \phi < \pi/2$$ $$-\pi < \lambda \leq \pi$$.

Domain of the inverse of the generating function or mapping equations	$$\frac{x^2}{a^2} + \frac{y^2}{a^2} + \frac{z^2}{b^2} = 1 \text{ and } z \neq \pm b.$$
Notes	1. The CS surface is the oblate ellipsoid (or sphere) surface excluding the pole points. 2. The geodetic 3D CS induces this CS on the 3rd coordinate surface at any point for which $h = 0$. 3. If a = b, the geodetic latitude φ coincides with the spherical latitude θ. 4. For WGS-84 a= 6,378,137 m and b = 6,356,752 m. The inverse flattening ratio f^{-1} is 298.257223563.

7.1.1. Earth-Centered SRS (aka Rectangular Geocentric SRS)

The earth-centered SRS defines a three-dimensional Euclidian space with respect to the geometric center of the reference ellipsoid, the center of the earth. The reference datum of the Earth-centered SRS is based on the WGS-84 ellipsoid reference model. In this SRS, the z-axis is pointing at the North Pole, the x-axis is pointing at the intersection of the equator and the Greenwich meridian, the prime meridian, and the y-axis is pointing at the intersection of the equator and 90° east longitude. The associated coordinate system is called the World Coordinate System and its units are meters. The world coordinate system is used to specify the 3D position of objects with respect to the earth-centered SRS. This coordinate system is used as an intermediate system to convert geodetic coordinates to LVCS and vice versa

7.1.2. General Cartesian SRS

The Cartesian spatial reference frame defines a three-dimensional Euclidian space with respect to an arbitrary origin. The reference datum specifying the origin and the orientation of the SRS is arbitrary, i.e. the reference datum can be specified within a geocentric SRS, a LVCS SRS or any other SRS. The SRS is right-handed and orthonormal. In this SRS system, the z-axis is pointing up and both the x-axis and y-axis lie in the horizontal plane. The associated coordinate system is called the General Cartesian Coordinate System; coordinates are specified in meters. This coordinate system is used for the representation of 3-D objects, moving and/or static. Its use is generally constrained to objects that are small in comparison to the earth [3].

7.1.3. Local Vertical SRS

The Local Vertical SRS (LVCS) spatial reference frame defines a three-dimensional Euclidian space. It is a SRF similar to the Geocentric SRF except that the origin of the SRF is translated and rotated to a point on the surface of the WGS-84 ellipsoid. At that point, the x-y plane is tangent to the surface

of the earth and the z-axis is normal to the ellipsoid. The associated coordinate system is called the local vertical coordinate system; the coordinates are specified in meters. In this coordinate system, the z-axis is pointing up, the y-axis is pointing north and the x-axis is pointing east. Its use is generally constrained to a surface that is small in comparison to the earth [4].

7.2. Geodetic to Geocentric transformation [1]

The following equations are used to transform geodetic information to geocentric information according to the following:

1. If $<\phi, \lambda, h>$ represents the geodetic coordinates to be transformed, where ϕ is the latitude, λ is the longitude, and h is the WGS84 height above the reference ellipsoid; and

2. If $<x, y, z>$ represents the geocentric coordinates; then using the WGS84 ellipsoid equatorial radius, a, of 6,378,137.0m and the WGS84 ellipsoid polar radius, b, of 6,356,752.314245m, the flattening f, the eccentricity e and the radius of curvature as a function of latitude $N(\phi)$ are given by equation eq. A-1:

	(eq. A-1)
$$f = \frac{a-b}{a}$$ $$e^2 = 2f - f^2$$ $$N(\varphi) = \frac{a}{\sqrt{1 - e^2 \sin^2 \varphi}}$$	

From these equations, we define the transformation of each geodetic coordinate as:

	(eq. A-2)
$$x = (N(\varphi) + h)\cos\varphi\cos\lambda$$ $$y = (N(\varphi) + h)\cos\varphi\sin\lambda$$ $$z = (N(\varphi)(1 - e^2) + h)\sin\varphi$$	

7.3. Geocentric to Geodetic Transformation

Geocentric coordinates cannot be transformed to the geodetic coordinate system directly. Instead, a successive approximation approach is used to compute the new coordinates. The following describes the algorithm to convert geocentric coordinates $<x, y, z>$ to geodetic coordinates $<\phi, \lambda, h>$, where ϕ is the latitude, λ is the longitude, and h is the WGS84 height above the reference ellipsoid. First, using the WGS84 ellipsoid equatorial radius, a = 6,378,137.0 m and the WGS84 ellipsoid polar radius, b = 6,356,752.314245 m, the flattening f and the eccentricity e of the ellipsoid are given by

equation A-3:

$$f = \frac{a - b}{a}$$ $$e^2 = 2f - f^2$$	(eq. A-3)

We first compute the longitude λ with equation A-4:

[a4]	*math/a4.png*	(eq. A-4)

We then compute a first approximation of the latitude assuming a spherical earth model with equation A-5:

$$\varphi = \tan^{-1}\left(\frac{z}{\sqrt{x^2 + y^2}}\right)$$	(eq. A-5)

Then, we iteratively compute the radius of curvature as a function of latitude $N(\phi)$ and, as a result we iteratively converge to a new, more accurate latitude ϕ' with equation A-6:

$$N(\varphi) = \frac{a}{\sqrt{1 - e^2 \sin^2 \varphi}}$$	(eq. A-6)

For each iteration, ϕ is replaced with ϕ', until the difference between the two values is less than a preset allowable error. The resulting latitude error will be less than ε. Finally, we compute the height above the reference ellipsoid h with equation A-7

$$h = \frac{\sqrt{x^2 + y^2}}{\cos \varphi} - N(\varphi)$$	(eq. A-7)

7.4. Geodetic to LVCS Coordinate Transformation

The transformation of a geodetic coordinate into an LVCS coordinate is decomposed into two parts:

1. Apply a coordinate transformation to each coordinate of an object from the geodetic coordinate system to the rectangular geocentric coordinate system.

2. Then apply a second transformation to go from the geocentric coordinate system to LVCS.

The first transformation, from geodetic to rectangular geocentric is described in section K.4. The transformation is applied to the origin of the object. The result of this transformation is the origin x_0 of the object in the geocentric coordinate system. Then for each coordinate x of the object, we apply the geodetic to geocentric transformation to coordinate x and we then compute the translation vector t between x and x_0 in the geocentric coordinate system with equation A-8

[a8] | *math/a8.png*	(eq. A-8)

The second transformation, from geocentric to LVCS is presented here as an algorithm to transform all coordinates of an object from the geodetic coordinate system to LVCS. The transformation from geodetic to LVCS first requires the assembly of a 3x3 rotation matrix M with equation A-9:

$$M = \begin{bmatrix} -\sin \lambda_0 & \cos \lambda_0 & 0 \\ -\sin \varphi_0 \cos \lambda_0 & -\sin \varphi_0 \sin \lambda_0 & \cos \varphi_0 \\ \cos \varphi_0 \cos \lambda_0 & \cos \varphi_0 \sin \lambda_0 & \sin \varphi_0 \end{bmatrix}$$	(eq. A-9)

Where: ϕ_0 and λ_0 = the latitude and longitude of the origin of the object.

Finally, the rotation matrix M is applied to the translation vector t to obtain each coordinate $\mathbf{x_L}$ in the local vertical coordinate system with equation A-10:

$$x_L = Mt$$	(eq. A-10)

7.5. Angular Displacements to Linear Displacement

For WGS84, which is an elliptical representation of the earth, the transformation from angular displacements to equivalent linear displacements in a tangential plane is slightly different than that for a spherical earth.

For WGS84 we get...

$$\delta X = \rho_t \cos(lat)\delta lon$$

$$\delta Y = \rho_m \delta lat$$

... as opposed to for a spherical earth

$$\delta X = \rho \cos(lat)\delta lon$$

$$\delta Y = \rho \delta lat$$

where...

δX, δY are the linear displacements along the x and y axes.

ρ_m, ρ_t are the meridional and transverse radiuses of curvature.

ρ is the radius of the spherical earth.

δlat, δlon are small displacements at location *lat/lon*

we have...

$$\rho_m = \frac{a(1 - e^2)}{\left[1 - e^2 \sin^2(lat)\right]^{3/2}}$$

$$\rho_t = \frac{a}{\sqrt{1 - e^2 \sin^2(lat)}}$$

$$e^2 = 1 - \frac{b^2}{a^2}$$

$$f = \frac{a - b}{a} \Rightarrow b = a(1 - f)$$

where...

e^2 is the square of the eccentricity

a,b are the semi-major and the minor axes of the earth

f is the flattening

This section describes the transformations required to go to-and-from the DIS/HLA and the CDB moving model coordinate systems.

7.6. 3D Model Coordinate System

The CDB 3D model coordinate system conventions are presented earlier in the OGC CDB Rules for Encoding Data using OpenFlight Best Practice.
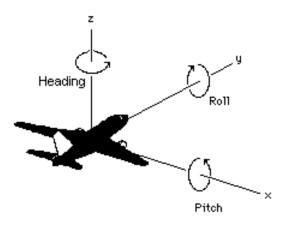
Figure 2: CDB 3D Model Coordinate System

The DIS coordinate system is used on a HLA network and is represented on the following figure.
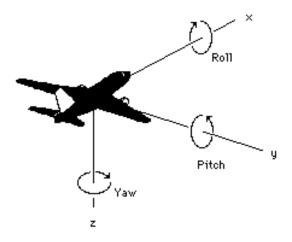

Figure 3: DIS Entity [5] Coordinate System

The two coordinate systems differ in the axis conventions (Z is up in the CDB while Z is down in DIS). Furthermore, the position of the origin also differs; DIS requires that the origin of its coordinate system be located at the center of the entity's bounding box excluding its articulated and attached parts [6]. The CDB standard uses a different convention.

The transformation from the CDB coordinate system to the DIS coordinate system involves one translation followed by two rotations. The translation represents the offset to the DIS origin as defined in chapter 6. Assume that P_0 represents the coordinate of the DIS origin.

$P_0 = (x_0, y_0, z_0)$	(eq. A-11)

The two rotations are relatively simple. First, rotate 180° about the X-axis. This rotation will position the Z-axis in its correct position. Equation A-12 represents this rotation.

$$M_x = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{Bmatrix}$$

(eq. A-12)

Second, rotate -90° about this new Z-axis. This last rotation completes the transformation and is represented by equation A-13.

$$M_z = \begin{Bmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{Bmatrix}$$

(eq. A-13)

Now, if we combine equations A-11, A-12 and A-13, we can transform a point P expressed in the CDB coordinate system into point P' in the DIS coordinate system. Equation A-14 presents the complete transformation.

$$P' = M_z M_x (P - P_0)$$

(eq. A-14)

The combined matrix gives equation A-15 and the resulting individual terms are presented in A-16.

$$M_z x = \begin{Bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{Bmatrix}$$

(eq. A-15)

$$x = y - y_0$$

$$y = x - x_0$$

$$z' = z_0 - z$$

(eq. A-16)

If a single transformation matrix M is preferred then Matrix M_{zx} and point P_0 are combined to obtain the set of equations A-17.

To convert from the DIS coordinate system back to the CDB coordinate system, the inverse transformation is applied. Knowing that unscaled rotation matrices (the upper 3 x 3 portion of M) have the property that their inverse is their transpose, we obtain the set of equations A-18.

$$P' = MP$$

where

$$M = \begin{Bmatrix} 0 & 1 & 0 & -y_0 \\ 1 & 0 & 0 & -x_0 \\ 0 & 0 & -1 & z_0 \\ 0 & 0 & 0 & 1 \end{Bmatrix}$$

and ...

$$P = \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix}$$

(eq. A-18)

[3] To ensure that the object preserves its shape, size, orientation, and relative geometry.

[4] To ensure that the object preserves its shape, size, orientation, and direction

[5] DIS refers to a 3D model as an entity.

[6] This definition can be found on page 3 of IEEE Std 1278.1-1995. Note that the CDB provides the means to store the DIS origin within the coordinate system space of the model.

Annex A: Revision History

Date	Release	Editor	Primary clauses modified	Description
2016-02-05	1.0	C. Reed	Various	Prepare as version 1.
2016-08-03	1.0	C. Reed	Various	Modify based on 2016-03-08 SWG discussions
2016-06-22	1.0r2	C.Reed	Various	Correct ambiguity WRT how altitude is defined.
2016-07-10	R3	C. Reed	Various	Final edits for publication
2016-11-21	1.0	C. Reed		Ready for publication
2017-12-28	1.1	C. Reed	Minimal	Update for version 1.1. Very minor edits.
2019-12-16	1.2	C. Reed	Various	Changes for version 1.2

Annex B: Bibliography