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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex **(e.g. 3.1)**	Paragraph/ Figure/Table/Note	**Type of comment**	**Commend (justification for change) by the MB**	**Proposed change by the MB**	**Secretariat observations on each comment submitted**
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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DRAFT International Standard

ISO/IEC DIS 18026

Information technology — Spatial Reference Model (SRM)

Technologies de l'information — Modèle de référence spatial (SRM)

ICS: 35.140

ISO/IEC JTC **1**/SC **24**

Secretariat: **BSI**

Voting begins on: **2024-07-08**

Voting terminates on: **2024-09-30**

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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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

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

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

ISO/IEC 18026 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 24, *Computer graphics, image processing and environmental data representation*, in collaboration with The SEDRIS Organization.

This third edition cancels and replaces the second edition (ISO/IEC 18026:2009), of which it constitutes a major revision.

ISO/IEC 18026 Edition 3 introduces new capabilities and extends and improves existing Edition 2 capabilities. The new and/or enhanced technical content includes:

1) Comprehensive and improved treatment of geodesics
2) Similarity transformation templates (STT)
3) Revisions to *Profiles* and *Conformance* clauses, as well as informative Annex I.6 to cover positional error measurement cases
4) Improved accuracy domains in the Default Profile
5) Incorporation of a new clause *Orientation – change of basis and rotation*
6) Revision to *Coordinate Systems*, *Spatial Reference Frames*, and *Operations* clauses
7) Other improvements throughout the standard, including editorial and self-consistency improvements, incorporation of new figures, and correction of defects.

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0 Introduction

0.1 Purpose

Spatial information processing requires a robust capability to describe geometric properties such as position, direction, orientation, and distance. Information is sometimes spatially referenced to local structures (Example: interior walls and doorways within a building) or local regions (Example: streets and buildings within a city), or to the Earth as a whole (Example: global weather). Information is sometimes spatially referenced to other celestial bodies (Examples: astronomical, orbital, and geomagnetic observations). Information is also sometimes spatially referenced to objects defined within contexts such as virtual realities (Example: 3D models). In each of these cases, a spatial reference frame is defined, with respect to which the values of geometric properties can be determined.

It is often necessary to represent a position in several different spatial reference frames, simultaneously, according to the context in which the position is to be used. Each spatial reference frame corresponds to a particular way of expressing position. Spatial reference frames are sometimes specified relative to moving objects (Examples: planets and spacecraft), and therefore provide spatial values that are a function of time. It is necessary to specify the time to which the spatial position refers, and the time for which the spatial reference frame is defined.

This International Standard defines the conceptual model and the methodologies that allow the description, and transformation or conversion, of geometric properties within or among spatial reference frames. The Spatial Reference Model (SRM) supports unambiguous specification of the positions, directions, orientations, distances, and times associated with spatial information. It also defines algorithms for precise transformation of positions, directions, orientations, and distances among different spatial reference frames.

0.2 Design criteria

The concepts in this International Standard were developed to fulfil the following requirements:

a) *Unification*: Define a comprehensive set of general principles and specific concepts that allow spatial information to be shared among different communities.

b) *Unambiguity*: Provide for the unambiguous specification of spatial concepts and the spatial relationships among geometric objects.

c) *Extensibility*: Provide a framework under which future spatial concepts can be accommodated through registration of new concepts.

d) *Completeness*: Specify a broad set of well-defined spatial reference frames, their parameter sets, and spatial operations.

e) *Implementability*: Define an application program interface supporting spatial reference frames and spatial operations.

f) *Mathematical formulation explicitness:* Provide mathematical formulations to support conformance testing.

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Information technology — Spatial Reference Model (SRM)

1 Scope

This International Standard specifies the Spatial Reference Model (SRM) defining relevant aspects of spatial positioning and related information processing. The SRM allows precise and unambiguous specification of geometric properties such as position, direction, orientation, and distance. The SRM addresses the needs of a broad community of users, who have a range of accuracy and performance requirements in computationally intensive applications.

Aspects of this International Standard apply to, but are not limited to:

a) mapping, charting, geodesy, and imagery;

b) topography;

c) location-based services;

d) oceanography;

e) meteorology and climatology;

f) interplanetary and planetary sciences;

g) embedded systems; and

h) modelling and simulation.

The SRM specifies an application program interface (API) that supports the representations, conversion, and transformation of position and orientation information in a variety of forms. To ensure that spatial operations are performed consistently, the application program interface specifies conversion operations between alternative representations of geometric properties.

This International Standard is not intended to replace the standards and specifications developed by ISO/TC 211, ISO/TC 184, the International Astronomical Union (IAU), and the International Association of Geodesy (IAG). It is applicable to applications whose spatial information requirements overlap two or more of the application areas that are the scope of the work of ISO/TC 211, ISO/TC 184, the IAU, and the IAG.

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2 Normative references

The following documents are referred to in the text in such a way that some or all their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE Because citations to International Standards are made by giving the number of the standard followed by the year (if applicable) and any other specific information identifying the portion of the standard cited, identifiers are not needed for this purpose. Therefore, the identifier element is grey when a reference is an International Standard.

Identifier	Reference
	ISO 8601, *Data elements and interchange formats — Information interchange — Representation of dates and times*.
	ISO/IEC 9973, *Information technology — Computer graphics, image processing and environmental data representation — Procedures for registration of items.*
	ISO/IEC/IEEE 60559, *Information technology — Microprocessor Systems — Floating-Point arithmetic*
	ISO 80000-2, *Quantities and units — Part 2: Mathematical signs and symbols to be used in the natural sciences and technology.*
	ISO 80000-3, *Quantities and units — Part 3: Space and time.*
I460	International Telecommunication Union (ITU). *Standard-Frequency and Time-Signal Emissions* [online]. Geneva: ITU, 2002 [cited 25 August 2022]. Available from World Wide Web: <https://www.itu.int/rec/R-REC-TF.460-6-200202-I/en>. ITU document ITU-R TF.460-6:2002.
83502T	US National Geospatial-Intelligence Agency (NGA). *Department of Defense World Geodetic System 1984 - Its Definition and Relationships with Local Geodetic Systems* [online]. Third Ed. Washington: NGA, 2000 [cited 7 May 2023]. Available from World Wide Web: <https://apps.dtic.mil/sti/citations/ADA280358>. Technical report TR 8350.2.
NGA36	US National Geospatial-Intelligence Agency (NGA). *Department of Defense World Geodetic System 1984 - Its Definition and Relationships with Local Geodetic Systems* [online]. Version 1.0.0 [cited 25 August 2022]. Available from World Wide Web: <https://nsgreg.nga.mil/doc>.

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3 Terms, definitions, symbols, and abbreviations

3.1 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org

Terms defined in the body of this International Standard are presented in italics at the point where they are defined. The Index provides a directory of those terms.

3.1.1
Earth gravitational model
spherical harmonic expansion of the gravitational field potential

Note 1 to entry: Gravity includes rotational effects; however, such rotational effects are not included in this model.

3.1.2
ecliptic plane
plane defined by the orbit of a planet at a point in time

3.1.3
equatorial plane
plane through a designated centre of an object and perpendicular to the rotational axis of the object

3.1.4
geodetic datum
datum (or reference frame) describing the relationship of a 2- or 3-dimensional coordinate system to the Earth

Note 1 to entry: ISO 19111:2019 uses the term *geodetic reference frame*.

Note 2 to entry: In most cases, the geodetic datum includes an ellipsoid definition.

[SOURCE: ISO 19111:2019, 3.1.34]

3.1.5
north pole
that pole of rotation that lies on the north side of the invariable plane of the solar system

Note 1 to entry: Some planets have retrograde rotation with respect to this definition.

Note 2 to entry: Map north (see 5.3.7.1) may be unrelated to this direction.

Note 3 to entry: The north side of the invariable plane of the solar system is the side facing in the direction of Polaris.

[SOURCE: RIIC15]

3.1.6
replete set
a connected subset of a Euclidean space with non-empty interior is replete if all of its points belong to either its interior or to the topological closure of its interior

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Note 1 to entry: A replete set is a generalization of an open set that allows the inclusion of boundary points. Boundary points are important in the definitions of certain coordinate systems.

3.1.7
spatial object
physical or virtual object to which spatial information applies

3.1.8
spatial operation
mathematical function that re-expresses coordinates, directions, and/or orientations expressed in one spatial reference frame in terms of a different spatial reference frame; or mathematical function for distance or other geometric quantities within a single spatial reference frame

3.2 Notation, symbols, and abbreviations

In this International Standard, dates that are included in an element of a concept instance specification shall conform to the notation and formats of ISO 8601.

Table 3.1 lists mathematical notation conventions commonly used in this document.

Table 3.1 — Mathematical notation

Style	Use	Examples
lower case, bold, italic	points, vectors	$\boldsymbol{x}, \boldsymbol{p}$
lower case, italic	variables, scalars, scalar-valued functions, axes of a linear coordinate system	a, b, f, x-axis
upper case, bold, italic	vector-valued functions, matrices, orthogonal frames	$\boldsymbol{F}, \boldsymbol{G}, \boldsymbol{M}$
upper case, italic	sets	S, T

Upper case italic letter symbols are also used for scalar-valued functions that are customarily capitalized.

Table 3.2 lists symbols commonly used throughout this document. Additional symbols used only in individual clauses are defined within those individual clauses.

Table 3.2 — Symbols

Symbol	Definition
SRF_S	source spatial reference frame
SRF_T	target spatial reference frame
ORM_S	object reference model of SRF_S
ORM_R	reference ORM for a given spatial object
CS_S	spatial coordinate system of SRF_S
$\mathbf{0}$	origin of an orthonormal frame
a	major semi-axis length of an oblate ellipsoid
b	minor semi-axis length of an oblate ellipsoid
$\boldsymbol{C}_i[\boldsymbol{G}]()$	i^{th} coordinate-component curve at a point

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Symbol	Definition
$\boldsymbol{c}_S$	coordinate of a position in SRFs
$d_E(\ )$	Euclidean distance function
$d_G(\ )$	geodesic distance function
E	computational error
$\boldsymbol{E}$	embedded orthonormal frame
E_S	extended region of SRFs
$\boldsymbol{E}(\ )$	embedding function
$(\boldsymbol{e_1}, \boldsymbol{e_2}, \boldsymbol{e_3})$	set of Cartesian basis vectors of an orthonormal frame
(e_0, e_1, e_2, e_3)	quaternion in 4-tuple form
$(e_0, \boldsymbol{e})$	quaternion in scalar vector form
f	flattening of an oblate ellipsoid
$\boldsymbol{G}$	generating function of a coordinate system
$\boldsymbol{G}_L$	generating function of a localized coordinate system
$\boldsymbol{G}_S$	spatial generating function of CSs
$Dom(\boldsymbol{G}_S)$	domain of the generating function $\boldsymbol{G}_S$
$Rng(\boldsymbol{G}_S)$	range of the generating function $\boldsymbol{G}_S$
$\boldsymbol{H}_{F\leftarrow E}$	similarity transformation from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
h	ellipsoidal height
h_0	ellipsoidal height at the CS origin
h_e	elevation with respect to the geoid
h_o	orthometric height
$\boldsymbol{I}$	identity matrix (or operator)
$\boldsymbol{I}_{F\leftarrow E}$	identity transformation from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
k_0	central scale
k_{scaled}	point scale
k, m, n	number of dimensions, $1 \leq k, m, n \leq 3$
$k(\ )$	point distortion function
$\boldsymbol{L}$	localized orthonormal frame
$\boldsymbol{L}_{3D}$	localization operator (3D)
$\boldsymbol{M}_{F\leftarrow E}$	rotation matrix from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
$\mathcal{M}(\varphi)$	radius of curvature in the meridian at latitude φ
$\mathcal{N}(\varphi)$	radius of curvature in the prime vertical at latitude φ
$\boldsymbol{n}_S$	direction vector in SRFs
(n_1, n_2, n_3, θ)	rotation representation in terms of axis unit vector components and rotation angle
$\boldsymbol{O_E}$	origin of the embedded orthonormal frame $\boldsymbol{E}$

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Symbol	Definition
$\overrightarrow{\boldsymbol{O_E O_F}}$	vector from the origin of frame $\boldsymbol{E}$ to the origin of frame $\boldsymbol{F}$
$\overrightarrow{\boldsymbol{O_E p}}$	vector from the origin of frame $\boldsymbol{E}$ to the position $\boldsymbol{p}$
$\boldsymbol{P}$	generating projection
$\boldsymbol{P}_{\mathrm{S}}$	mapping equations for SRFs
$\boldsymbol{p}, \widetilde{\boldsymbol{p}}$	position vector
$\boldsymbol{p}_{\boldsymbol{E}}$	coordinate of position $\boldsymbol{p}$ expressed in terms of frame $\boldsymbol{E}$
$\left(p_x, p_y, p_z\right)_{\boldsymbol{E}}$	Coordinate-components of position $\boldsymbol{p}$ in terms of frame $\boldsymbol{E}$
$\boldsymbol{Q}$	inverse generating projection
$\boldsymbol{Q}_{\mathrm{S}}$	inverse mapping equations for SRFs
$\boldsymbol{q}, \boldsymbol{r}, \boldsymbol{s}, \boldsymbol{t}$	localization parameters
$\boldsymbol{R}$	rotation operator
$\mathbb{R}^{\boldsymbol{m}}$	vector space of m-tuples
$\boldsymbol{R}_{\boldsymbol{n}}\langle\theta\rangle$	rotation through angle θ about the axis $\boldsymbol{n}$
$[\boldsymbol{R}_{\boldsymbol{n}}\langle\theta\rangle]$	matrix representation of rotation operator $\boldsymbol{R}_{\boldsymbol{n}}\langle\theta\rangle$
$\boldsymbol{R}_{\boldsymbol{n},\boldsymbol{t}}\langle\theta\rangle$	non-origin-fixed rotation through angle θ about the directed axis $\{\boldsymbol{t} + \alpha\boldsymbol{n} \mid \alpha \in \mathbb{R}\}$ passing through the position vector $\boldsymbol{t}$ and parallel to the unit vector $\boldsymbol{n}$
$\boldsymbol{R}_{\boldsymbol{E}\rightarrow\boldsymbol{F}}$	orientation of frame $\boldsymbol{F}$ with respect to frame $\boldsymbol{E}$
$\boldsymbol{S}_i[\boldsymbol{G}]( )$	i$^{\text{th}}$ coordinate-component surface at a point
$\boldsymbol{\mathcal{S}}(\varphi)$	meridional distance from latitude φ to the equator
u_{F}	false easting
$[u, v]^{\mathsf{T}}$	2D position vector components
$[u, v, w]^{\mathsf{T}}$	3D position vector components
V_{S}	applicable region of SRFs
v_{F}	false northing
$\boldsymbol{v}_{\mathrm{S}}$	vector quantity in SRFs
$v( )$	vertical offset at a position
$\boldsymbol{W}$	world 3x3 transformation matrix
$[x, y]^{\mathsf{T}}$	2D position vector components
(x, y, z)	Cartesian coordinate tuple
$[x, y, z]^{\mathsf{T}}$	3D position vector components
$[x, y, z]^{\mathsf{T}}_{\boldsymbol{E}}$	3D position vector components with respect to the basis of frame $\boldsymbol{E}$
$\boldsymbol{x}$-$\boldsymbol{y}$-$\boldsymbol{z}$	Euler angle convention for sequence of body-fixed principal axis rotations
α	geodetic azimuth
α_0	geodetic azimuth of the secondary axis relative to local north
(α, ρ)	azimuthal coordinate tuple

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Symbol	Definition
(α, ρ, h)	azimuthal cylindrical coordinate tuple
(α, ρ, θ)	azimuthal spherical coordinate tuple
γ	convergence of the meridian
Δs	scale difference from unity
$[\Delta x, \Delta y, \Delta z]^{\mathsf{T}}$	origin displacement vector components
$\vec{\Delta}_{F \leftarrow E}$	origin displacement vector from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
ε	(first) eccentricity of an oblate ellipsoid
ε'	second eccentricity of an oblate ellipsoid
ε_{D}	directional error bound
ε_{P}	positional error bound
ε_{R}	ratio error bound
θ	spherical latitude, depression/elevation, cylindrical, polar, or rotation angle
$\Lambda_C(\lambda, \lambda_C)$	longitudinal centring function
λ	geodetic or planetodetic longitude
$\lambda_{\mathrm{origin}}$	origin longitude
(λ, φ)	surface geodetic coordinate tuple
(λ, θ, ρ)	equatorial spherical coordinate tuple
(λ, φ, h)	geodetic coordinate tuple
ρ	radius or range
(ρ, θ)	polar coordinate tuple
(ρ, θ, h)	cylindrical coordinate tuple
φ	geodetic latitude
$\varphi_{\mathrm{origin}}$	origin latitude
(φ, λ)	surface planetodetic coordinate tuple
(φ, λ, h)	planetodetic coordinate tuple
σ	scale factor, map scale
$\sigma_{F \leftarrow E}$	scale factor from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
ω_i	i$^{\mathrm{th}}$ principal axis angle of rotation
$\boldsymbol{\Omega}_{F \leftarrow E}$	change of basis operator from frame $\boldsymbol{E}$ to frame $\boldsymbol{F}$
$[\boldsymbol{\Omega}_{\boldsymbol{E} \leftarrow \boldsymbol{F}}]$	matrix representation of change of basis operator $\boldsymbol{\Omega}_{F \leftarrow E}$

A shortened form of a word or phrase is commonly referred to as an abbreviation, an acronym, or an initialism. In this International Standard, all of these are collectively termed abbreviations. Table 3.3 lists the abbreviations used in this document, with two exceptions. Abbreviations used in the API (Clause 11) in the formation of enumerant and record data type element names are listed in Table 11.1. Abbreviations used in the construction of labels (see 13.2.2) are listed in Table F.1.

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In the specification of an abbreviation, the letters in the word or phrase used to form the abbreviation are underlined.

Table 3.3 — Abbreviations

Abbreviation	Word or phrase
1D	one-Dimensional
2D	two-Dimensional
3D	three-Dimensional
AFWA	Air Force Weather Agency
API	Application Program Interface
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
CAD/CAM	Computer-Aided Design/Computer-Aided Manufacturing
CFR	Coordinate Frame Rotation
CH1903	CH 1903 ("CH" is the ISO 3166-1 country code for Switzerland)
CS	Coordinate System
COAMPS	Coupled Ocean/Atmospheric Mesoscale Prediction System
COM	Convergence of the Meridian
D73	Datum 1973
DHDN	Deutschen Hauptdreiecksnetzes
DOS	Directorate of Overseas Surveys
DRAM	Dynamic Random Access Memory
DSS	Designated Spatial Surface
E	East
ENU	East-North-Up
ERM	Earth Reference Model
ESA	European Space Agency
ETRF	European Terrestrial Reference Frame
ETRS89	European Terrestrial Reference System 1989
FRG	Federal Republic of Germany
GCS	Global Coordinate System
GDA	Geocentric Datum of Australia
GGRS	Greek Geodetic Reference System
GPS	Global Positioning System
GRS	Geodetic Reference System
GTRS	Geo Tile Reference System
IAG	International Association of Geodesy

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Abbreviation	Word or phrase
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IERS	International Earth Rotation and Reference Systems Service
IGLD	International Great Lakes Datum
IGN	Institut Géographique National (France)
IGRF	International Geomagnetic Reference Field
ISO	International Organization for Standardization
JTC	Joint Technical Committee
KKJ	Kartastokoordinaattijarjestelma
MGI	Militärgeographisches Institut
MM5	Mesoscale (weather) Model 5
MODTRAN	Moderate resolution Transmittance (atmospheric radiation transfer)
MP	Map Projection
MSL	Mean Sea Level
N	North
NASA	National Aeronautics and Space Administration
NAVD	North American Vertical Datum
NED	North-East-Down
NGO	Norges Geografiske Oppmåling
NOGAPS	Navy Operational Global Atmospheric Prediction System (United States)
NT	unknown
NTF	Nouvelle Triangulation Français (France)
OBRS	Object Binding Rule Set
ORM	Object Reference Model
ORMT	Object Reference Model Template
OSGM	Ordinance Survey Geoid Model
PVR	Position Vector Rotation
RD	Reference Datum
RT	Reference Transformation
RT90	Rikets Triangelnät 1990
S	South
S-JTSK	System - Jednotné Trigonometrické Síti Katastrální (Czechoslovakia)
SI	Système International d'unités (International System of Units)
SIRGAS	Sistema de Referencia Geocéntrico para las Américas (The Americas)
SO(3)	Special Orthogonal Group of degree 3

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Abbreviation	Word or phrase
SRF	Spatial Reference Frame
SRFT	Spatial Reference Frame Template
SRM	Spatial Reference Model
SSM	SRF Set Member
STT	Similarity Transformation Template
TAI	Temps Atomique International (International Atomic Time)
UK	United Kingdom
UPS	Universal Polar Stereographic
US	United States
USGS	United States Geological Survey
UT0	Universal Time observed
UT1	Universal Time polar motion corrected
UT2	Universal Time Earth rotation corrected
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
VOS	Vertical Offset Surface
W	West
WGS	World Geodetic System
WMM	World Magnetic Model

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4 Concepts

4.1 Overview

The SRM provides an integrated framework and precise terminology for describing spatial concepts and operations on spatial information. The SRM includes the following features:

a) precise and uniform definitions of commonly used spatial coordinate systems, including those based on map projections,

b) spatial referencing of positions, directions, vector quantities, and orientations for physical and abstract objects,

c) spatial operations and transformations on positions, directions, vector quantities, and orientations, including coordinate conversions and transformations, and calculations of distances and other geometric quantities,

d) an application program interface for performing the defined spatial operations,

e) codes and labels to support the encoding and exchange of spatial data,

f) an extensible framework that supports the registration of additional instances of SRM concepts, and

g) profiles to allow subsets of the SRM to be defined to conform to the specific requirements of an application or an application domain.

This International Standard is based on the following set of foundational and unifying core concepts, which are addressed in greater detail in the remainder of this clause and subsequent clauses:

a) Spatial points are identified by coordinates in a *spatial reference frame* associated with a spatial object of interest, such as the Earth or an engineering model. An *object-space* is the collection of points associated with a spatial object of interest (see 4.2.3).

b) *Position-space* is the Euclidean vector space of dimension $n = 1, 2$ or 3 that serves as a mathematical abstraction of object-space of matching dimension. In both position-space and object-spaces, *orthonormal frames* are defined by the selection of an origin point and a set of mutually perpendicular basis vectors. A *normal embedding* is a length-preserving function that maps positions in position-space to points in an object-space of the same dimension. There are infinitely many possible normal embeddings of an n-dimensional position-space for a given object-space (see 4.2.2).

c) An *abstract coordinate system* assigns a unique coordinate n-tuple defined in a *coordinate-space* to each point in a subset of position-space of dimension n or greater. An abstract coordinate system has a *generating function* that assigns a coordinate in coordinate-space to a corresponding point in position-space (see 4.3.1).

d) A *spatial coordinate system* assigns a unique coordinate in coordinate-space to each point in a region of object-space. A spatial coordinate system assigns a coordinate in coordinate-space to a unique point in object-space using a spatial generating function that is the functional composition of an abstract coordinate system generating function with a normal embedding. Different normal embeddings produce different spatial coordinate systems (see 4.3.2).

e) A *temporal coordinate system* is a Euclidean 1D coordinate system that assigns a one-to-one relationship between temporal coordinate values and instants in time. Temporal coordinate systems are used when spatial coordinate values are time-dependent to associate unique instants in time with events or references (see 4.3.3).

f) *Orientation* is the rotational relationship between a rigid object of interest and a reference. Orientation is specified in terms of the angular displacement, or attitude, of the object's orthonormal frame with respect to an orthonormal reference frame (see 4.4).

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g) A *reference datum* is a geometric primitive, such as a point, directed curve, or oriented surface in position-space, whose determining characteristics are bound to a measured or conceptual geometric aspect of a spatial object in an object-space (see 4.5).

h) An *object reference model* is a set of bound reference datums that implicitly defines a unique normal embedding of position-space into object-space. An object reference model is a generalised abstraction of the geodesy notion of a datum (see 4.6).

i) A *spatial reference frame* is a means of specifying a spatial coordinate system for an object-space. A spatial reference frame specification includes (1) an object reference model, (2) a compatible abstract coordinate system, and (3) the binding of object reference model parameters to corresponding abstract coordinate system parameters (if any). The normal embedding implicitly defined by the object reference model is then functionally composed with the abstract coordinate system to produce a spatial coordinate system for the object-space (see 4.7).

j) *Vertical offset surfaces* are introduced to define heights with respect to equipotential or other complex surfaces (see 4.8).

The relationships among some of these concepts are depicted in Figure 4.1. In this figure, spherical coordinate tuples are defined in a coordinate-space. An abstract spherical coordinate system is then defined by its generating function, which uniquely assigns spherical coordinate tuples to each point in 3D position-space, based on its canonical orthonormal frame. A normal embedding implicitly defined by an object reference model of the Earth is used to map the position-space orthonormal frame to a corresponding orthonormal frame embedded in the Earth's object-space. A spatial coordinate system based on this embedded frame allows points in the Earth's object-space to be located, and various spatial operations to be performed.

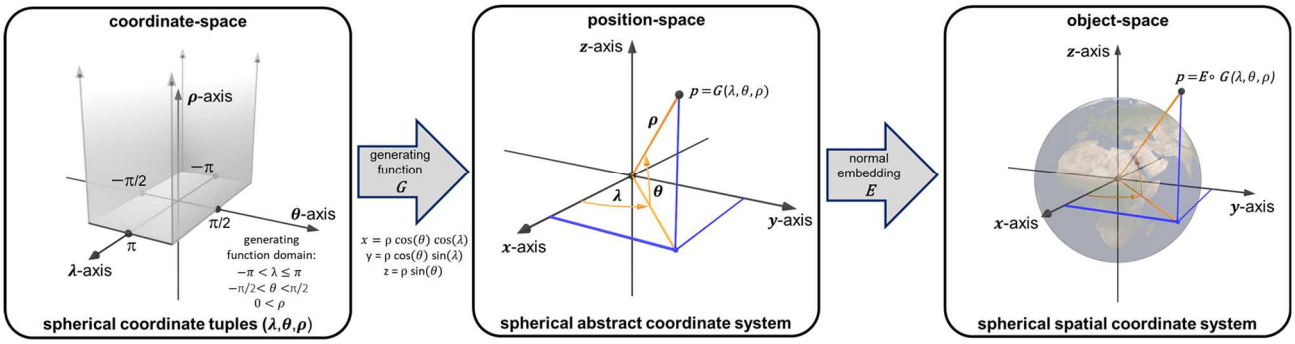


Figure 4.1 — Coordinate-space, position-space, and object-space relationships

The concepts introduced in this subclause are discussed in greater detail in the remainder of this clause. This International Standard takes a functional approach to the definition of these concepts. Basic geometric concepts, including the concepts of point, line, and plane, are assumed. Annex A provides a concise summary of mathematical concepts, including specialized concepts, and notational conventions used in this International Standard.

In this International Standard, the unit of length is the metre and the unit of angular measure is the radian (see ISO 80000-3) unless explicitly identified otherwise. Some angular values are specified in the units of either arc degree or arc second, to support common usage or to prevent loss of precision in data specification.

An application or an exchange format using the data storage structures specified in this International Standard (see 11.5) may use equivalent units of measure, provided those units are identified. For a unit not defined in ISO 80000-3, the conversion factor to metre or radian, as appropriate, shall be explicitly stated. One suitable mechanism for accomplishing the identification of a unit is to use unit and unit scale identifiers as specified in Clause 7 of ISO/IEC 18025.

When interfacing with the methods and/or functions of the SRM (see 4.10), applications shall use the units of metre and radian, as appropriate. All length and angular data shall be converted to the units of metre or radian, as appropriate, before the data is provided as input to an SRM method or function.

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When measures of computational accuracy are being determined, such measurements shall be expressed in the units of metre and radian, where applicable.

4.2 Coordinate-space, position-space, and object-space

4.2.1 Coordinate-space

A *coordinate* is an ordered n-tuple $(1 \leq n \leq 3)$. A *coordinate-component* is an individual component of a coordinate n-tuple. A *coordinate-space* specifies a set of coordinate n-tuples that forms a Euclidean vector space (see A.2). The domain of a coordinate system is a replete subset of coordinate space. Such coordinate n-tuples include, but are not restricted to, Cartesian (x, y, z), polar (ρ, θ), cylindrical (ρ, θ, h), and geodetic (λ, φ, h).

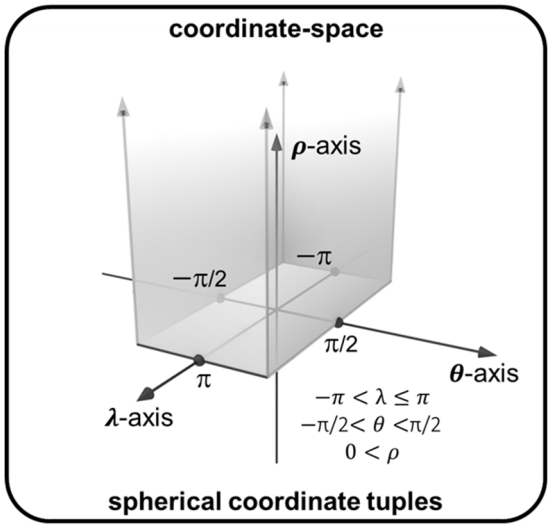


Figure 4.2 — A coordinate-space (for spherical coordinates)

Figure 4.2 illustrates the structure of a coordinate-space for 3D spherical coordinate tuples of the form (λ, θ, ρ). The coordinate-components of these tuples are:

λ: longitude in radians, such that $-\pi < \lambda \leq \pi$,
θ: spherical latitude in radians, such that $-{}^{\pi}/_{2} < \theta < {}^{\pi}/_{2}$, and
ρ: radius in metres, such that $0 < \rho$.

Coordinate-space is further defined in 5.2.1.

4.2.2 Position-space and orthonormal frames

Position-space of dimension m, $(1 \leq n \leq m \leq 3)$, is the Cartesian vector space $\mathbb{R}^m$ (see A.2), which serves as a mathematical abstraction of an object-space. Position-space allows abstract coordinate systems to be applied to object-spaces for many different types of spatial objects of interest.

An ordered set of m mutually perpendicular unit position vectors forms a canonical Cartesian basis for position-space, which allows positions, directions, vector quantities, and distance measurements in position-space to be quantified.

The origin and Cartesian basis vectors together define an *orthonormal frame*. Every point in position-space is uniquely represented by a linear combination of the orthonormal frame's basis vectors represented by a corresponding n-tuple of scalars in the basis order. An orthonormal frame is *right-handed* if the vertices of the triangle formed by its basis unit vectors are in clockwise order when viewed from the origin, as defined in ISO 80000-2.

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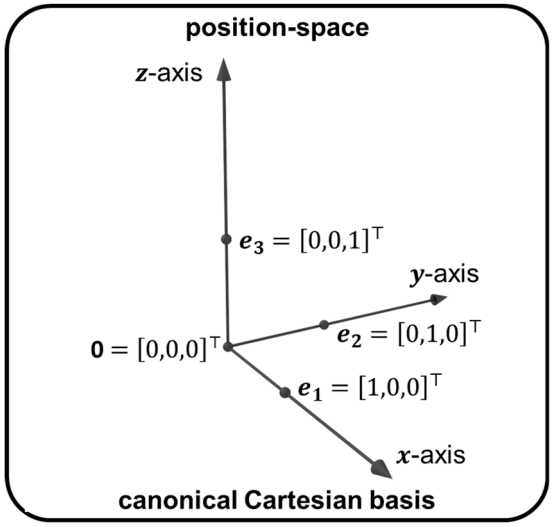


Figure 4.3 — 3D position-space and its canonical Cartesian basis

Figure 4.3 illustrates 3D position-space, showing its origin, and the unit vectors that form its canonical Cartesian basis.

Orthonormal frames and position-space are further defined in 5.2.2 and 5.2.3, respectively.

The *position* of a point is the directional displacement of that point with respect to a designated point, called the origin. The position of a point is represented in terms of a position vector. The position of an object is typically expressed in terms of the position of a representative point within the object.

A *direction* is represented by a unit vector with respect to an orthonormal frame. *Vector quantities*, such as velocity and acceleration, combine a direction vector with a magnitude.

4.2.3 Object-space and normal embeddings

An *object-space* is the collection of points that is fixed to a designated spatial object of interest. Object-space provides the application domain context for spatial concepts including positions, directions, vector quantities, and orientations.

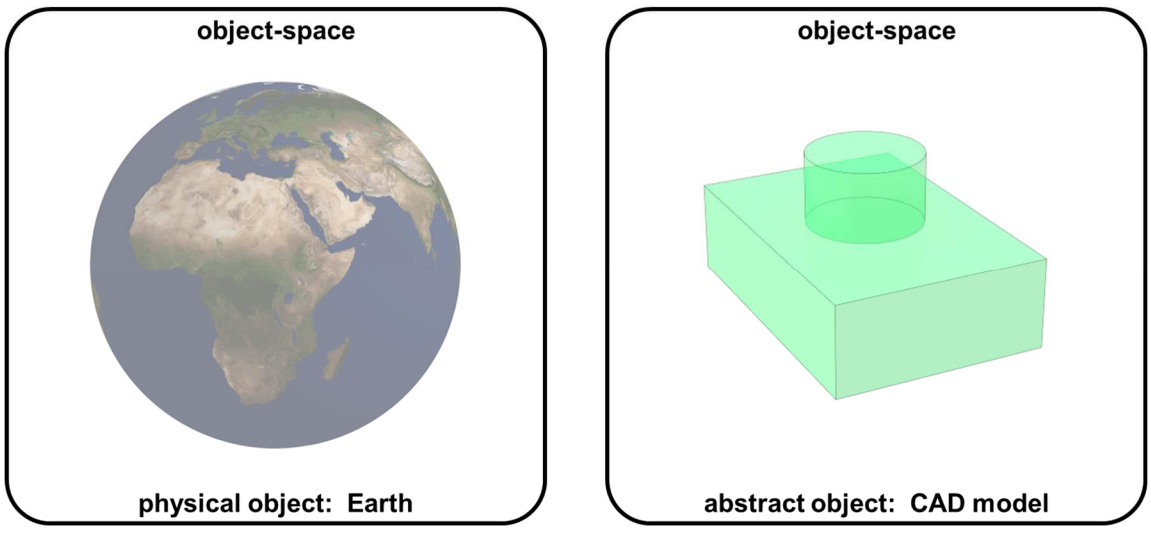


Figure 4.4 — Object-spaces for the Earth and for a CAD model

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The spatial objects of interest in this International Standard include physical and abstract objects. *Physical objects* are real-world objects, such as Earth or a building. *Abstract objects* are conceptual objects including engineering, mathematical, and virtual models. Figure 4.4 illustrates two object-spaces: one for a physical object (i.e., the Earth), and one for an abstract object (i.e., a CAD model).

A *normal embedding* is a distance-preserving function mapping vectors in position-space to points in an object-space of the same dimension. Position-space together with a normal embedding provides a specific algebraic model of an object-space by determining an orthonormal frame embedded in the object space. There are infinitely many normal embeddings of an n-dimensional position-space for a given object-space, depending on the placement of the origin and direction of the axes. The method of specifying a normal embedding varies across disciplines and application domains. This International Standard encapsulates these methods within the concepts of reference datum (see 4.5) and object reference model (see 4.6).

Object-space and normal embeddings are further defined in 5.2.4 and 5.2.5, respectively.

4.3 Coordinate systems

4.3.1 Abstract coordinate systems

An *abstract coordinate system* assigns a unique coordinate n-tuple to each point in a subset of m-dimensional position-space $(1 \leq n \leq m \leq 3)$. An abstract coordinate system is comprised of a domain, a range, and a generating function. The *generating function* is a *smooth*, one-to-one function from the domain in n-dimensional coordinate-space onto the range that is a set of positions in m-dimensional position-space. The generating function may be parameterized by coordinate system parameters. The domain can be a proper subset of coordinate-space.

Figure 4.5 illustrates these components for the Equatorial Spherical abstract coordinate system.

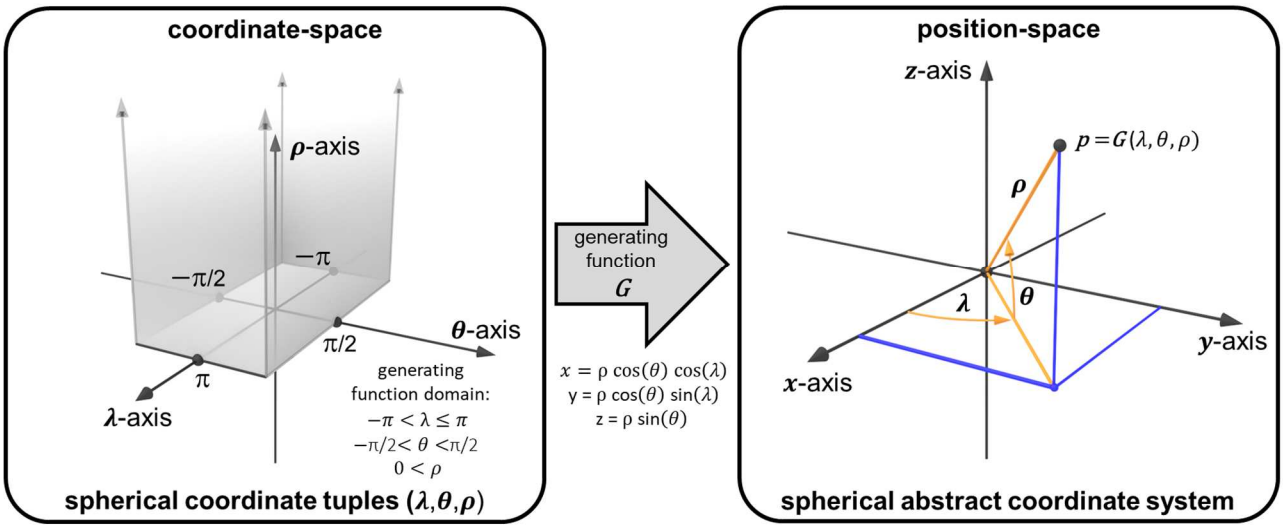


Figure 4.5 — Abstract equatorial spherical coordinate system example

In this International Standard, the term “coordinate system”, if not otherwise qualified, means “abstract coordinate system.”

A coordinate system is *linear* if its generating function is an *affine* function. Otherwise, it is curvilinear. The Geodetic 3D coordinate system and all map projection coordinate systems are curvilinear. A linear coordinate system is orthogonal if its axes are pairwise perpendicular. A Cartesian coordinate system is a linear coordinate system that is also orthogonal. A three-dimensional coordinate system is *right-handed* if the vertices of the triangle formed by its basis unit vectors are in clockwise order when viewed from the origin, as defined in ISO 80000-2.

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The coordinate-space and position-space dimensions characterize a *coordinate system type* as in Table 4.1.

Table 4.1 — Coordinate system types

Coordinate system type	Dimension of coordinate-space	Dimension of position-space
3D	3	3
surface	2	3
curve	1	3
2D	2	2
plane curve	1	2
1D	1	1

Many applications need to perform operations involving multiple related coordinate systems. The relationships between coordinate systems used in an application often reflect corresponding relationships among the objects of interest within the application context. Such abstract coordinate system relationships are the foundation for corresponding spatial coordinate system and spatial reference frame relationships in object-space. This International Standard provides a set of parameterized localization operators for defining local coordinate systems relative to base coordinate systems and specifies several standard localized coordinate systems.

It is also useful in some applications to reduce the dimensionality of a coordinate system by fixing the values of one or more of its coordinate-components. The resulting *coordinate-component surfaces* and *curves* are particularly useful when dealing with curvilinear coordinate systems. Thus, fixing the ellipsoidal height coordinate-component (h) of a 3D geodetic coordinate system to zero results in an induced surface geodetic coordinate system that represents positions on the surface of the ellipsoid modelling the Earth. This International Standard provides functions for creating coordinate-component surfaces and curves and specifies several standard induced surface coordinate systems.

The two coordinate-component curves at a point on a curvilinear surface, such as an ellipsoid-based model of the Earth, can be used to define a plane that is tangent to the curves at the point. This tangent plane can be used to define a localized 2D or 3D coordinate system. These *localized coordinate systems* are used in modelling the position and orientation of objects, such as vehicles and sensors, located on or near the Earth or other celestial bodies. Such localized coordinate systems also provide Euclidean vector spaces for denoting directions in curvilinear coordinate systems.

Maps are traditionally created by functionally projecting a region of the surface of an oblate ellipsoid (or sphere) onto a flat 2D surface for presentation and other user purposes. These and similar functions are termed *mapping equations* and are defined in terms of surface geodetic coordinates on the ellipsoid. When inverse mapping equations are composed with the generating function of the surface geodetic coordinate system, the resulting function is the generating function for a surface coordinate system. In this way, coordinate systems based on traditional map projections may be treated as a special case of abstract coordinate systems of coordinate system type surface. This special case is termed a *map projection coordinate system*.

NOTE In other contexts, map projection coordinate systems are sometimes described as rectilinear or Cartesian because of the vector space structure of coordinate-space. That description does not imply that a map projection coordinate system is a linear coordinate system. Map projection coordinate systems are not linear because the associated generating functions are not affine. With respect to a linear coordinate system for the same position-space, map projection coordinate systems exhibit various types of distortion (see 5.3.7.3). In applications the effect of distortion is often mitigated by restricting the coordinate system domain of the map projection to a smaller sub-set.

Abstract coordinate systems are addressed in greater detail in 5.3. This International Standard specifies a standardized set of abstract coordinate systems (see 5.3.8).

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4.3.2 Spatial coordinate systems

A *spatial coordinate system* assigns a unique coordinate to each point in a region of object-space. Abstract coordinate systems are defined (see 4.3.1) for position-space. Position-space can serve as a model of an object-space by specifying a normal embedding that maps the position-space orthonormal frame to a corresponding orthonormal frame embedded in object-space. Using this concept, a spatial coordinate system is defined as the functional composition of an abstract coordinate system generating function and a normal embedding. The abstract coordinate system generating function $\boldsymbol{G}$ associates coordinates in coordinate-space to positions in position-space. A normal embedding $\boldsymbol{E}$ maps those positions in position-space to points in object-space. Different normal embeddings produce different spatial coordinate systems. If $\boldsymbol{c}$ is a coordinate for the coordinate system, then $\boldsymbol{c}$ identifies the object-space point $\boldsymbol{p} = \boldsymbol{E} \circ \boldsymbol{G}(\boldsymbol{c})$.

Figure 4.6 illustrates a spatial surface coordinate system bound with a normal embedding of 3D position-space to the 3D object-space. In this illustration, a surface coordinate (u, v) in coordinate-space is associated to a position vector (x, y, z) in position-space. That position then identifies a location in the space of an object via the normal embedding of position-space. In this example, the normal embedding is determined by the selection of an origin and three unit points.

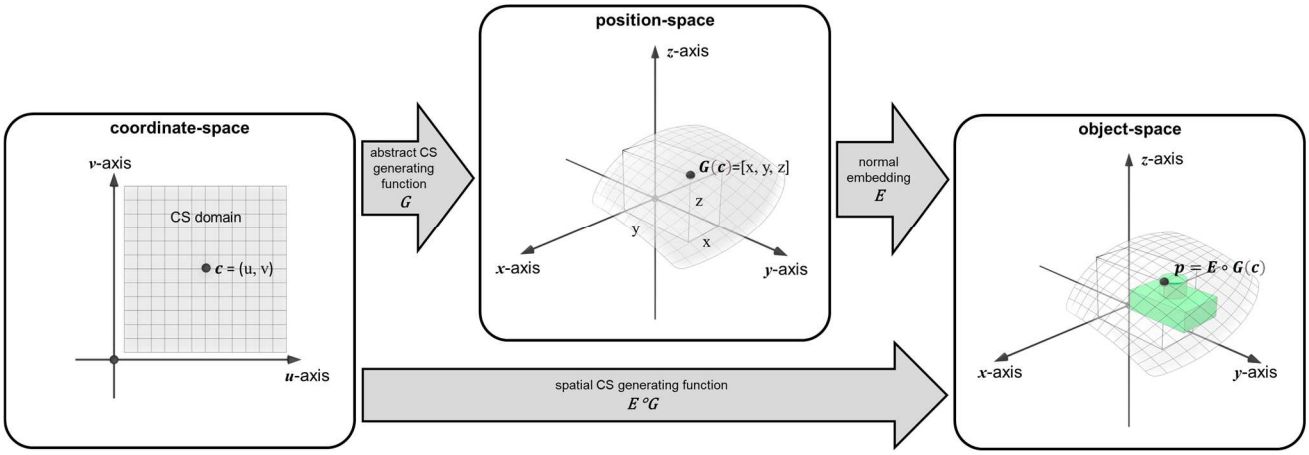


Figure 4.6 — A normal embedding of an abstract coordinate system

In applications where a one spatial coordinate system is defined in terms of another spatial coordinate system, the relationships between them build upon the corresponding relationships between their respective abstract coordinate systems (see 4.3.1).

The details of spatial coordinate systems are addressed in 5.4.

4.3.3 Temporal coordinate systems

A *temporal coordinate system* is a realization of an abstract Euclidean 1D coordinate system that assigns a one-to-one monotonically increasing relationship between temporal coordinate values and instants in time, such that larger coordinate values are assigned to later instants in time. A temporal coordinate system is used to associate a unique instant in time with an event or reference.

There is a requirement to identify time as well as position in environmental representation. Time and position are often used together by an application to describe when a given condition exists or when an object was present at a given location. Furthermore, in dynamic physical systems, the normal embedding that maps position-space to an object-space may change over time. As a result, the relationship between coordinates and positions is time-dependent. In such systems, time and time differences must be considered in order to accurately determine positions and position differences.

This International Standard uses the concept of time in several ways. An object reference model (see 4.6) has either a static or dynamic binding to a spatial object. In the latter case, time is a parameter of the reference

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transformation that specifies the binding (see 7.5). Spatial reference frames (see 4.7) that are based on dynamic object reference models also depend on a time parameter. However, these dynamic cases reduce to the corresponding static cases by fixing a value for the time parameter.

Time is also a factor for static object reference model bindings that are based on physical measurements of objects or systems that change with time. Time is used to identify the epoch for which these measurements are applicable.

The details of temporal coordinate systems are specified in 5.5.

4.4 Orientation

The *orientation* of a rigid object describes its angular displacement, or attitude, with respect to a reference. When the object is represented by an orthonormal frame attached to the object, the orientation of the object is represented by the angular displacement of the object's frame with respect to a reference frame. Orientation can be specified in terms of either: 1) a change of basis operation that would convert a coordinate from the object's frame to the reference frame (see 6.2), or 2) a rotation operation that would move the object's frame away from alignment with the reference frame (see 6.4).

Several representations of orientation and rotations are in wide use in different application domains. Consistent definitions of orientations and rotations are required to support interoperability of systems and applications. This International Standard supports several common representations of orientations and rotations (see 6.6), as well as inter-conversion operations between these representations (see 6.7). The supported representations defined include:

a) 3x3 matrix,

b) axis-angle,

c) Euler angles, including proper Euler angles and Tait-Bryan angles, and

d) quaternions.

4.5 Reference datums

A *reference datum* is a geometric primitive in position-space. In 2D position-space, reference datums are points or directed curves. In 3D position-space, reference datums are points, directed curves, or oriented surfaces. Oblate ellipsoid surfaces are commonly used to model the Earth and other celestial bodies.

EXAMPLE 1 An ellipsoid reference datum with major semi-axis a and minor semi-axis b is the surface implicitly defined by:

$$f(x,y,z) = \frac{x^2}{a^2} + \frac{y^2}{a^2} + \frac{z^2}{b^2} - 1 = 0$$

and is illustrated in Figure 4.7. The WGS_1984 ellipsoid reference datum has major semi-axis $a = 6\,378\,137$ metres and flattening $f = 1/298{,}257\,223\,563$, resulting in a minor semi-axis $b = a - af = 6\,356\,752$ metres.

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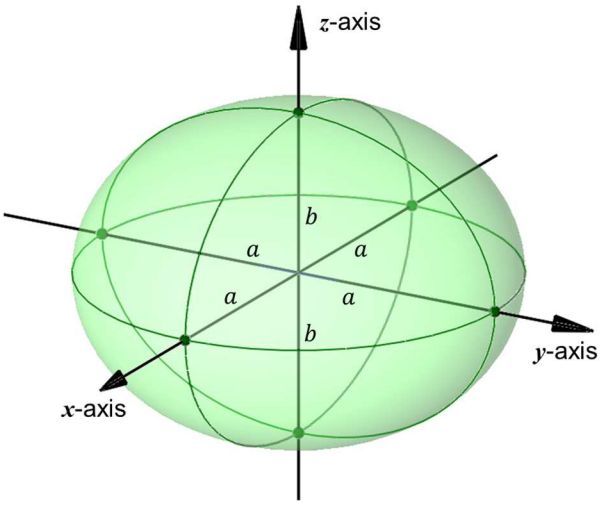


Figure 4.7 — An ellipsoid reference datum

A reference datum is *bound* when the reference datum in position-space is identified with a corresponding constructed entity (i.e., a measured or conceptual geometric aspect of a spatial object) in object-space. The term “corresponding” in this context means that each position-space reference datum is bound to a constructed entity of the same geometric primitive type. That is, position-space points are bound to object-space points, position-space curves to object-space curves, and position-space surfaces to object-space surfaces.

Figure 4.8 illustrates two distinct bindings of a point reference datum. On the upper right, the point reference datum is bound to a specific point in the object-space of a CAD/CAM model. On the lower right, the point reference datum is bound to a corresponding point in the object-space of a physical object that has been manufactured in accordance with that CAD/CAM model. Similarly, the yz-plane reference datum is bound to corresponding planes in the two object-spaces.

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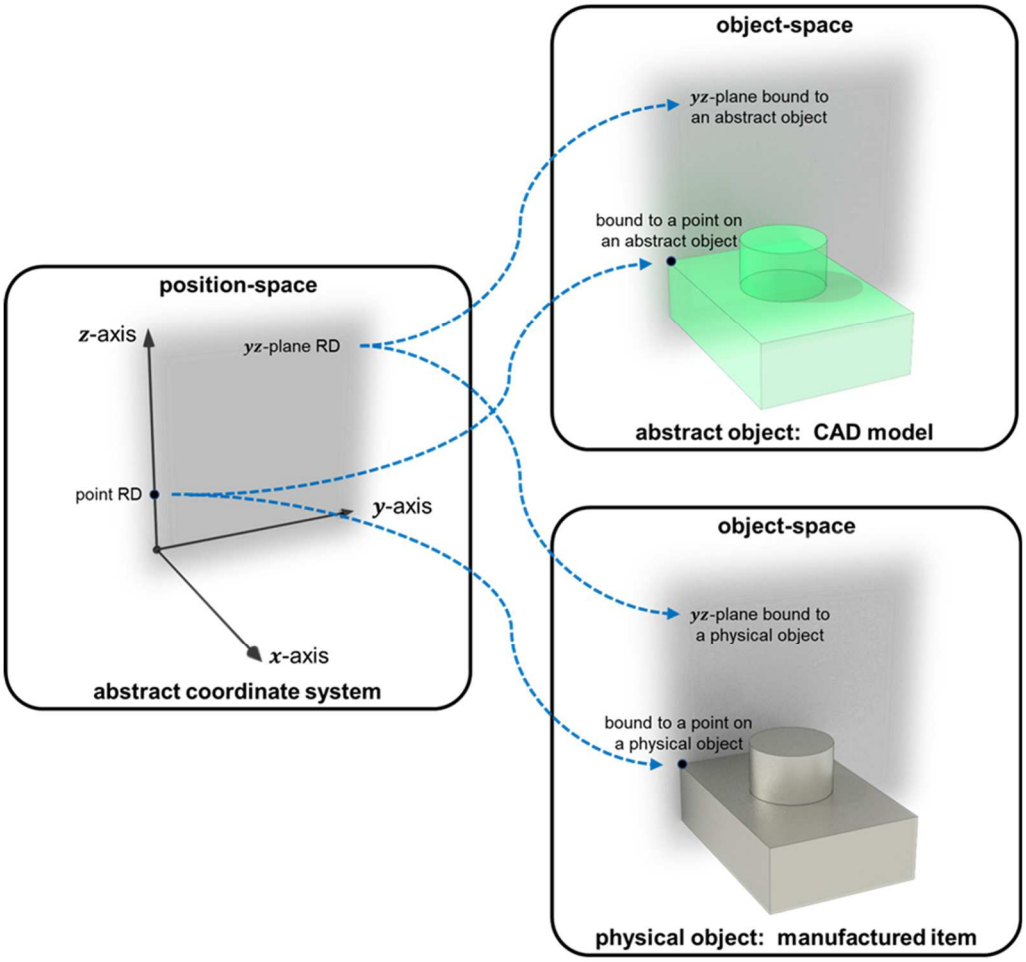


Figure 4.8 — Reference datums bound to abstract and physical objects

In some application domains, bound reference datums are used to model a significant aspect of the problem domain. In geodesy, oblate ellipsoids are used to model the figure of the Earth or a subset thereof.

EXAMPLE 2 Semi-axis values a and b, $a \geq b$, are selected to specify an oblate ellipsoid reference datum. The following steps (see Figure 4.9) illustrate one way to bind an ellipsoid reference datum specified by semi-axis values a and b to a conceptual ellipsoid that represents the figure of the Earth in a region as approximated by a geodetic survey control network:

a) A point on the surface of the reference datum is specified. This point has a computable geodetic latitude φ.

b) The specified position-space point is identified with a specific point in object-space.

c) The direction of the oblate ellipsoid rotational axis is constructed in object-space.

d) The direction of the outward surface normal at the point is constructed in object-space so that the angle it makes with respect to the oblate ellipsoid rotational axis direction is $(\pi/2 - \varphi)$.

This binding requires the specification of a point and two directions in object-space.

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