4 Concepts

4.1 Introduction

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).

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.

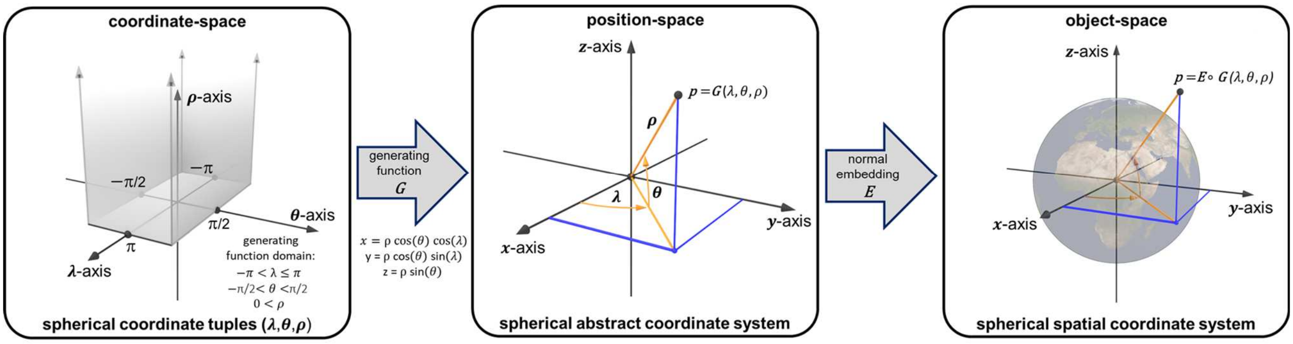

Figure 4.1 — Coordinate-space, position-space, and object-space relationships

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.

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).

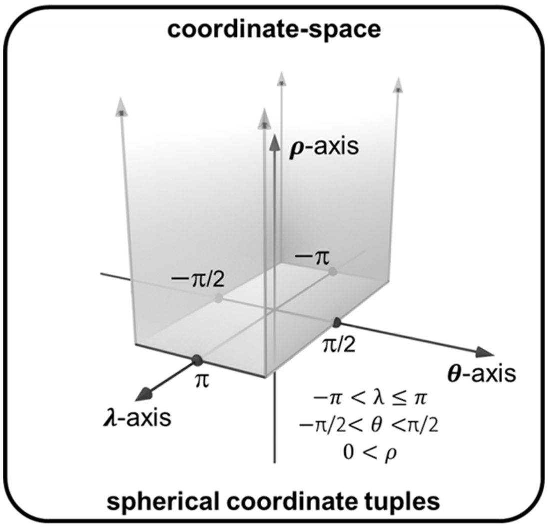

Figure 4.2 — A coordinate-space (for spherical coordinates)

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.

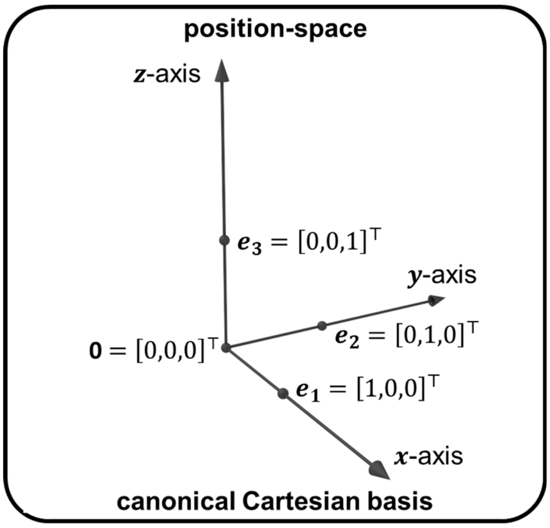

Figure 4.3 — 3D position-space and its canonical Cartesian basis

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

Position-space and orthonormal frames 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.

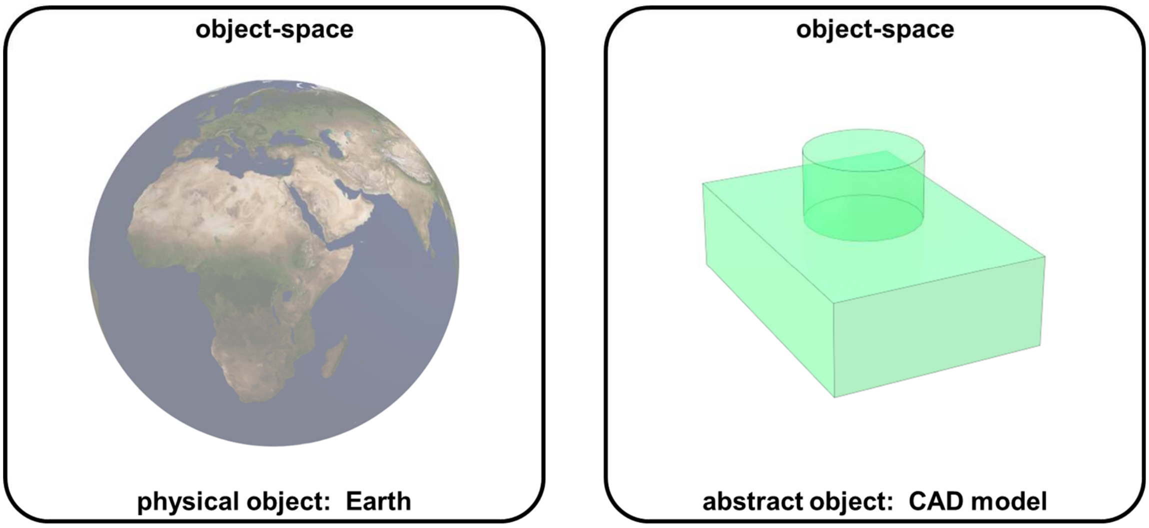

Figure 4.4 — Object-spaces for the Earth and for a CAD model

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.

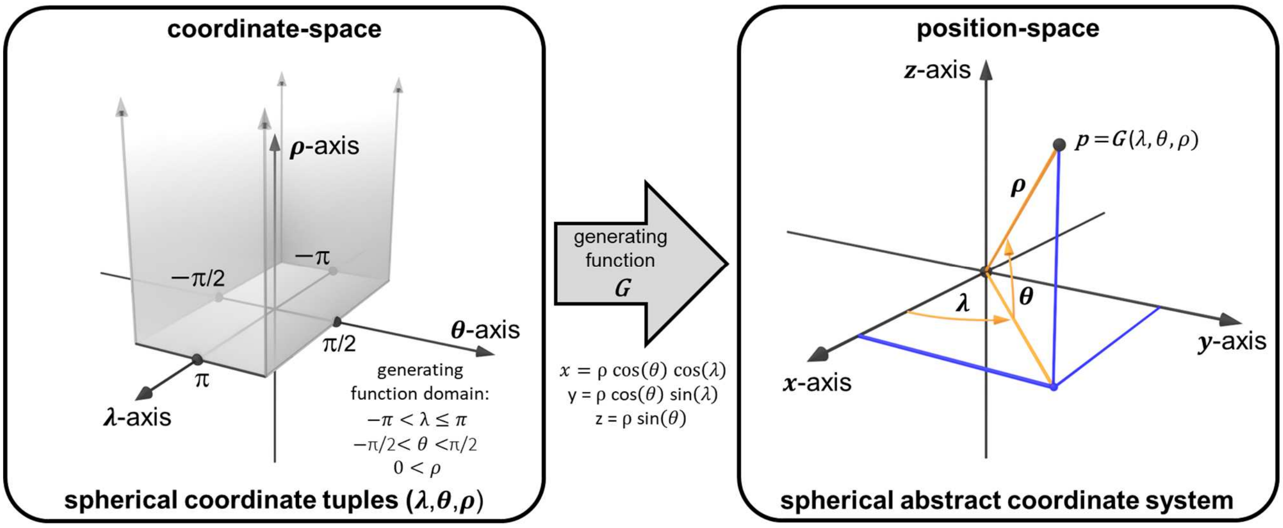

Figure 4.5 — Abstract equatorial spherical coordinate system example

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 right angles. 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.

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).

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. 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.

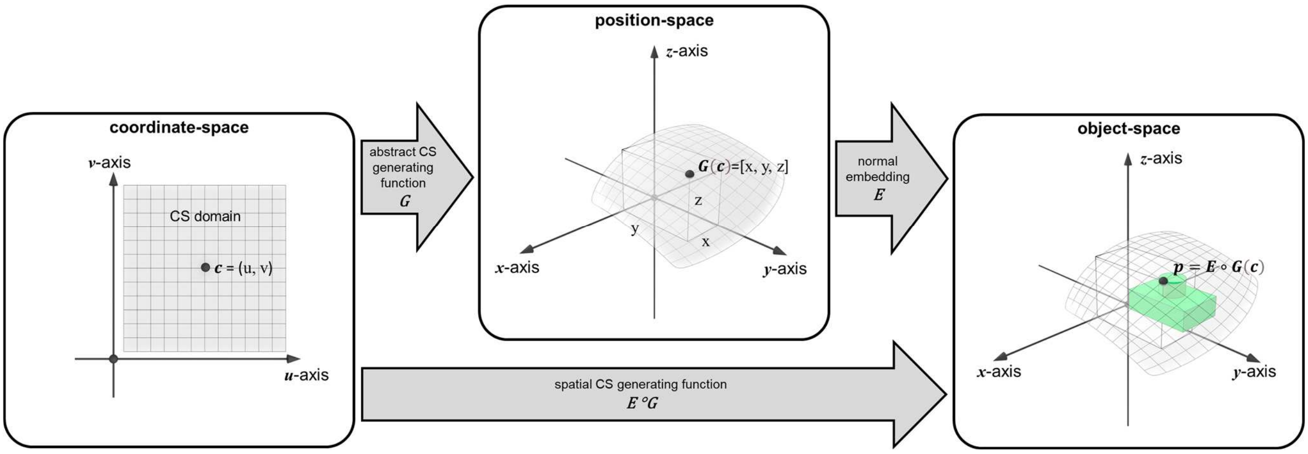

Figure 4.6 — A normal embedding of an abstract coordinate system

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 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.

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 4.7 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.

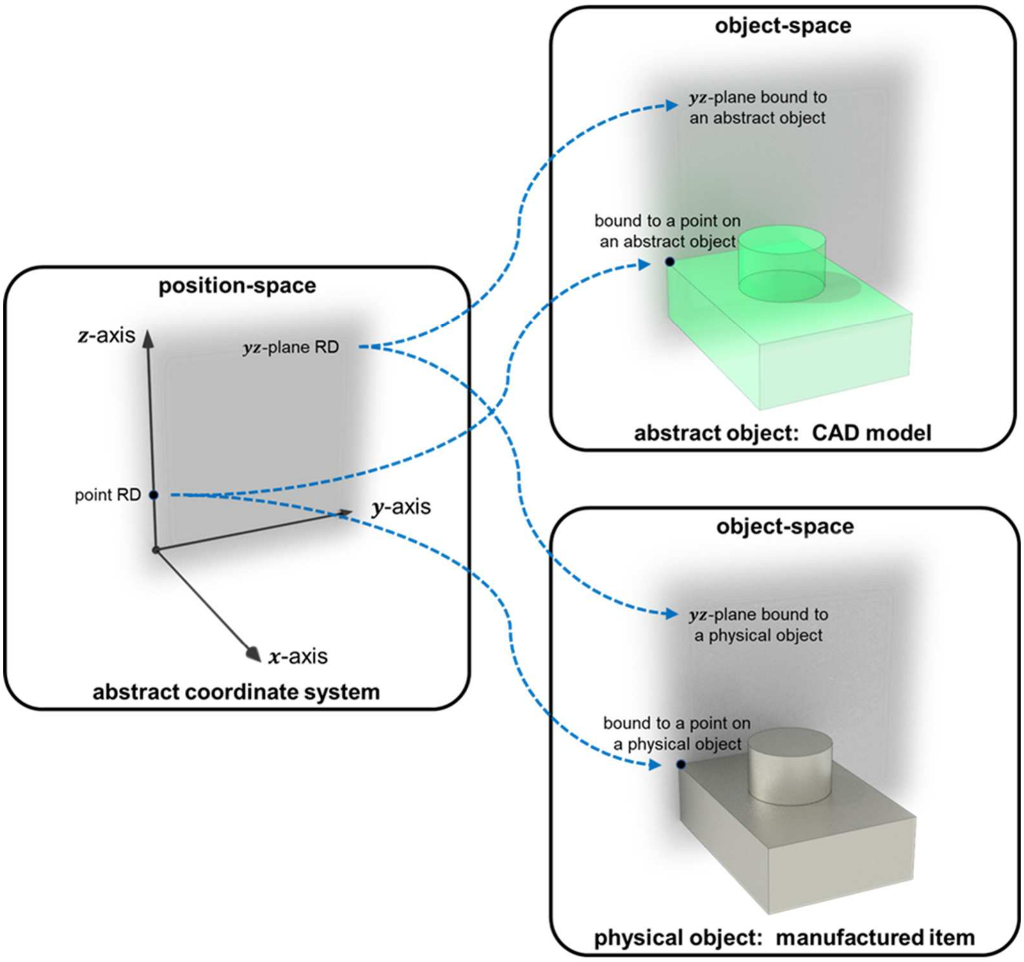

Figure 4.7 — Reference datums bound to abstract and physical objects

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 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 4.8.

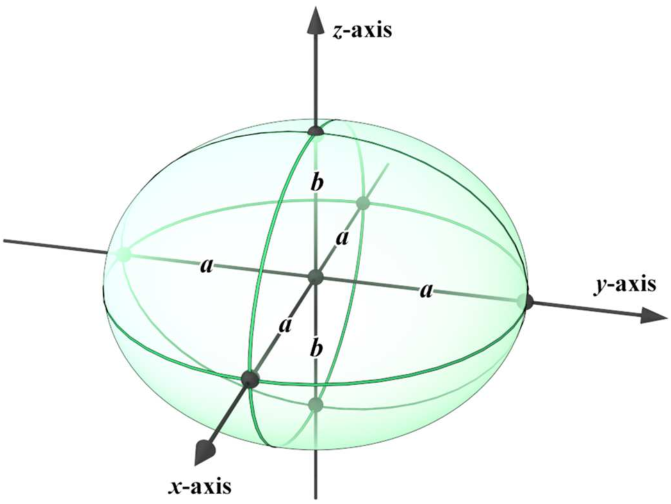

Figure 4.8 — An ellipsoid reference datum

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.

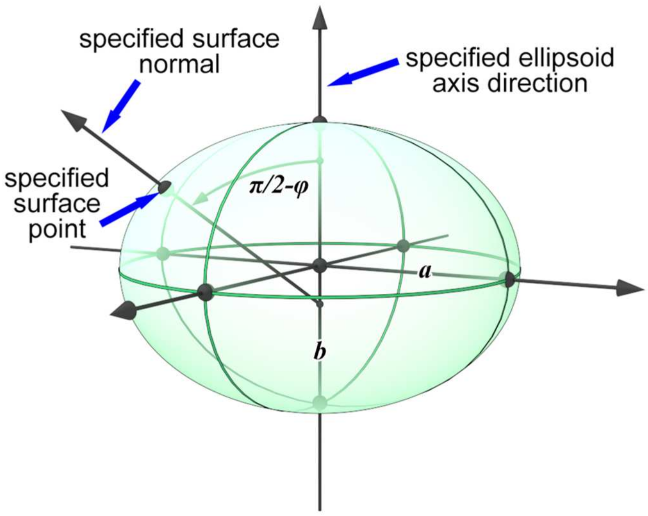

Figure 4.9 — A reference datum binding

This International Standard specifies a set of reference datums for use in subsequent specifications, including points, axis lines, planes, and ellipsoid surfaces.

A *reference datum binding* associates the reference datum in position-space with a corresponding constructed entity in object-space. A normal embedding also associates the same reference datum with its embedded image in object-space. A reference datum binding and a normal embedding are termed compatible if the embedded image of the reference datum primitive is coincident with the points (and direction or orientation, as applicable) of the measured or constructed entity of the reference datum binding.

Given a set of two or more bound reference datums, it is possible that a single normal embedding exists that is compatible with all the reference datum bindings. By properly combining multiple reference datum bindings, a unique compatible normal embedding can be specified.

EXAMPLE 3 Given a) the origin point reference datum is bound to a specific constructed point in object-space, and b) the x-axis reference datum is bound to a specific constructed directed line in object-space, no compatible normal embedding exists unless the constructed point lies on the constructed directed line. In 1D position-space, if the point lies on the directed line, then there is exactly one compatible normal embedding. In 2D or 3D position-spaces, if the point lies on the directed line, there are infinitely many compatible normal embeddings.

Reference datums and reference datum bindings are addressed in greater detail in 7.2. This International Standard specifies a set of reference datum categories in 7.2.4 and a standardized set of reference datums associated with physical objects in Annex D.

4.6 Object reference models

An *object reference model* for a spatial object is a set of bound reference datums for which there exists exactly one normal embedding of position-space into object-space that is compatible with each reference datum binding in the set. Object reference models and the mechanisms to create and use them are addressed in greater detail in 7.4.

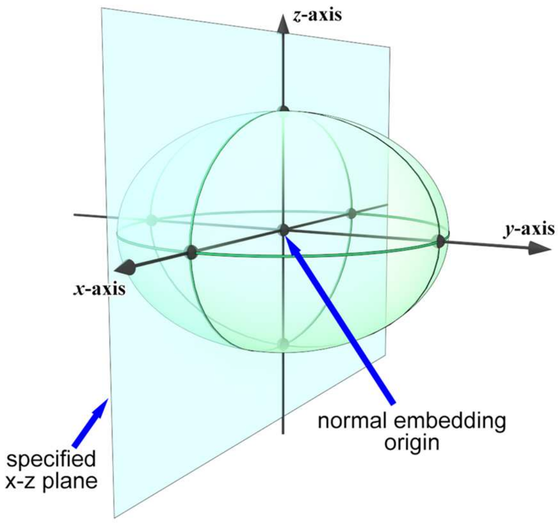

Figure 4.10 — An object reference model

EXAMPLE 1 An object reference model of the Earth is created from three reference datums: an oblate ellipsoid reference datum (with specified parameter values a and b), a z-axis reference datum, and an xz-plane reference datum (see Figure 4.10). These reference datums are bound as follows:

a) The oblate ellipsoid reference datum is bound to a constructed ellipsoid in object-space as in 4.5 Example 2 with major and minor semi-axis values a and b metres, respectively.

b) The z-axis reference datum is bound to a constructed line in object-space. This constructed line is selected to coincide with the axis of rotation of the constructed ellipsoid to ensure the existence of a compatible normal embedding.

c) The equatorial plane of the constructed ellipsoid determines the xy-plane of any resulting spatial coordinate system. The intersection of the equatorial plane of the constructed ellipsoid with the z-axis constructed line determines the origin and the z-axis of the resulting spatial coordinate system. However, these two reference datum bindings alone do not fully determine the direction of the x-axis of the resulting spatial coordinate system.

d) The xz-plane reference datum then is bound to a constructed plane in object-space. This constructed plane is selected to contain the z-axis constructed line to ensure the existence of a compatible normal embedding.

e) The z-axis constructed line divides the xz-constructed plane into two half-planes. One half-plane is designated as the x-positive half-plane. The intersection of the equatorial plane of the constructed ellipsoid with this x-positive half-plane determines the x-axis of the spatial coordinate system and its direction. Since there is one and only one y-axis choice that is right-handed, a compatible normal embedding is uniquely determined by these three reference datum bindings.

The only compatible normal embedding that can result from this construction will have its xz-plane coinciding with the RD xz-plane, its origin at the centre of the ellipsoid, and its z axis coinciding with the RD z axis.

A *binding constraint* is a relationship in object-space between the constructed entities of two or more bound reference datums, or a size relationship between a reference datum geometric primitive and its corresponding constructed entity. Binding constraints are formulated to ensure that there will exist at least one compatible normal embedding when the reference datums are bound.

EXAMPLE 2 The object reference model in Example 1 includes the following three binding constraints:

a) The oblate ellipsoid reference datum is bound to a constructed ellipsoid that has major semi-axis length of a metres and minor semi-axis length of b metres.

b) The z-axis reference datum is bound to an object-space constructed line that coincides with the axis of rotation of the constructed ellipsoid.

c) The xz-plane reference datum is bound to an object-space constructed plane that contains the z-axis constructed line.

An *object reference model template* is a standardized mechanism for specifying an object reference model. An object reference model template consists of a set of reference datums and a set of binding constraints for those reference datums, where the bound reference datums are compatible with one and only one normal embedding. Object reference model templates provide a convenient way to specify object reference models that share the same set of reference datum primitives and binding constraints.

EXAMPLE 3 Based on Example 1, a 3D object reference model template may be specified by the following set of three reference datums and set of three binding constraints. The reference datum set is:

a) An oblate ellipsoid with major semi-axis a and minor semi-axis b.

b) The z-axis.

c) The xz-plane.

The binding constraints are:

a) The object-space ellipsoid major semi-axis length shall be a metres and the minor semi-axis length shall be b metres.

b) The z-axis binding shall coincide with the axis of rotation of the ellipsoid.

c) The xz-plane binding shall contain the z-axis.

An object reference model is a *realization* of an object reference model template, if the reference datums of the object reference model match the reference datum set of the object reference model template and the reference datum bindings of the object reference model are compliant with the binding constraints of the object reference model template.

EXAMPLE 4 The object reference model in Example 1 is a realization of the object reference model template in Example 3.

EXAMPLE 5 Object reference model European Datum 1950 (specified in Annex E as object reference model EUROPE_1950) is a realization of the object reference model template in Example 3 using the semi-axes values specified in the International 1924 ellipsoid reference datum (specified in Annex D as reference datum INTERNATIONAL_1924).

The object reference model template concept is addressed in greater detail in 7.4.4. This International Standard specifies a standardized set of object reference model templates (see 7.4.4) and a set of standardized object reference models (see Annex E).

4.7 Spatial reference frames

A *spatial reference frame* is a means of specifying a spatial coordinate system for an object-space. A spatial reference frame for a spatial object includes:

a) an object reference model for the spatial object

b) an abstract coordinate system

c) a binding of the abstract coordinate system parameters, if any, to specific values, and

d) (optionally) other names and/or symbols for coordinate-components.

The object reference model implicitly defines a normal embedding. The functional composition of the abstract coordinate system and that normal embedding results in a spatial coordinate system for the object space (see 4.3.2). If the abstract coordinate system requires parameter values, the object reference model parameter binding associates reference characteristic values to corresponding abstract coordinate system parameters. To match common usage, the spatial reference frame specification may optionally rename and/or use alternate symbols for the coordinate-components of the abstract coordinate system.

The binding of the coordinate system parameters is often related to characteristics of the reference datum components of the object reference model used. Spatial reference frames and the mechanisms to create them are addressed in greater detail in Clause 8. A spatial reference frame specification includes an applicable region that may restrict the coordinate system domain. Uses of acceptable regions are specified in 8.3.2.4.

A *spatial reference frame template* is a standardized mechanism for specifying a spatial reference frame. A spatial reference frame template consists of an abstract coordinate system, coordinate component names, coordinate system parameter binding rules, and object reference model constraints. Spatial reference frame templates provide a consistent and convenient way to specify spatial reference frames that share these common elements. The spatial reference frame template concept is addressed in greater detail in 8.5.

In this International Standard, each spatial reference frame is derived from a spatial reference frame template that is specified in 8.5.

It is often the case, particularly with map projection coordinate systems, that one spatial reference frame cannot cover a large area within the limits of allowable distortion. A *spatial reference frame set* for a spatial object is a finite parameterized set of two or more spatial reference frames. The specification of a spatial reference frame set may add restrictions to the object reference model constraints of the specified spatial reference frame template. The spatial reference frame set concept is specified in 8.7.

In many applications it is useful or necessary to define a spatial reference frame in terms of another spatial reference frame. The relationships between spatial reference frames (see 8.4) build upon the corresponding relationships between their respective spatial coordinate systems (see 4.3.1).

Spatial reference frame relationships are specified using localization, induced surfaces, and local tangent frames. This International Standard specifies several standard spatial reference frame templates (see 8.5) and several spatial reference frame sets (see 8.7) that incorporate such relationships.

4.8 Designated spatial surfaces and vertical offset surfaces

Many spatial applications require the specification of surfaces in object-space that are more complex than simple geometric primitives used to specify reference datums. These surfaces often represent some conceptual or physical aspect of the object-space such as a gravity equipotential surface. Such surfaces are termed *designated spatial surfaces*. A model of the *geoid* is a designated spatial surface.

For spatial reference frames that have a vertical coordinate-component, certain designated spatial surfaces may be used to define vertical offset values. Many real-world measurement systems used in geodesy define the value of the *vertical coordinate-component* of a spatial reference frame to be zero at a designated spatial surface. A common example is the mean sea level surface.

If the point of intersection between each vertical *coordinate-component curve* and the designated spatial surface is unique, that point specifies a vertical offset value, and the designated spatial surface is termed a *vertical offset surface* for the given spatial reference frame.

Figure 4.11 illustrates a vertical offset surface in a case where the vertical coordinate-component is ellipsoidal height h. The *vertical offset* v at a point $\boldsymbol{p}$, with geodetic coordinate (λ, φ), is the distance from the (reference datum) ellipsoid surface to the vertical offset surface along the ellipsoidal height coordinate-component curve that contains $\boldsymbol{p}$. The vertical offset $v = \boldsymbol{v}(\lambda, \varphi)$ depends only on the point of intersection of the ellipsoid surface and the ellipsoidal height curve. A model of the geoid is a vertical offset surface relative to ellipsoidal height. In that case, the elevation h_e of a point $\boldsymbol{p}$ with respect to the vertical offset surface is defined to be $h_e = h - \boldsymbol{v}(\lambda, \varphi)$.

A collection of designated spatial surfaces that are vertical offset surfaces with respect to a vertical coordinate-component of ellipsoidal height are specified in Clause 9. Although distances from vertical offset surfaces are not allowed as coordinate elements, the API (Clause 11) provides a method for vertical offset computation with respect to ellipsoidal height, if the surface can be modelled with a *smooth surface* generating function.

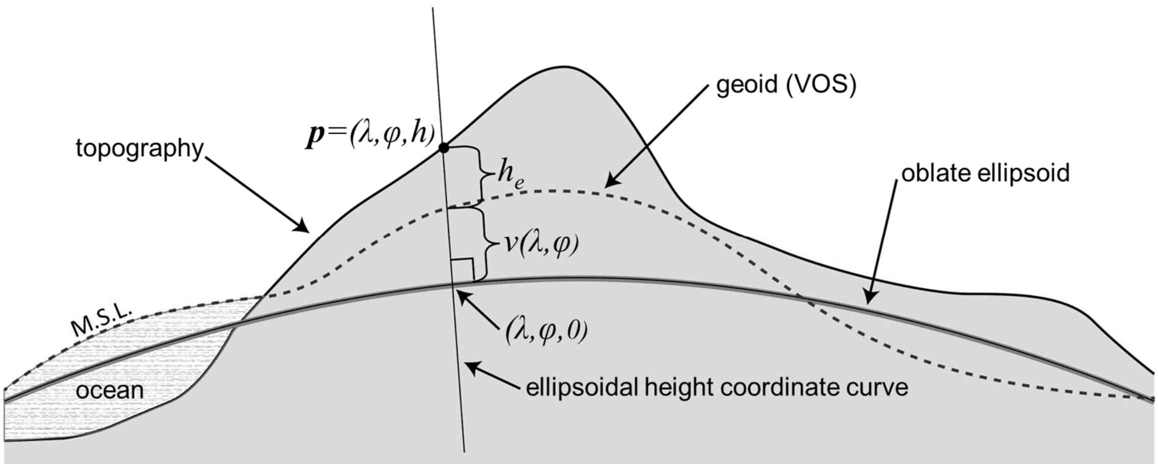

Figure 4.11 — A vertical offset surface for ellipsoidal height

4.9 Spatial operations

A *spatial operation* computes geometric quantities:

- within a single spatial reference frame,
- between different spatial reference frames for the same spatial object, or
- between different spatial reference frames for different spatial objects.

The geometric quantities include coordinates, directions, vector quantities, and distances. The following standard spatial operations are defined in Clause 10:

a) Operations relating two object reference models for the same object (e.g., the Earth) or for different objects (see 10.3)

b) Operations to represent a position in a different spatial reference frame (see 10.4)

c) Operations to represent a direction or vector quantity in a different spatial reference frame (see 10.5)

d) Operations to compute the Euclidean distance between two points in an object space (see 10.6)

e) Operations to compute the geodesic distance between two points on a smooth surface (see 10.7)

A common operation is to compute the coordinate-component values of a position in a different spatial reference frame. Given source and target spatial reference frames SRF_S and SRF_T and a point $\boldsymbol{p}$ in object-space, the coordinate $\boldsymbol{c}_T$ of $\boldsymbol{p}$ in SRF_T can be computed from the coordinate $\boldsymbol{c}_S$ of $\boldsymbol{p}$ in SRF_S. In its most general form this coordinate computation is given by $\boldsymbol{c}_T = \boldsymbol{G}_T^{-1} \circ \boldsymbol{H}_{T \leftarrow S} \circ \boldsymbol{G}_S(\boldsymbol{c}_S)$ where $\boldsymbol{G}_S$ and $\boldsymbol{G}_T$ are the coordinate system generating functions (see 4.3.1) and $\boldsymbol{H}_{T \leftarrow S}$ is a similarity transformation (see 7.3.2) between the object reference models for SRF_S and SRF_T (see 10.4). This operation is illustrated in Figure 4.12.

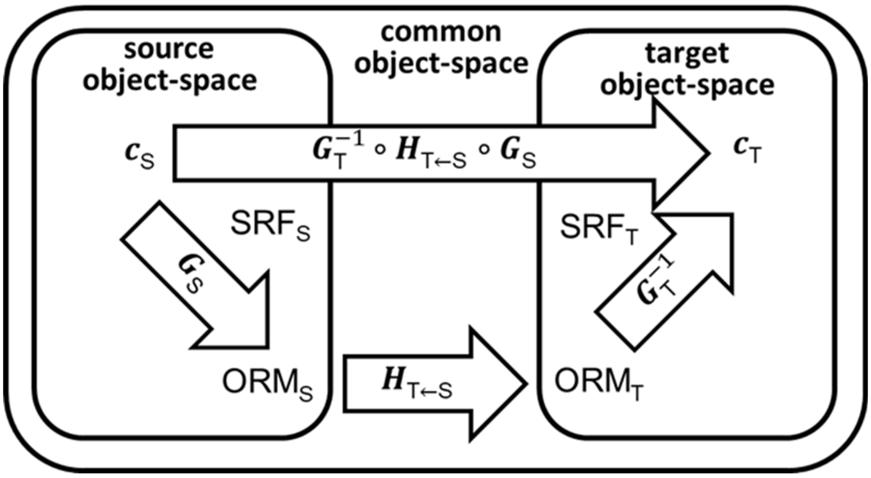

Figure 4.12 — Change of spatial reference frame operation applied to a coordinate

4.10 Application program interface

Clause 11 specifies data types for representing spatial information based on concepts in the SRM. It also specifies an extensible object-oriented application program interface that can be used to implement the spatial operations defined in this International Standard. The data objects and functional methods in this interface are based on the methods and spatial operations specified in Clauses 5, 6, 7, 8, 9, and 10.

4.11 Profiles

A *profile* is a subset of the SRM that is tailored to meet the needs of a specific application area (see Clause 12). The "default" profile is specified in 12.3. Only those subsets of the SRM that can, as a minimum, define, represent, and/or process positions shall be allowed. Conformance of functional implementations and exchange formats are defined in the context of a profile (see 4.13).

4.12 Registration

This International Standard specifies standardized instances of SRM concepts. This International Standard allows new instances of SRM concepts, identified in the list below, to be specified by registration in accordance with Clause 13. These new instances are termed *registered items*. Registered items may be accessed at the International Register of Items.

New instances of the following SRM concepts may be registered:

a) abstract coordinate systems (see 5.3),

b) temporal coordinate systems (see 5.5),

c) reference datums (see 7.2),

d) similarity transformation templates (see 7.3.3),

e) object reference model templates (see 7.4.4),

f) object reference models (see 7.4.5),

g) reference transformations (see 7.4.6),

h) object binding rule sets (see 7.5),

i) spatial reference frame templates (see 8.5),

j) spatial reference frames (see 8.6),

k) spatial reference frame sets and their members (see 8.7),

l) designated spatial surfaces (see Clause 9), and

m) profiles (see Clause 12).

In addition, references for new instances of the above SRM concepts may be registered (see 13.2.5).

New items are registered using the established procedures of the ISO/IEC Registration Authority for Items[1]. These procedures require the submitter to supply all information for a new SRM registered item. Registration shall be according to the procedures in ISO/IEC 9973. The guidelines that shall be followed in preparing registration proposals are specified in Clause 13. Annex H provides a set of templates that may be used in the registration process.

Registration shall not be used to modify any existing standardized or SRM registered item except as allowed by ISO/IEC 9973 (see Annex G for details concerning how standardized and registered items may be deprecated). Deprecated items, if any, are listed in Annex J.

Other International Standards that normatively reference this International Standard, implementations of those standards, and implementations of this International Standard shall not use any SRM registered item codes in the value ranges reserved for registration or future standardization by this International Standard with any meaning other than the one defined in this International Standard or in the International Register of Items.

[1] Contact information for the ISO-designated Registration Authority for Items registered under the ISO/IEC 9973 procedures is available at the ISO Maintenance agencies and registration authorities web site: https://www.iso.org/maintenance_agencies.html.

4.13 Conformance

Conformance to this International Standard (see Clause 14) is specified with respect to:

a) functional implementations of the SRM (14.2),

b) exchange formats that use SRM data structures and associated data types (14.3),

c) language bindings of the SRM API (14.4),

d) applications that use the SRM API (14.5), and

e) specifications that reference this International Standard (14.6).

Functional implementation and exchange format conformance are based on profiles. Conformance of an application to a profile is defined in 14.5.