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OGC Dynamic Features Discussion Paper

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Table of Contents

i. Abstract

Moving Feature standards and technologies have made considerable progress. It is time to evaluate the foundations of OGC standards to determine if they are sufficient to support current and future Moving Feature standards. This discussion paper examines ISO and OGC standards against current and anticipated future needs. It also examines other standards and conventions which may be useful for enhancing the OGC/ISO foundation.>

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NOTE

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Chapter 1. Scope

Moving Feature standards and technologies have made considerable progress. It is time to evaluate the foundations of OGC standards to determine if they are sufficient to support current and future Moving Feature standards. This discussion paper examines ISO and OGC standards against current and anticipated future needs. It also examines other standards and conventions which may be useful for enhancing the OGC/ISO foundation.

Chapter 2. References

As a Discussion Paper, this document contains no normative references. Citations for resources referenced in this document are listed in the Bibliography (Annex B).

Chapter 3. Terms and Definitions

This document uses the terms defined in Sub-clause 5.3 of [OGC 06-121r8], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word “shall” (not “must”) is the verb form used to indicate a requirement to be strictly followed to conform to this Best Practice.

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

3.1. base representation

<moving features>representation, using a local origin and local ordinate vectors, of a geometric object at a given reference time [ISO 19141:2008, definition 4.1.1]

NOTE 1 A rigid geometric object may undergo translation or rotation, but remains congruent with its base representation.

NOTE 2 The local origin and ordinate vectors establish an engineering coordinate reference system (ISO 19111), also called a local frame or a local Euclidean coordinate system.

3.2. design coordinate reference system

engineering coordinate reference system in which the base representation of a moving object is specified. [ISO 19141:2008, definition 4.1.3]

3.3. direct position

DirectPosition object data types hold the coordinates for a position within some coordinate reference system.

3.4. external coordinate reference system

the coordinate reference system in which the geometry of the curve for a trajectory is defined. Usually an earth-fixed geographic CRS. [ISO 19141:2008, derived]

3.5. feature

abstraction of real world phenomena [ISO 19101:2002, definition 4.11]

NOTE A feature may occur as a type or an instance. Feature type or feature instance shall be used when only one is meant.

3.6. foliation

one parameter set of geometries such that each point in the prism of the set is in one and only one trajectory and in one and only one leaf [ISO 19141:2008, definition 4.1.8]

3.7. geometric object

spatial object representing a geometric set [ISO 19107:2003, definition 4.47]

3.8. geometric primitive

geometric object representing a single, connected, homogeneous element of space [ISO 19107:2003, definition 4.48]

NOTE Geometric primitives are non-decomposed objects that present information about geometric configuration. They include points, curves, surfaces, and solids.

3.9. global coordinate system

the CRS of the trajectory of the reference point.

NOTE A global coordinate system is usually in terms of the moving frame of the curve (oriented on the local tangent) or in terms of the external CRS in which the geometry of the curve is defined. [ISO 19141:2008, derived]

3.10. GM_Point

GM_Point is the basic data type for a geometric object consisting of one and only one point. That point is represented as a DirectPosition.

3.11. instant

0-dimensional geometric primitive representing position in time [ISO 19108:2002, definition 4.1.17]

3.12. leaf

<one parameter set of geometries> geometry at a particular value of the parameter [ISO 19141:2008, definition 4.1.12]

3.13. one parameter set of geometries

function f from an interval $t \in [a, b]$ such that $f(t)$ is a geometry and for each point $P \in f(a)$ there is a one parameter set of points (called the trajectory of P) $P(t) : [a, b] \rightarrow P(t)$ such that $P(t) \in f(t)$ [ISO 19141:2008, definition 4.1.15]

EXAMPLE A curve C with constructive parameter t is a one parameter set of points c(t).

3.14. prism

<one parameter set of geometries> set of points in the union of the geometries (or the union of the trajectories) of a one parameter set of geometries [ISO 19141:2008, definition 4.1.18]

NOTE This is a generalization of the concept of a geometric prism that is the convex hull of two congruent polygons in 3D-space. Such polyhedrons can be viewed as a foliation of congruent polygons.

3.15. temporal coordinate system

temporal reference system based on an interval scale on which distance is measured as a multiple of a single unit of time [ISO 19108:2002, definition 4.1.31]

3.16. temporal position

location relative to a temporal reference system [ISO 19108:2002, definition 4.1.34]

3.17. temporal reference system

reference system against which time is measured [ISO 19108:2002, definition 4.1.35]

3.18. trajectory

path of a moving point described by a one parameter set of points [ISO 19141:2008, definition 4.1.22]

3.19. vector

quantity having direction as well as magnitude [ISO 19123:2005, definition 4.1.43]

Chapter 4. Conventions

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

4.1. Identifiers

The normative provisions in this document are denoted by the URI

http://www.opengis.net/spec/{standard}/{m.n}

All requirements and conformance tests that appear in this document are denoted by partial URIs which are relative to this base.

NOTE	A description of UML and how it is used in ISO and OGC standards will be included here.

Chapter 5. Dynamic Features

Introductory text

5.1. Geometry in 3 Dimensions

Topic: Is the OGC Geometry model sufficient to support 3D?

5.1.1. Feature Model

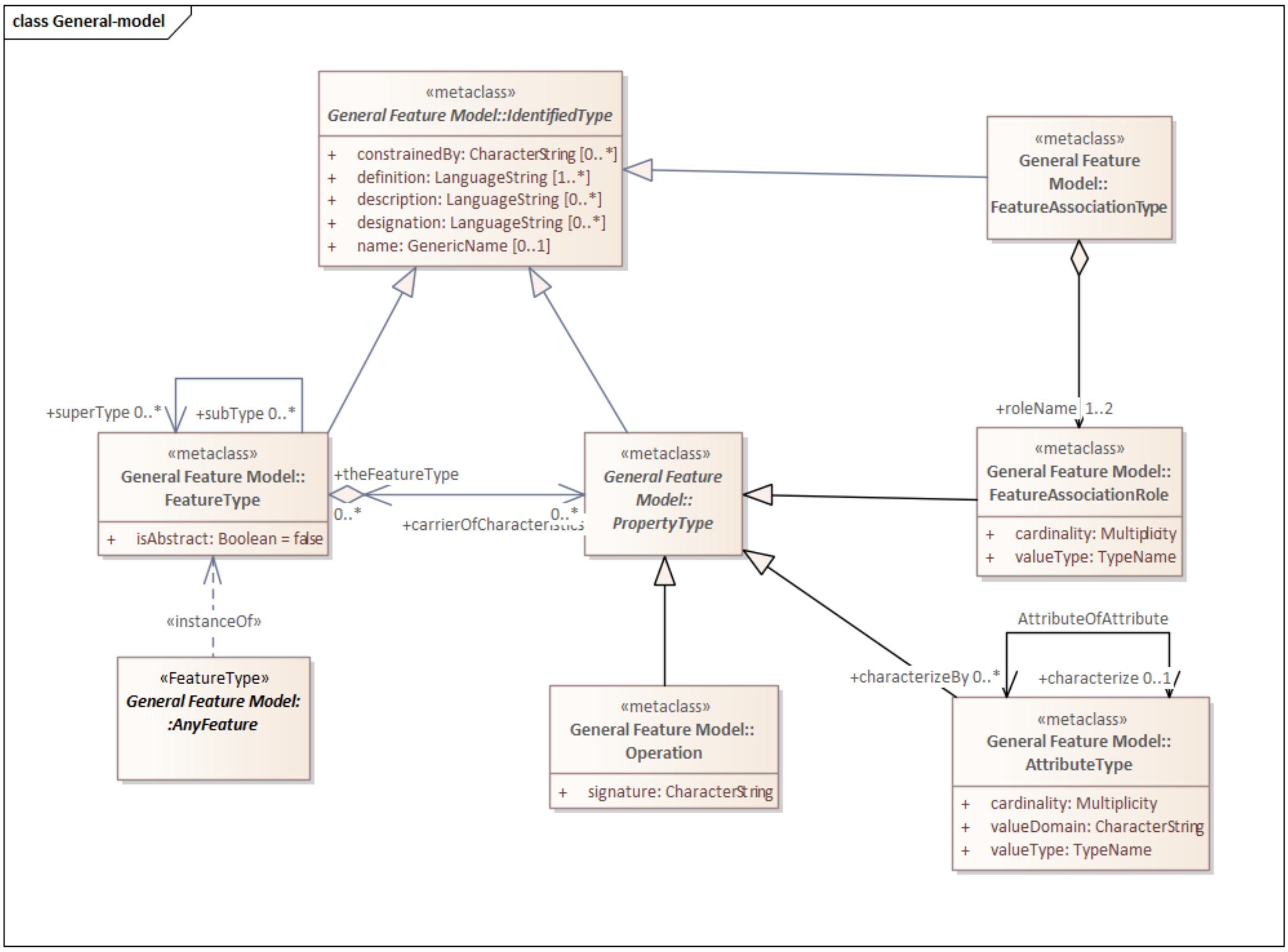
Before we can discuss geometry, we must first have a conceptual model of the universe. The OGC and ISO TC211 provide that model in ISO 19109. This standard defines the General Feature Model (GFM). The GFM defines the concept of a Feature, its components, and behaviors.

ISO TC211 defines a Feature as an "Abstraction of real world phenomena" (ISO 19101-1:2014)

A Feature, then, is a high level abstraction for anything that does or could exist in the universe.

The General Feature Model further refines the concept of a Feature. The following principles are most relevant for this discussion:

1. A Feature can be a FeatureType or an Instance of a FeatureType (AnyFeature).
2. FeatureTypes can form a taxonomy (inheritance)
3. Features possess characteristics (Properties)
4. A Property of a Feature can be an Operation, Attribute, or Association.

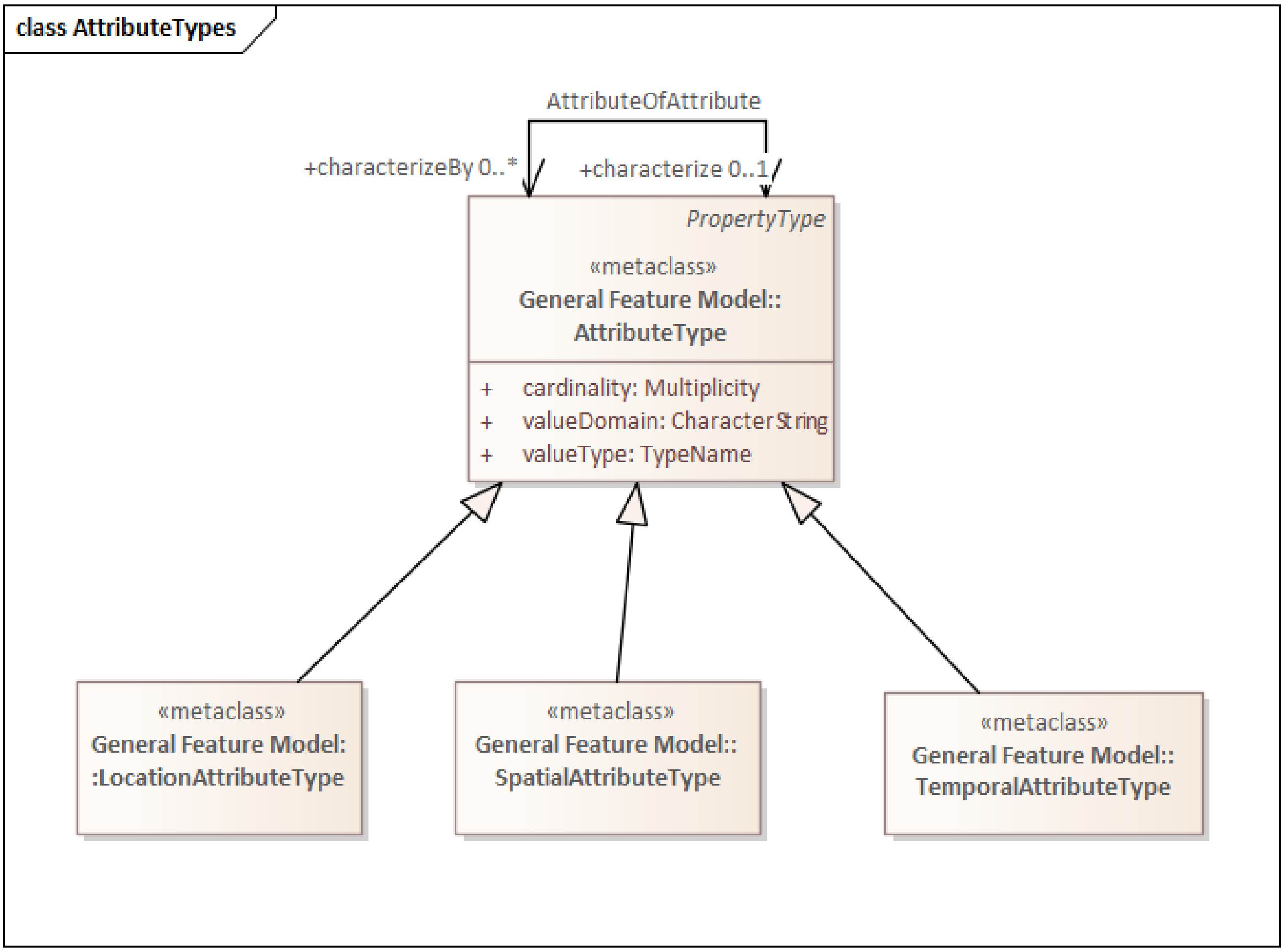


The resulting model is sufficient to describe a Feature's identity (IdentifiedType), what it is (FeatureType), what it can do (Operations), its observable characterisitics (Attributes), and any associations with other Feature instances.

5.1.2. Feature Geometry

The General Feature Model treats geometry as an attribute of the Feature. In addition, it defines three types of attribute which are useful for associating geometry with a Feature in a standard manner:

- SpatialAttributeType: Geometries (GM_Object) and Topologies (TP_Object)
- LocationalAttributeType: Named locations, extents, and points.
- TemporalAttributeType: Temporal objects (TM_Object)


class AttributeTypes
AttributeOfAttribute
+characterizeBy 0..*
+characterize 0..1
PropertyType
«metaclass»
General Feature Model::
AttributeType
+ cardinality: Multiplicity
+ valueDomain: CharacterString
+ valueType: TypeName
«metaclass»
General Feature Model:
:LocationAttributeType
«metaclass»
General Feature Model::
SpatialAttributeType
«metaclass»
General Feature Model::
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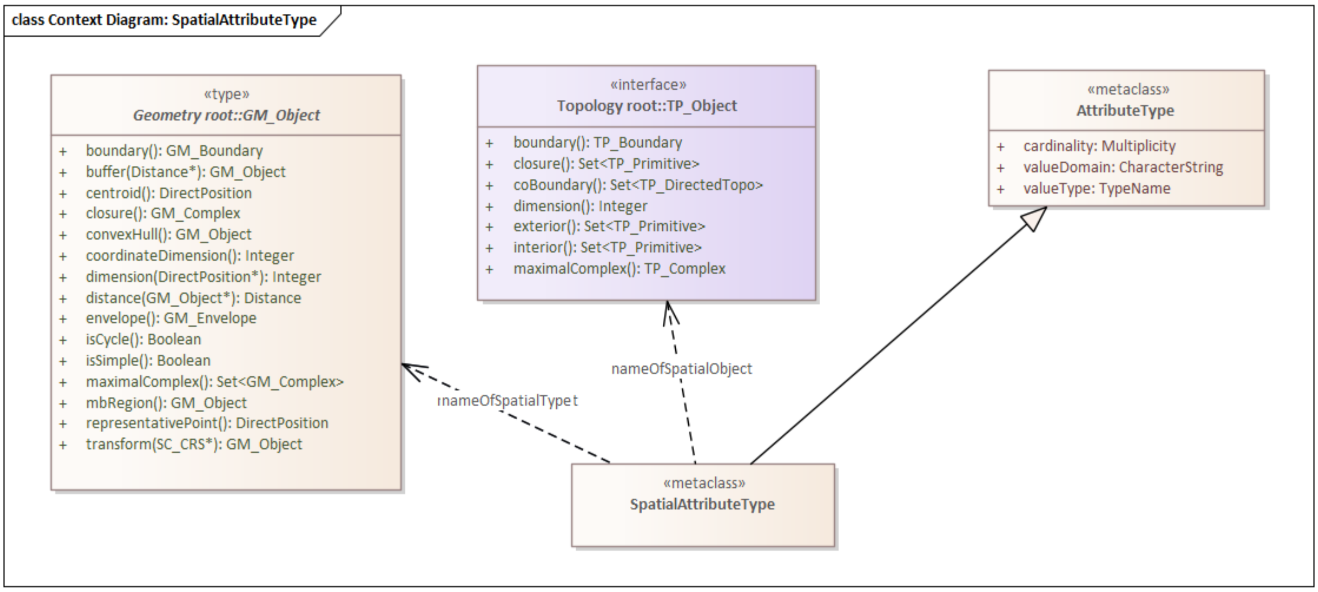
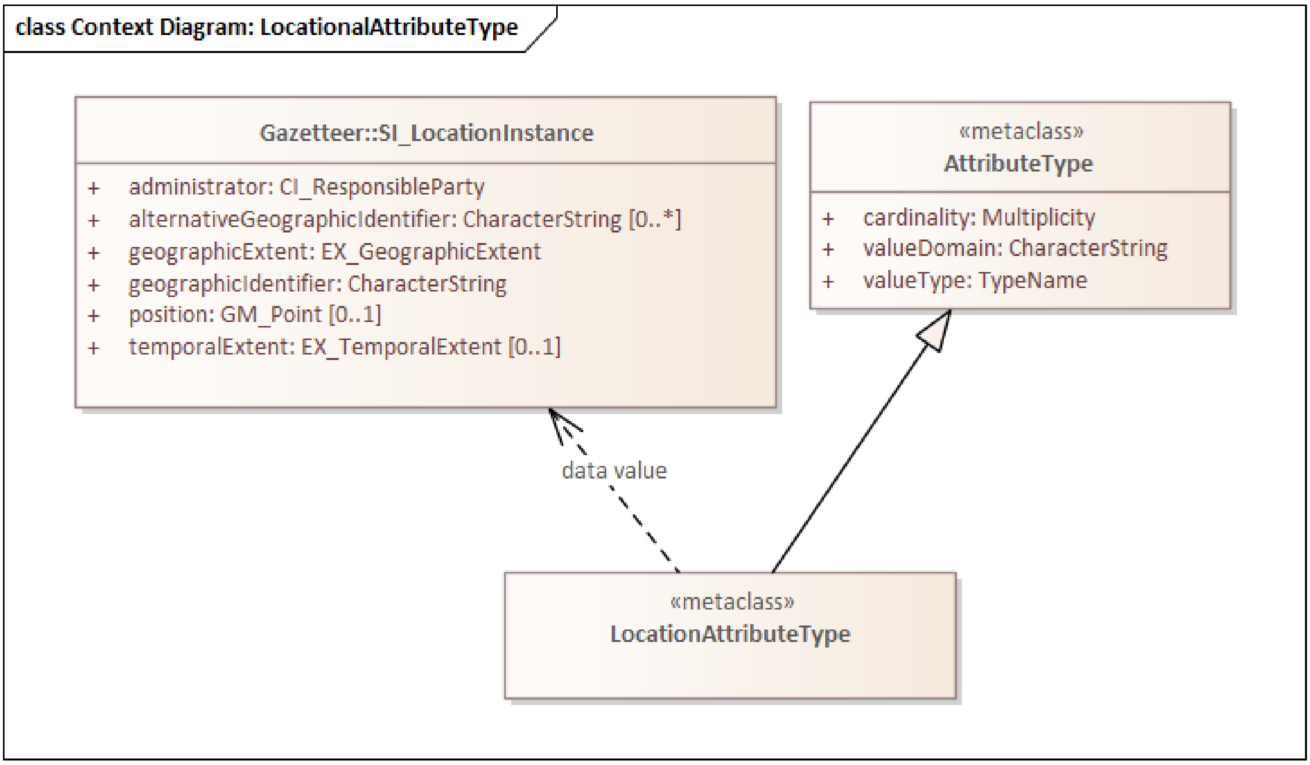
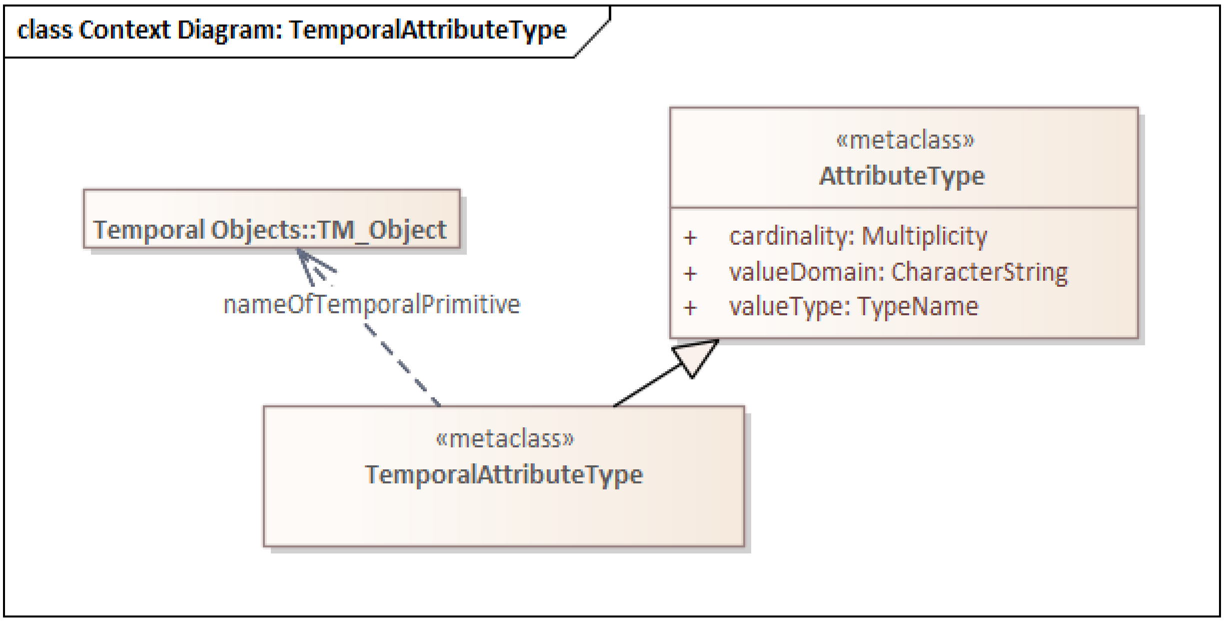

class Context Diagram: SpatialAttributeType
«type»
Geometry root::GM_Object
+ boundary(): GM_Boundary
+ buffer(Distance*): GM_Object
+ centroid(): DirectPosition
+ closure(): GM_Complex
+ convexHull(): GM_Object
+ coordinateDimension(): Integer
+ dimension(DirectPosition*): Integer
+ distance(GM_Object*): Distance
+ envelope(): GM_Envelope
+ isCycle(): Boolean
+ isSimple(): Boolean
+ maximalComplex(): Set<GM_Complex>
+ mbRegion(): GM_Object
+ representativePoint(): DirectPosition
+ transform(SC_CRS*): GM_Object
«interface»
Topology root::TP_Object
+ boundary(): TP_Boundary
+ closure(): Set<TP_Primitive>
+ coBoundary(): Set<TP_DirectedTopo>
+ dimension(): Integer
+ exterior(): Set<TP_Primitive>
+ interior(): Set<TP_Primitive>
+ maximalComplex(): TP_Complex
«metaclass»
AttributeType
+ cardinality: Multiplicity
+ valueDomain: CharacterString
+ valueType: TypeName
nameOfSpatialObject
nameOfSpatialType
«metaclass»
SpatialAttributeType





In our discussion of Dynamic Features, we must allow for Features which are moving through three dimensions and have non-trivial three dimensional shapes. We must also consider that the shape of these objects may change with time. From this we see that the movement of the Feature and the shape of the Feature are two separate properties.

A measurement of movement would capture changes in location and orientation. Movement is in the eyes of an external observer. Therefore, movement should be specified using a coordinate reference system which is external to the Feature.

The shape of a Feature is independent of its location. A rigid body has the same shape reqardless of where it is or who is observing it. It's geometry should be self-contained. This requires use of an internal coordinate reference system.

This leads up to two postulates:

Postulate 1: The Locational Attribute of a 3D Feature is a GM_Point which locates the origin of the local CRS within an external CRS.

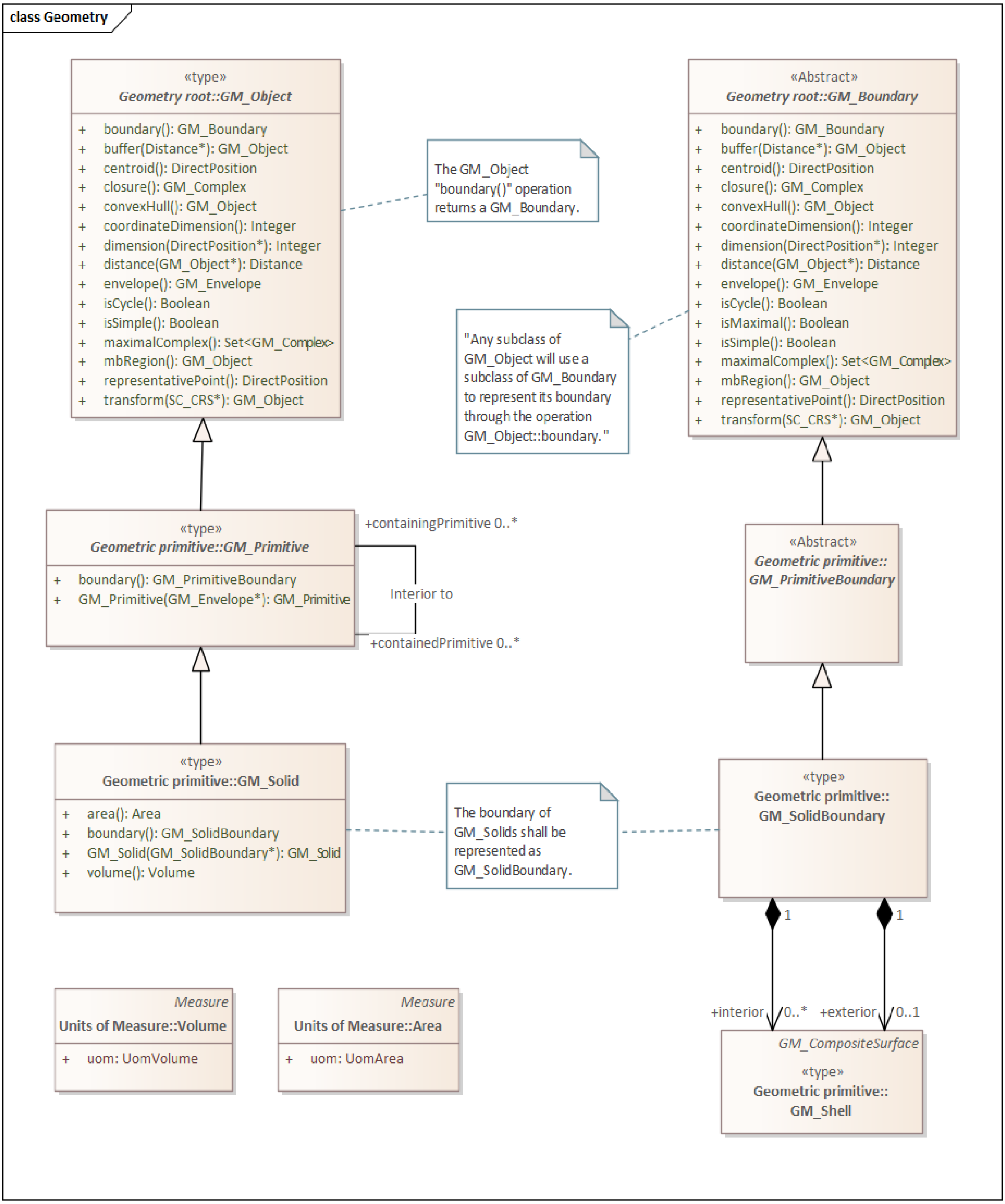
Postulate 2: The Spatial Attribute of a 3D Feature is one or more GM_Objects which define the shape of the Feature in the local coordinate refrence system.

One and two dimensional geometries are well understood. So the locational attribute poses few immediate problems. Three-dimensional shapes are another matter. Particularly if they are free from any bounding surface and capable of movement.

5.1.3. 3D Geometry

The applicable OGC/ISO standard for 3D geometries is ISO 19107:2003. While a new version was approved in 2019, it hasn't propagated through the rest of the ISO standards baseline. As a result, 19107:2003 is the most recent implemented version.

ISO 19107 defines both the GM_Object and GM_Boundary classes as root level geometry classes. The association between GM_Object and GM_Boundary is achieved through the "boundary()" operation on the GM_Object class.



Therefore, we can describe the shape of a Feature in terms of the space occupied by that Feature and the boundary which encloses that space.

Postulate 3: A 3D Feature is a Feature whos' geometry is defined by a volume enclosed by a boundary surface.

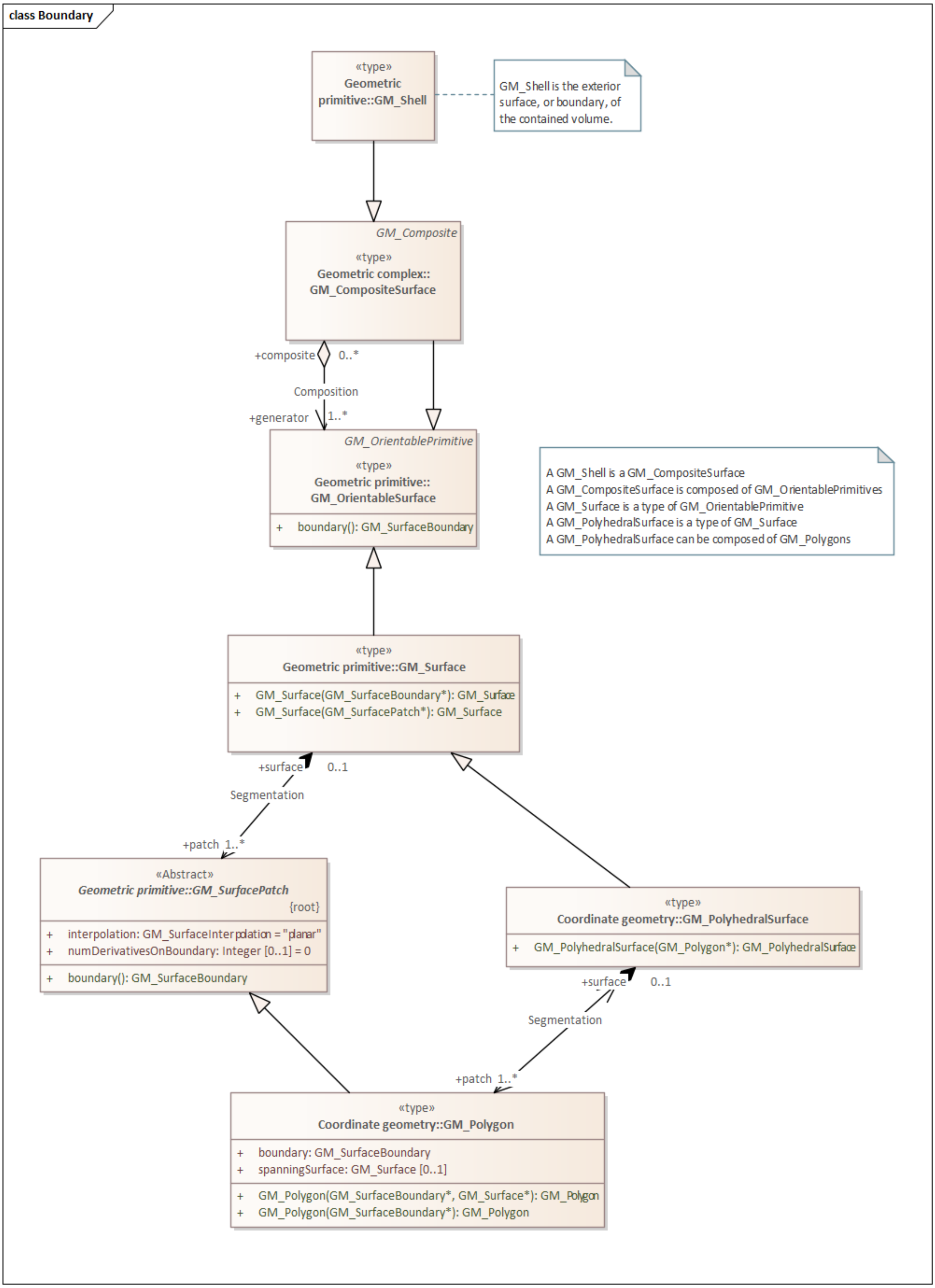
Volumetrics

GM_Object is subclassed into GM_Primitive then into GM_Solid. The "volume()" operation on GM_Solid returns the volume (defined in ISO 19103) associated with a Feature. Thus, ISO 19107 supports the concept of a 3D volume.

Real 3D objects are often not solid. So the 3D model must also support voids, or even entire 3D Features within their interior. GM_Primitive addresses this need through the “interior to” association. The two roles on this association are the containingPrimitive (the GM_Primitive which contains another GM_Primitive) and the containedPrimitive (the GM_Primitive which is contained). This association has proven its worth in 2D space so there is little doubt that it will be just as effective in 3D.

Boundaries

A 3D volume is delineated by a bounding surface. GM_Boundary is the root class for boundaries. The subclass GM_PrimitiveBoundary provides the boundary for GM_Primitives. The GM_PrimitiveBoundary subclass GM_SolidBoundary is defined as the boundary for a GM_Solid.



ISO 19107 goes even farther. A GM_SolidBoundary is composed of both interior and exterior boundaries. These boundaries are defined by the GM_Shell class. Following the class associations we see:

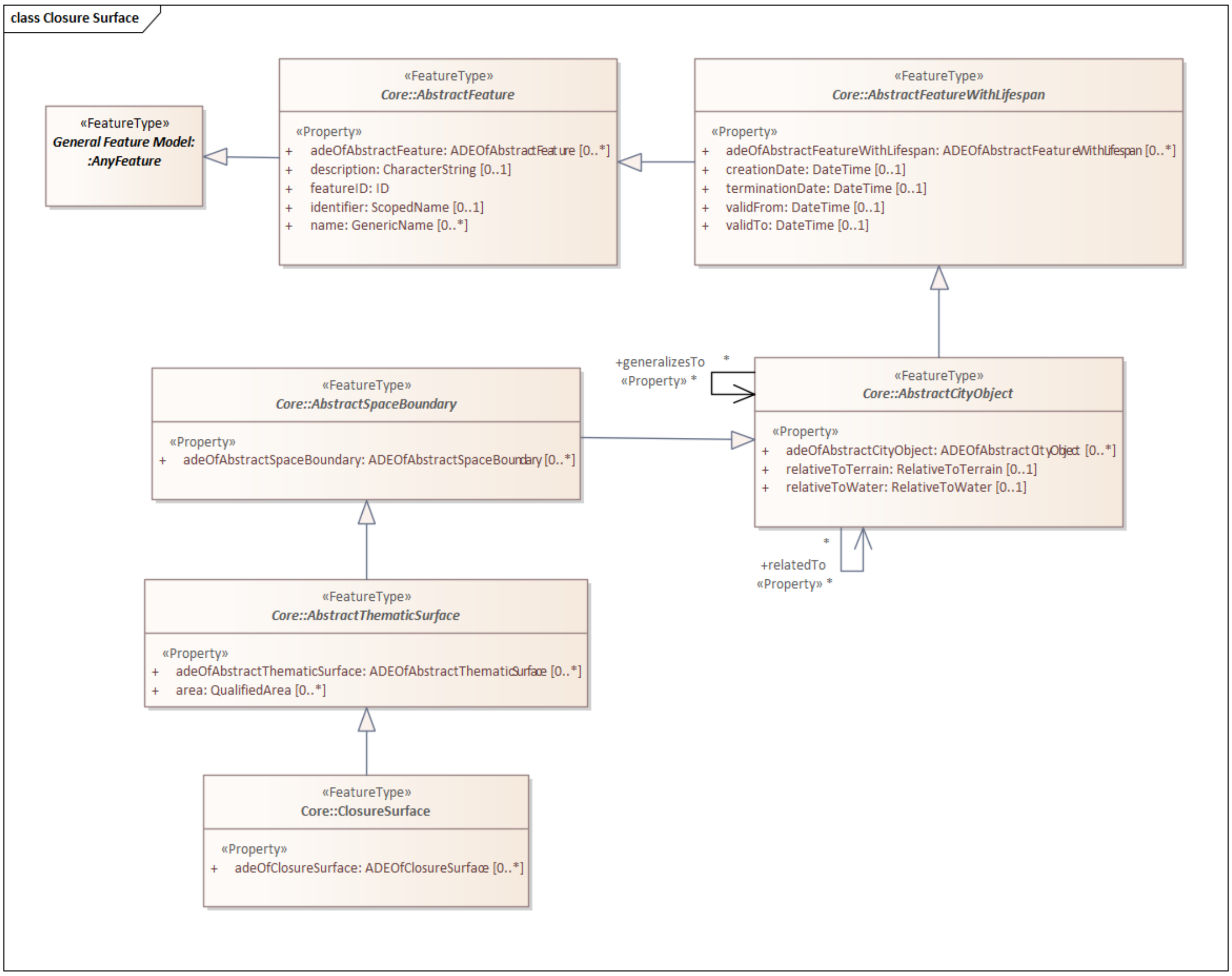
- A GM_Shell is a GM_CompositeSurface
- A GM_CompositeSurface is composed of GM_OrientablePrimitives
- A GM_Surface is a type of GM_OrientablePrimitive
- A GM_PolyhedralSurface is a type of GM_Surface
- A GM_PolyhedralSurface can be composed of GM_Polygons

A surface constructed of polygons is an example of Boundary Representation (B-Rep) of a surface. This approach is fundamental to rendering 3D computer graphics. (ref Adam Powers 1981)

Closure Surfaces

Some structures, such as a tunnel or overpass, pose difficulties for this geometry model. The boundary surface can be constructed so that it continues into the interior of the structure. That would make the interior of a tunnel external to the tunnel object. This is not always a desireable result. CityGML provides the concept of a "Closure Surface".

A Closure Surface is a surface which is a logical part of the object but does not correspond to a physical part of the object. For example, the entrance to a tunnel can have a closure surface. This surface allows you to treat the tunnel as a single three-dimension entity, even though there is a hole in the bounding surface.



As implemented in CityGML 3.0, the ClosureSurface class has quite an ancestory. We may want to generalize this concept for use outside of CityGML. However, the capabilties provided by the ancestor classes do provide value and may be worth incorporating into a general 3D model.

B-Rep

The polyhedral surfaces which bound volumetric shapes are similar to the Boundary Representation (B-Rep) approach used in CAD and computer graphics. B-Rep defines a 3-dimensional surface which serves as the interface between the interior of the volumetric shape and the exterior. This surface is usually defined by a collection of shape elements (polygons) which together form a closed surface.

https://en.wikipedia.org/wiki/Boundary_representation

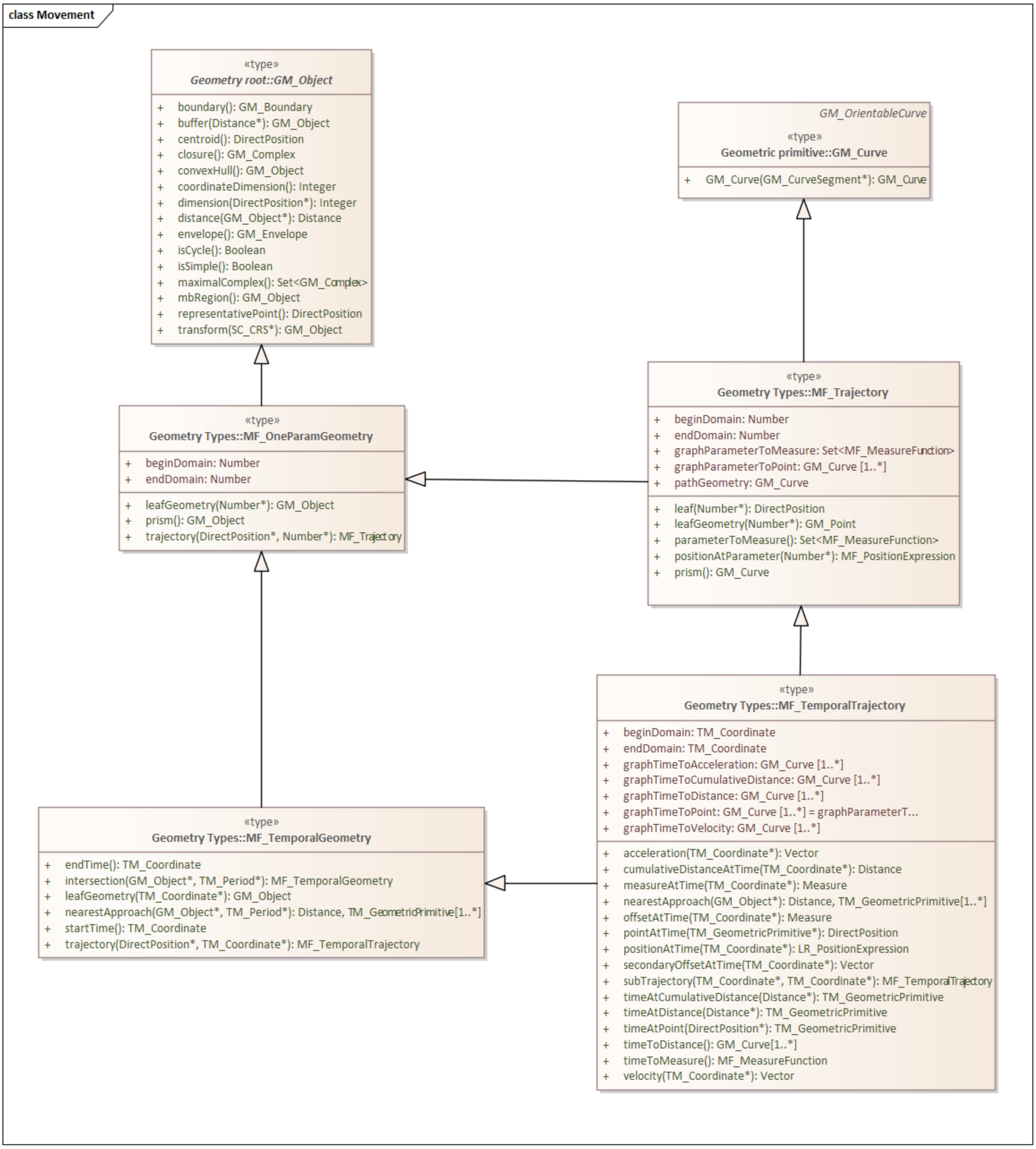
Point Clouds

"In addition to the spatial representations defined in the Core module, the geometry of physical spaces and of thematic surfaces can now also be provided by 3D point clouds using MultiPoint geometry. This allows, for example, spatially representing the building hull, a room within a building or a single wall surface just by a point cloud. All thematic feature types including transportation objects, vegetation, city furniture, etc. can also be spatially represented by point clouds. In this way, the ClearanceSpace of a road or railway could, for instance, be modelled directly from the result of a mobile laser scanning campaign. Point clouds can either be included in a CityGML dataset or just reference an external file of some common types such as LAS or LAZ."

5.2. Moving Features

Topic: Is the OGC geometry model sufficient to support 3D Moving Features?

ISO 19141 is the standard for Moving Features. It introduces Feature Properties whose values are a function of an input parameter. Typically that parameter is time.



5.2.1. Basic Concepts

Volume and Boundary surface

ISO 19107 provides us with the GM_Object and GM_Boundary classes. GM_Object represents the space that is occupied by a geometry. GM_Boundary represents a surface which forms the boundary between inside and outside of the associated GM_Object. GM_Object and GM_Boundary are both specialized according to the number of dimensions they support.

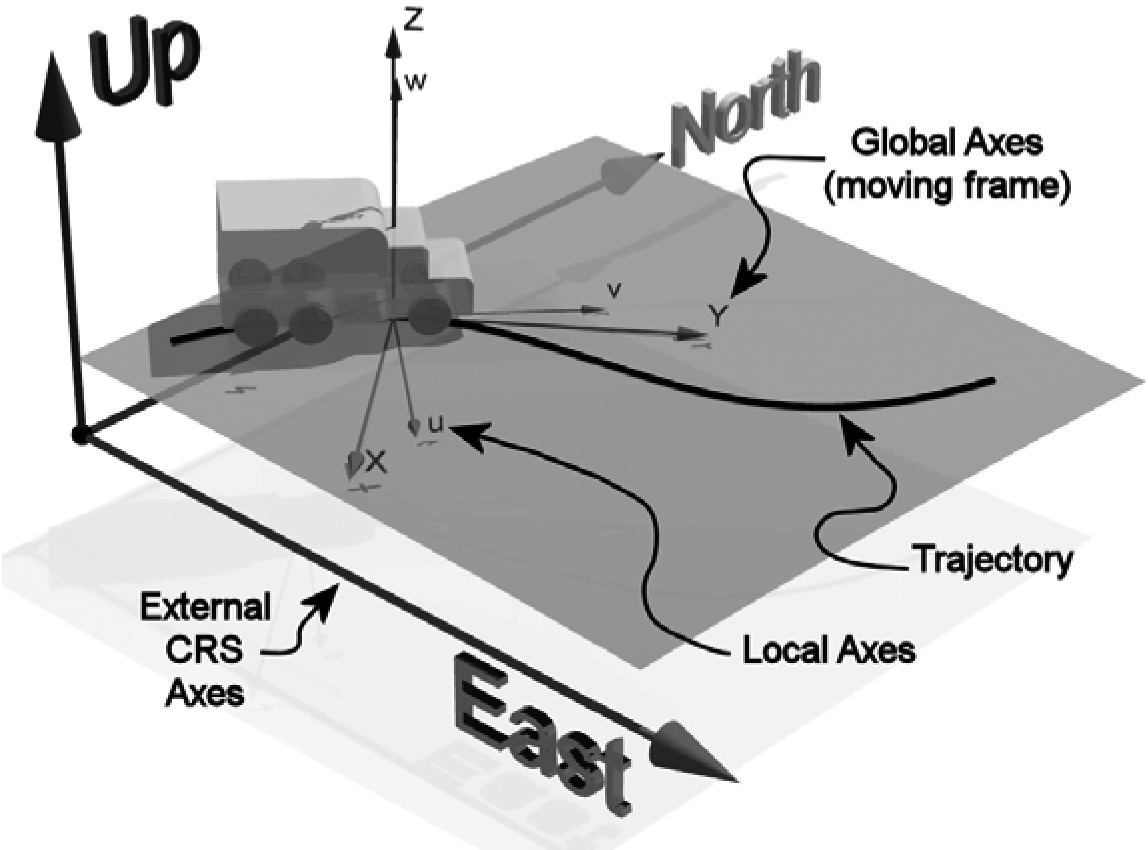
Location and shape

The location of a Feature is a single GM_Point which represents its current position in the universe.

GM_Point is a geometry of zero dimensions, but is specified with values of all of the applicable coordinate axis.

The Shape of a Feature is the bounding geometry. Shape tells you nothing about where a Feature is but does specify the volume of the space it occupies.

Coordinate systems



Moving Features deal with three spatial coordinate systems; External, Global, and Local.

The External coordinate system is the coordinate system within which the Moving Feature exists. Typically this is an Earth-centric geographic CRS.

The Global coordinate system is describes the area external to the Feature at a specific time. It is mostly used to identify the loctation and orientation of the Feature in regards to the path (tranjectory) in which it is traveling.

The local coordinate system is internal to the Feature. This is usually a cartisian coordinate system with the origin at a prominant point in the Feature such as the center of mass. The origin of the local coordinate system should also be the point where the location and orientation of the Feature is measured.

5.2.2. MF_OneParameterGeometry

We start our discussion with the class MF_OneParameterGeometry. MF_OneParameterGeometry is a subclass of GM_Object. So moving features have the 3D geometric properties of any other GM_Object. What is different is that this geometry can change as a function of a parameter. A one parameter set of geometries is defined as "a function f from an interval t Î [a, b] such that f(t) is a geometry and for each point P Î f(a) there is a one parameter set of points (called the trajectory of P) P(t) : [a, b] ® P(t) such that P(t) Î f(t). A leaf of a one parameter set of geometries is the geometry f(t) at a particular value of the parameter".

A one parameter geometry instance includes a "leafgeometry()" operation. This operation takes the parameter (t) as input and returns the leaf P(t) for that parameter as a GM_Object.

5.2.3. MF_TemporalGeometry

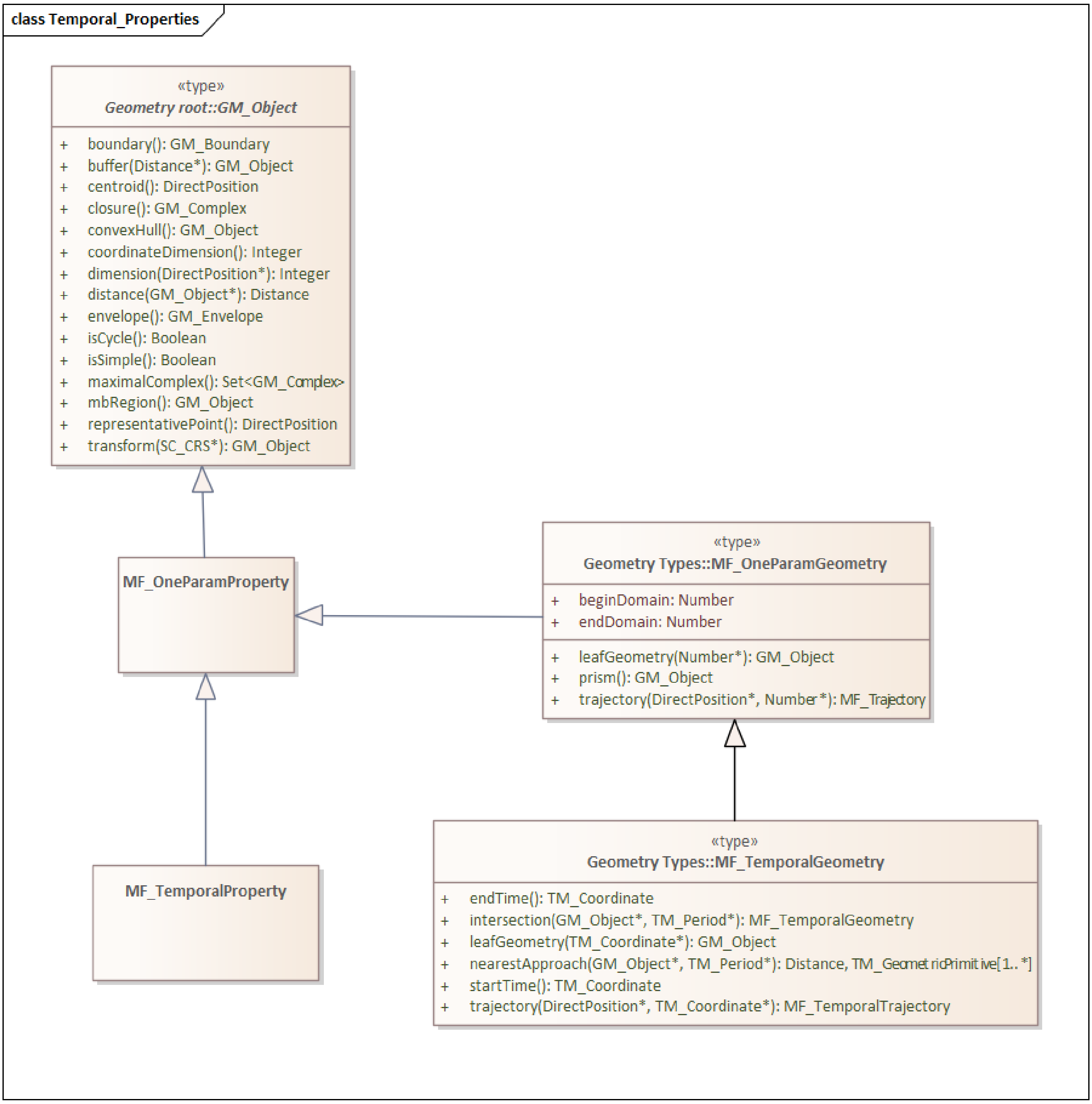
An MF_TemporalGeometry is a MF_OneParameterGeometry where the parameter is Time expressed as a TM_Coordinate. TM_Coordinate is specified in ISO 19108; it expresses time as a multiple of a single unit of measure such as year, day, or second. The "leafgeometry()" operation of an instance of MF_TemporalGeometry would take a TM_Coordinat in as input and return a GM_Object instance representing the geometry of the Feature at the specified point in time.

5.2.4. Temporal Properties

The JSON encoding of the OGC Moving Features standard introduces the concept of temporal properties.

"A TemporalProperties object is a JSON array of ParametricValues objects that groups a collection of dynamic non-spatial attributes and its parametric values with time."

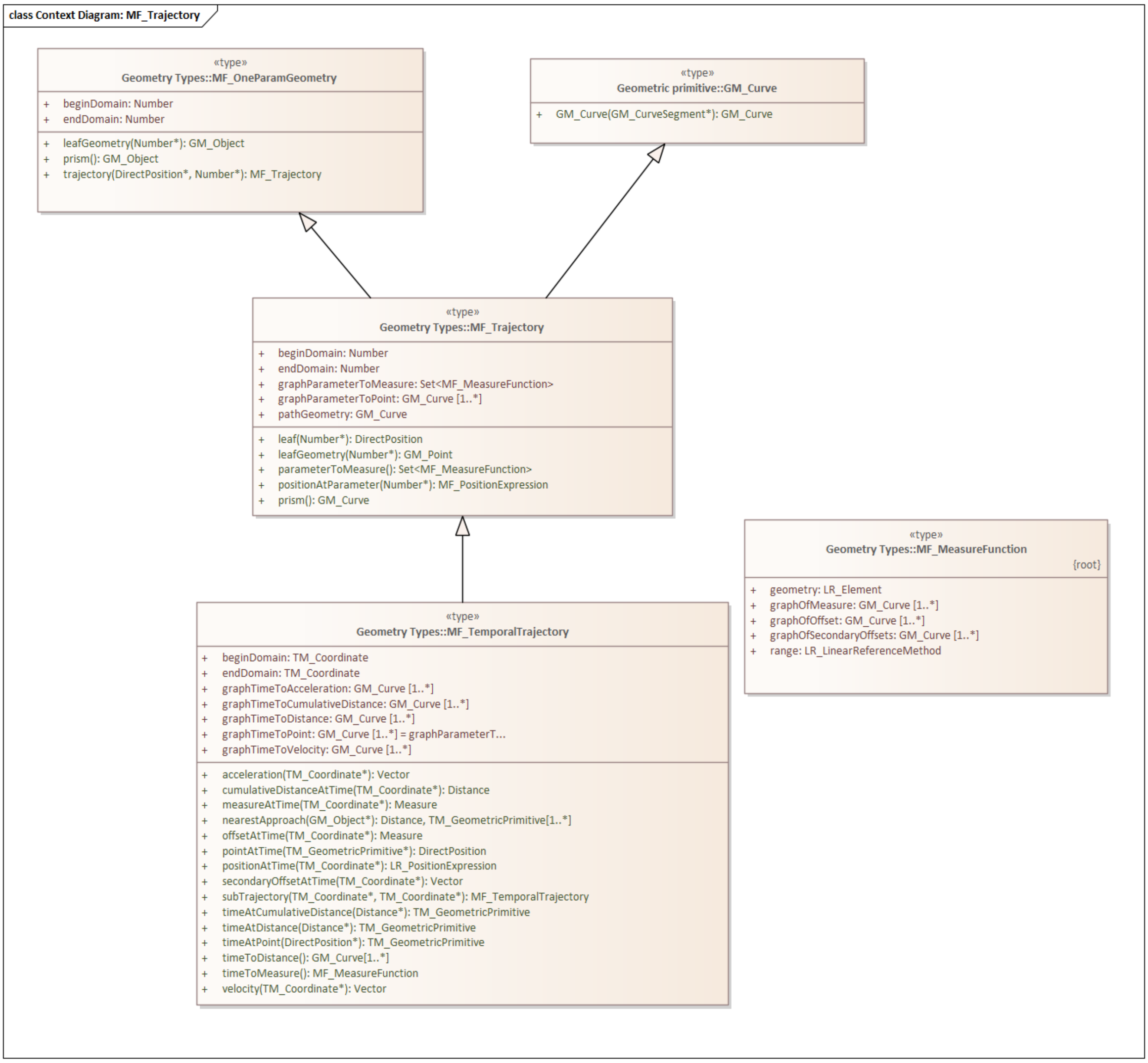
Logically TemporalProperties should be a subclass of OneParamProperties. Since Geometry is a property, then MF_TemporalGeometry should be a subclass of TemporalProperties. Which gives us the following UML.



Temporal properties are particularly useful for capturing state change. For example, the fuel load of an aircraft will change over time. The leafproperty() operation on a temporal fuel_load object would return the amount of fuel onboard at the specified time.

5.2.5. MF_TemporalTrajectory

A trajectory is a curve (GM_Curve) which represents the path that a Moving Feature takes as it moves. In other words, it represents the location of the Feature as a function of time.

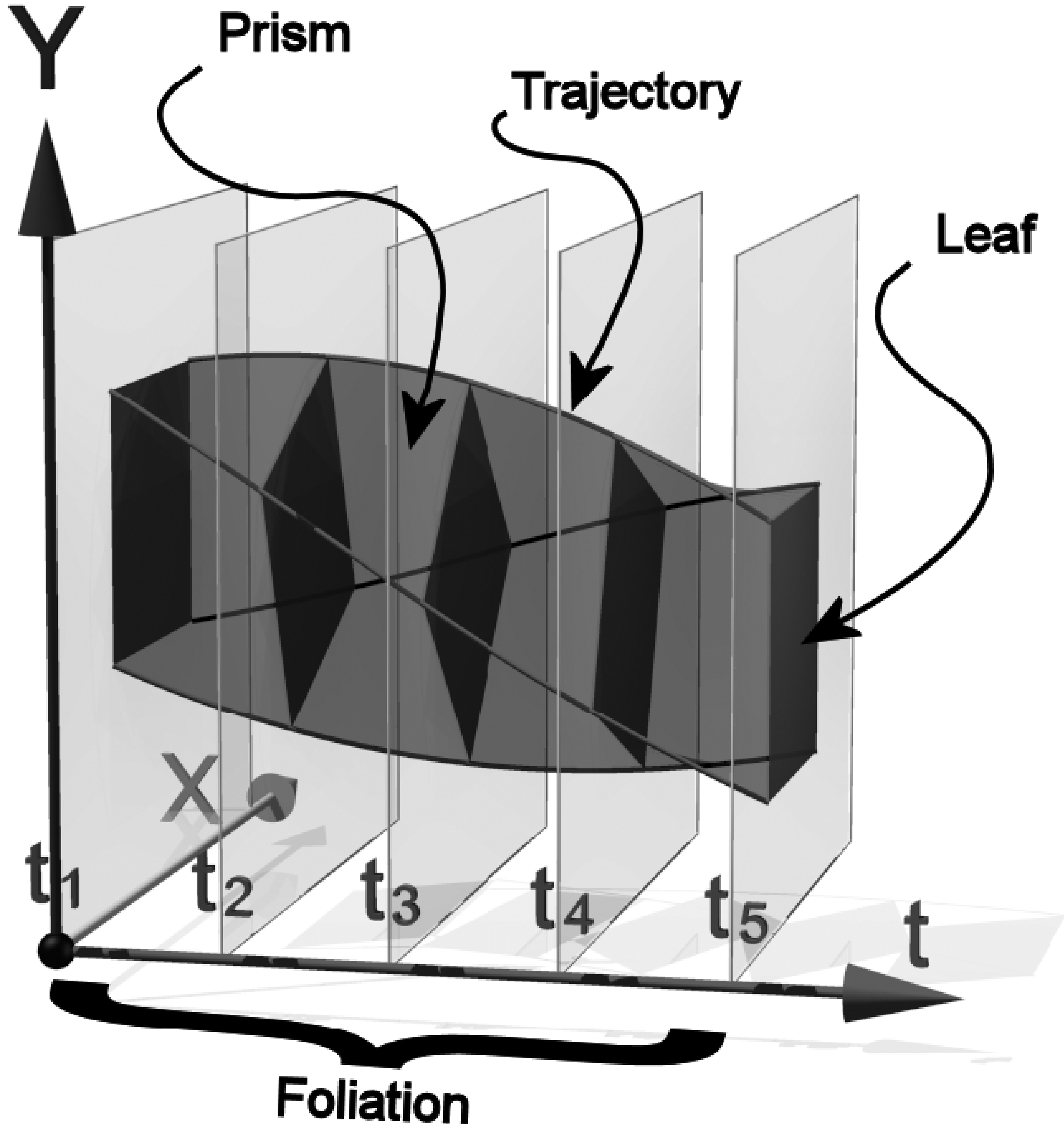


A Trajectory has two operations of particular interest; leaf() and leafgeometry(). The parameter for a Temporal Trajectory is always time (TM_Coordinate). One limitation of a trajectory is that it only represents location and orientation.

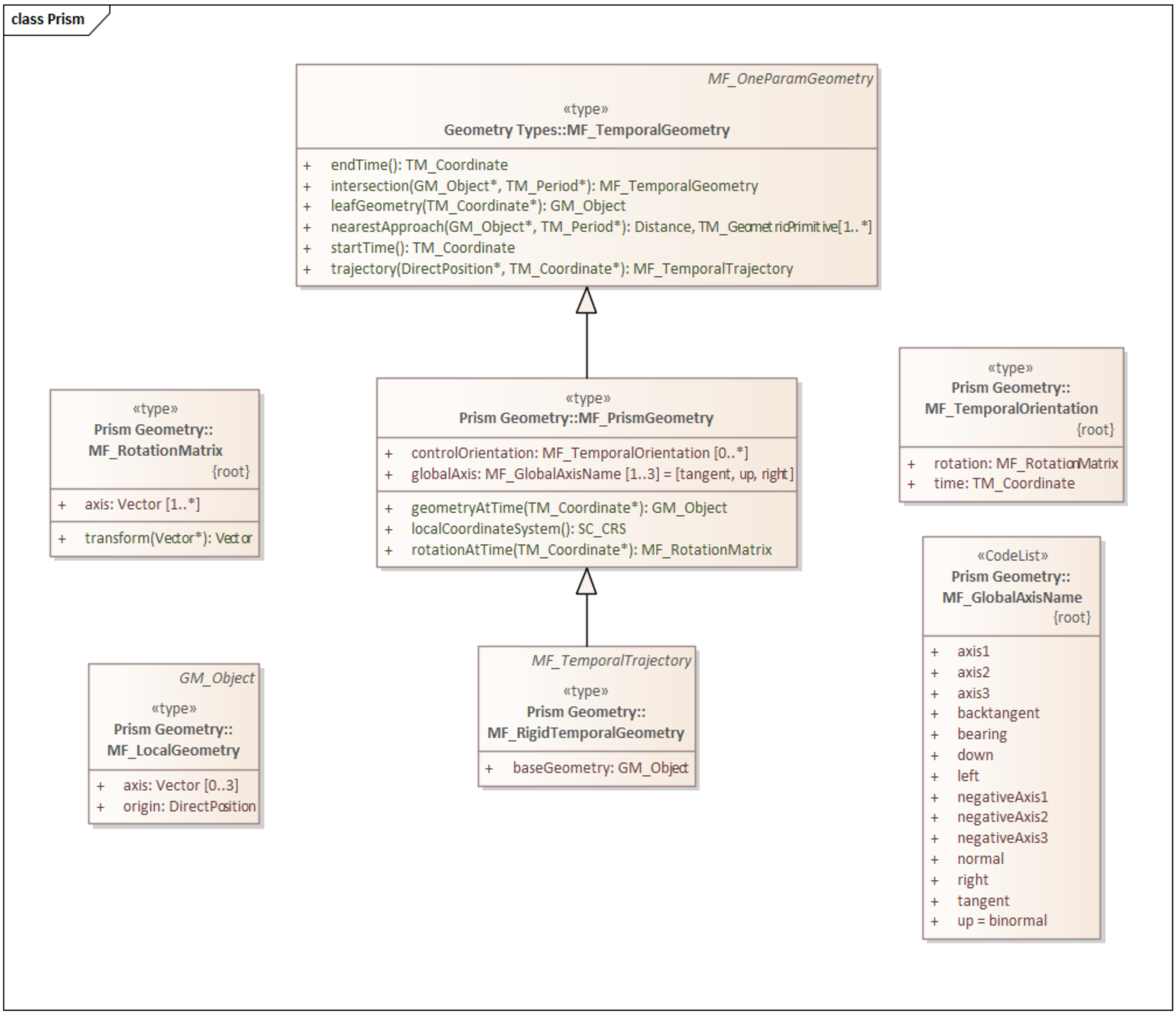
The leaf() operation returns the direct position that the trajectory passes at that value of the trajectory parameter. This is a point on the trajectory GM_Curve geometry. It typically serves as the origin of the Global CRS with the local tangent designating the X axis.

The LeafGeometry() operation returns the GM_Point that is at that position on the trajectory. This is the geometry of the Moving Feature expressed in the Local CRS. Since trajectories only convey location, only GM_Point geometries are supported.

5.2.6. MF_PrismGeometry



A Prism Geometry provides additional geometric information for a trajectory.



A trajectory provides the location of a Moving Feature as a function of time. Prism Geometry represents the full geometry (location, orientaion, and shape) of the Feature as a function of time.

Like a Temporal Trajectory, a Prism is a subclass of MF_TemporalGeometry. Prisms and Trajectories work together to provide this representation

The association role "originTrajectory" associates a Temporal Trajectory with a Prism. For any TM_Position, the associated Temporal Trajectory provides the location of the Moving Feature in the Global CRS. This point serves as the origin of the Local CRS.

The localCoordinateSystem() operation returns a SC_CRS for the design coordinate reference system in which the moving feature's shape is defined.

The rotationAtTime() operation accepts a time in the domain of the prism geometry and returns the rotation matrix that embeds the local geometry into geographic space at a given time (TM_Coordinate). The vectors of the rotation matrix allow the feature to be aligned and scaled as appropriate to the vectors of the global coordinate reference system.

This one association and two operations provide us with the location, orientation, axis definition, and units of measure needed to define identify the local CRS and to transform geometries between the Local and Global CRS.

Finally, the geometryAtTime() operation accepts a time in the domain of the prism geometry and returns the geometry of the moving feature, as it is at a given time in the global coordinate reference system. The return type is a GM_Object so this operation is not limited to points. It is fully capable of representing a 3D surface and volume.

5.2.7. Non-rigid Bodies

ISO 19141 only addresses rigid bodies. The shape returned by a geometryAtTime() operation will always be the same. However, it leaves open the opportunity to extend the Moving Feature model to support plastic (non-rigid) objects.

ISO 19141 postulates that trajectories can be used to represent non-rigid Features. This requires that each node on the geometry of the surface have its own trajectory. The shape of the Feature is defined by the bundle of trajectories for the surface points.

An alternate approach is to take advantage of temporal geometry to capture changes in the shape of a Feature as a function of time.

There are arguments for and against each approach. And an opportunity to do some valuable work.

5.3. Articulated Geometries

Given a suite of standards which allow you to define time-variant geometric elements, then the next step is to take a collection of those elements and assemble them into a complex object.

An articulated geometry is such an aggregation where each element has less than 6 degrees of freedom. Each element can move, but its movement is constrained by attachment to one or more additional elements.

The aggregate as a whole can also move, but that movement becomes more complex. typically we would model movement of the whole as a trajectory of the center of mass. However, the center of mass of an articulating Feature will change as the relative position of the elements change.

5.3.1. GeoPOSE

The Frame Transform is a representation of the transformation taking an Outer Frame coordinate system to an Inner Frame coordinate system. This abstraction is constrained in GeoPose v 1.0 to only allow transformations involving translation and rotation. The intention is to match the usual concept of a pose as a position and orientation. The formalism that expresses a GeoPose Frame Transform is a pair of Reference Frames, Outer and Inner, each defined by a Frame Specification.

A pose has a valid time (GeoPose_instant)

Discuss outer frame vs Inner Frame

EPSg 4979 is basis for all frames?

insert figure 8

Sequence

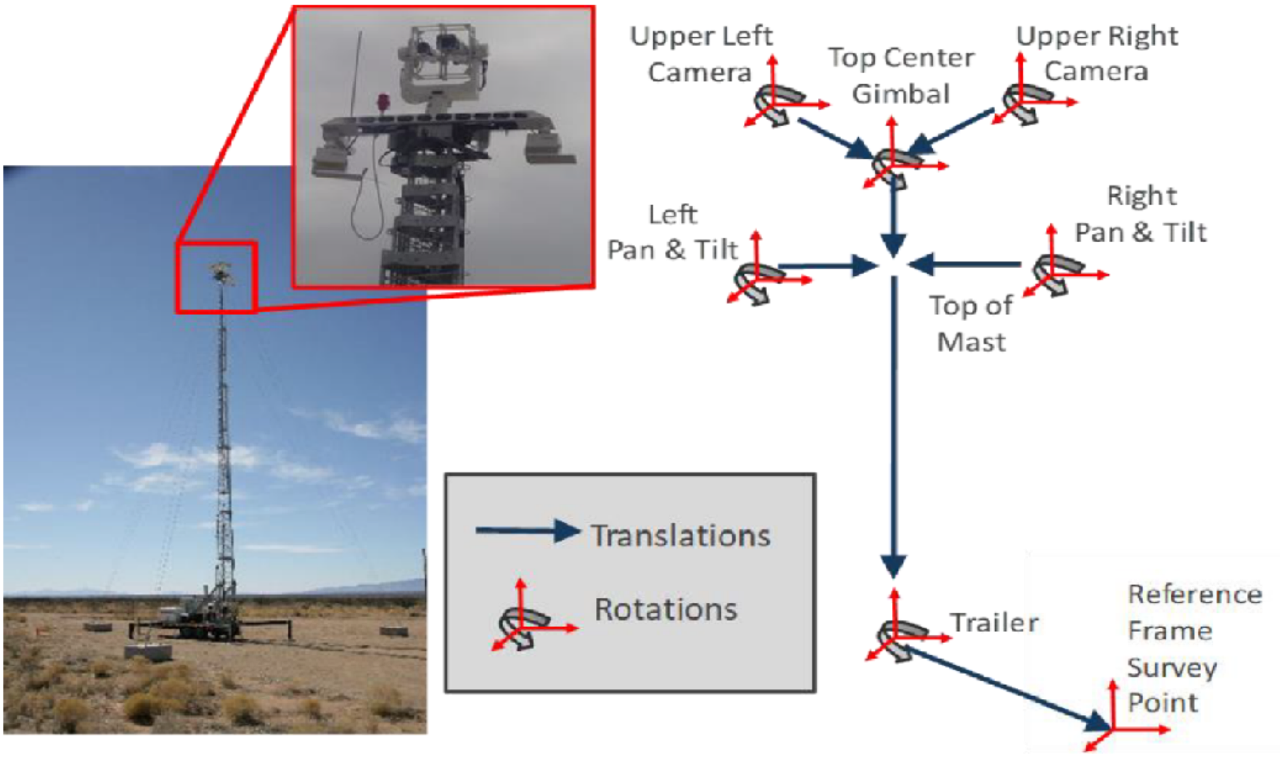
The sequence logical model defines a method for packaging of GeoPose data, where multipleGeoPoses in a sequence share the same Outer Frame and there is a time-dependent changing Inner Frame.

5.3.2. MISB Staging System

MISB 1906 Motion Imagery Metadata (MIMD): Staging System

"The Motion Imagery Metadata (MIMD) Model includes locations, orientations, and kinematics (velocity, acceleration, etc.) of platforms, gimbals, sensors, sensor elements, geospatial and other points. The locations and orientations are either absolute references to a well-known frame of reference (e.g., WGS84) or relative references to other locations and orientations. Each location and orientation pairing define a “stage” that has the potential to be the frame of reference for another location and orientation. Linking stages together forms the Staging System. The Staging System then defines an ability to describe, in metadata, the physical make-up and configuration of a system and the time varying physical relationships of the system and its sub-system components."

The MISB Staging System was designed to capture the instateneous configuration of an articulated sensor system.



Example Motion Imagery System with Multiple Sensors and Gimbals (Photo credit White Sands Missile Range)

Stage: a single frame of reference located at a point. It defines the location, orientation, and kinemantics of a coordinate system located at that point. These properties can be defined in terms of absolute values, or as relative values measured from an "parent" reference system.

Constellation: A system of one or more stages where the parent-child relationships between the stages is sufficient to calculate the absolute values for every stage.

Root Stage: This is the starting point for a Constellation. This stage is expressed in absolute values.

Table 1. Stage System Example

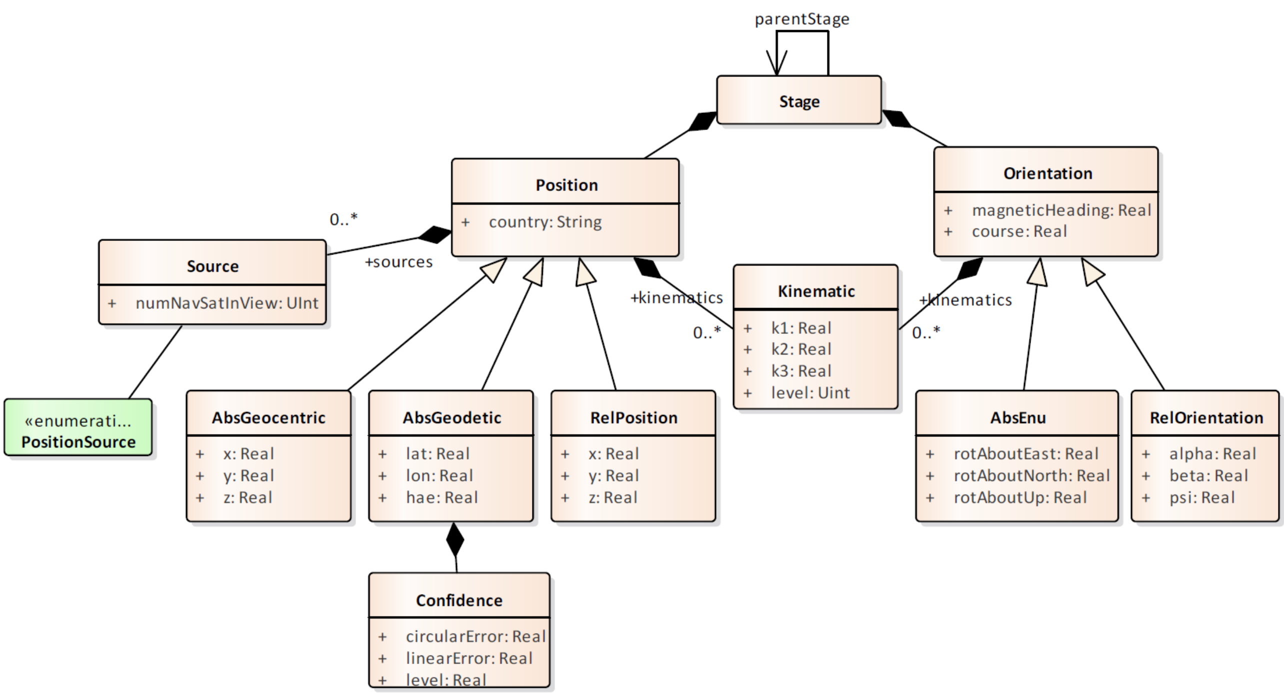
Stage	Component	Parent	Values
1	Reference Frame Survey Point	0	Absolute Position/Orientation
2	Trailer	1	Relative Position / Orientation
3	Left Camera	2	Relative Position / Orientation
4	Right Camera	2	Relative Position / Orientation
5	Top Center Gimbal	2	Relative Position / Orientation
6	Left Upper Camera	5	Relative Position / Orientation
7	Right Upper Camera	5	Relative Position / Orientation

The Staging System's absolute positions use either WGS84 Ellipsoid angular coordinates (i.e., geodetic Latitude, Longitude, Height above Ellipsoid (HAE)), or WGS84 geocentric Earth-Centered Earth-Fixed (ECEF) Cartesian coordinates (i.e., X, Y, Z).

The Staging System's relative positions use Cartesian coordinates (i.e., x, y, z) measured in meters from the parent stage frame of reference.

The Staging System's orientations use Euler rotations, measured in radians, around three axes (X, Y, and Z) of a righthanded coordinate system. The Staging System's absolute orientation has the X, Y, and Z axes aligned with the East, North, and Up (ENU) respectively.

The Staging System standardizes rotations to use a specific order of rotations. The Staging System uses Tait-Bryan angles with a Primary Rotation Order of Z-Y-X (see Appendix C); thereby the first rotation is around the Z-axis, the second rotation is around the new Y-axis (after rotation around the Z-axis), the final rotation is around the new X-axis (after rotation around the Z and then Y axes).



The Staging system does not explicity address temporality. However, this information is passed in the MISB KLV metadata stream. As such, each update is associated with the precision time stamp of that packet. In addition, an update can be associated with a Timer as described in section ----

5.3.3. Discussions

Quaternions vs. Euler rotations

Temporal representation

Standarize on a right-handed Cartisian coorinate system for all stages/Poses?

Common concepts:

1. An "anchor" node which ties the relative coordinates to an absolute CRS
2. Local coordinate systems associated with each other through standardized transformations

5.4. Mass Properties

Consider an articulated vehicle in free-flight. As the components change position, they change the center of mass, priciple axis of rotation, and a number of other mass properties. These changes affect the dynamic behavior of the vehicle. Most designers take great care to assure that problems cannot occur. But that doesn’t mean we should ignore the issue.

Comments?

5.5. Temporal Reference Systems

Proposition: Time is in the eye of the beholder. So all measurements of time must be local.

Dynamic Features are not tied to an Earth-centered static existance. Yet the concepts of time used in the geospatial community are almost exclusivly based on Earth-centric astronomical phenomena. They also assume a rather coarse degree of granularity. For dynamic features we need to use local clocks with precision down to the nanosecond. We are less concerned with absolute time than with relative time. State B was achieved 37 nanoseconds after State A.

It’s only when we begin aggregating these dynamic elements that we begin to worry about "absolute" time. Even then, we are more likely to convert from one local clock to another then to convert to an absolute time.

So if all time is local, we need a Temporal Reference System concept which captures the parameters needed to transform across TRS. A temporal equivalent to GeoPOSE.

Introduce the Timer concept from MISB.

Calendars and clocks

Local vs "Global" clocks

POSIX time is tied to a global datum, a calendar.

Local time is tied to a local counter.

Analogous to a Spatial Reference System vs. an Engineering CRS.

Is there an analog in the temporal world for the CRS transormation model?

5.6. Dynamic Features at Relativistic Velocities

At very high velocities, measurements between moving features sufer from relativistic effects. The proposition is to build on Minkowski SpaceTime to address these cases.

5.6.1. Lorentz Transformation

A transformation between two different coordinate frames that move at a constant velocity and are relative to each other.

ONly related to changes in inertial reference frames:

- Inertial frames - motion with a constant velocity
- Non-inertial frames - rotational motion with constant angular velocity, acceleration in curved paths.

In the reference frame "F" which is stationary, the coordinate defined are x, y, z, and t. In another reference frame F' which moves at a velocity v which is relative to F and the observer defines coordinate in the moving reverence frame as x', y', z', t'. In both the reference frames the coordinate axis are parallel and they remain mutually perpedicular. The relative motion is along the xx' axes. At t = t' = 0, the origins in both reference frames are the same (x,y,z) = (x',y',z') = (0,0,0).

The Lorentz factor g = 1 / (sqrt(1 - (v^2 / c^2)))

x' = g(x-vt) t' = g(t-(vx/c^2)) y' = y z' = z

This is not a complete coordinate transformation since F' has to be rotated and translated so as to be co-linear with F. However, it does add the impact that relative velocity (v) has on the measurements of x and t. In most cases this impact is neglegible (v^2 / c^2 approaches 0). However, when v is a significant percentage of c it should be applied.

5.6.2. Minkowski Space Time

It is basically a combination of 3-dimensional Euclidean Space and time into a 4-dimensional manifold, where the interval of spacetime that exists between any two events is not dependent on the inertial frame of reference.

Minkowski spacetime is a 4-dimensional coordinate system in which the axes are given by (x, y, z, ct)

Where ct is time (t) times the speed of light (c)

ds^2 = -c^{2dt}2 + dx^2 + dy^2, + dz^2 = the differential arc length in space time where:

1. dt = change in time
2. dx = change in x direction
3. dy = change in y direction
4. dz = change in z direction

Key point - while a Lorentz transformation deals with spatial measurements, Minkowski space includes time as part of that space-time. Thus ds is an arc length through space-time as opposed to a difference in x as in the Lorentz transform.

Question, since $c^{2dt}2$ is a negative term, does that inply that ct is an imaginary number orthagonal to x, y, and z (cti) such that i^2 = -1?

Yes for complex Minkowski space time. Here it is expressed as x^2 + y^2 + z^2 + (ict)^2 = const.

Complex Minkowski spacetime was replaced with real Minkowski space time where time is a real coordinate rather than an imaginary one.

Where v is velocity, and x, y, and z are Cartesian coordinates in 3-dimensional space, and c is the constant representing the universal speed limit, and t is time, the four-dimensional vector v = (ct, x, y, z) = (ct, **r**) is classified according to the sign of (c^2 t^2) − r^2. A vector is **timelike** if (c^2 t^2) > r^2, **spacelike** if (c^2 t^2) < r^2, and **null** or **lightlike** if (c^2 t^2) = r^2. This can be expressed in terms of the sign of η(v, v) as well, which depends on the signature. The classification of any vector will be the same in all frames of reference that are related by a Lorentz transformation (but not by a general Poincaré transformation because the origin may then be displaced) because of the invariance of the interval.

Annex A: Bibliography

Hughes, P. :Spacecraft Attitude Dynamics, Dover Publications Inc. 2024

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Annex B: Revision History

Date	Release	Editor	Primary clauses modified	Description
2016-04-28	0.1	G. Editor	all	initial version