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OGC® Moving Features Encoding Part I: XML Core

Warning

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License Agreement

Contents

i. Abstract

This OGC® Standard specifies standard encoding representations of movement of geographic features. The primary use case is information exchange.

ii. Keywords

ogcdoc, ogc document, moving features, gml

iii. Submitting organizations

The following organizations submitted this Implementation Standard to the Open Geospatial Consortium

a) Central Research Laboratory, Hitachi Ltd.

b) Center for Spatial Information Science, The University of Tokyo

c) Defense Systems Company, Hitachi, Ltd.

iv. Submission contact points

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

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v. Changes to the OGC® Abstract Specification

The OGC® Abstract Specification does not require changes to accommodate this OGC® standard.

Foreword

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights. However, to date, no such rights have been claimed or identified.

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

OGC Moving Features consists of the following parts under the general title *Moving Features Encoding*:

- *Part I:XML Core*
- *Part II: Simple CSV*

Introduction

Applications using **moving feature** data, typically representing vehicles or pedestrians, are rapidly increasing. Innovative applications are expected to require the overlay and integration of moving feature data from different sources to create greater social and business value. Examples of applications that require integrated simulation are disaster risk management, traffic information services, security services, navigation for robots, aviation or maritime traffic monitoring, and wildlife tracking and conservation. Moreover, systems relying on single-source moving feature data are now evolving into more integrated systems. Integration of moving feature data from different sources is a key to developing more innovative and advanced applications.

Efforts in this direction therefore should be encouraged by ensuring smoother data exchange because handling and integrating moving feature data will broaden the market for geo-spatial information such as Geospatial Big Data Analysis. ISO 19141:2008 is an existing abstract standard to model moving features; however encoding method is not provided.

Therefore, an XML (and GML) style encoding for Moving Features is standardized. The defined encoding standard is *ISO 19141:2008 Geographic Information – Schema for Moving Features* compliant implementation standard applicable for massive data handling. ISO 19141:2008 defines a method to describe the geometry of a feature that moves as a rigid body.

OGC® Moving Feature Encoding Part I: XML Core

1 Scope

This OGC™ Standard specifies an encoding format to describe the geometries of many features that move as rigid bodies. This OGC® Standard is applicable to features having the following characteristics.

a) Each moving feature can be described with Schema for Moving Features (ISO19141: 2008).

b) The number of features simultaneously encoded with this format can be massive (many thousands of features).

c) All features can be described using common space-time coordinates.

This standard does not address all types of moving features. Examples of features that are out of scope include the following:

– Deforming features, such as flood water.

– Feature's geometric representation should not be encoded inline in a geometric complex that contains the geometric representations of other features, since this would require the other features' representations to be updated as the feature moves.

This standard is focused on the encoding format, thus Web interface and inertial data models are out of scope also.

2 Conformance

Conformance with this specification shall be checked using all the relevant tests specified in Annex A (normative).

3 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of OGC Moving Features. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of OGC Moving Features are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

[OGC 07-036] OGC 07-036, OpenGIS® Geography Markup Language (GML) Encoding Standard

[ISO 19141:2008] ISO 19141:2008, Geographic information – Schema for moving features

[IETF RFC 2396] IETF RFC 2396, Uniform Resource Identifiers (URI): Generic Syntax. (August 1998)

[W3C XML] W3C XML, Extensible Markup Language (XML) 1.0 (Third Edition), W3C Recommendation (4 February 2004)

[W3C XML Namespaces] W3C XML Namespaces, Namespaces in XML, W3C Recommendation (14 January 1999)

[W3C XML Schema Part 1] W3C XML Schema Part 1, XML Schema Part 1: Structures, W3C Recommendation (2 May 2001)

[W3C XML Schema Part 2] W3C XML Schema Part 2, XML Schema Part 2: Datatypes, W3C Recommendation (2 May 2001)

4 Terms and definitions

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

4.1
Moving feature
representation, using a local origin and local ordinate **vectors**, of a **geometric object** at a given reference time

[ISO 19141:2008]

4.2
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]

4.3
geometric object
spatial object representing a geometric set

[ISO 19107:2003]

4.4
leaf
<one parameter set of geometries>

geometry at a particular value of the parameter

[ISO 19141:2008]

4.5
trajectory
path of a moving point described by a **one parameter set of points**

[ISIO19141:2008]

4.6
one parameter set of geometries
function f from an interval t □ [a, b] such that f(t) is a geometry and for each **point** P □ 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) □ f(t)

[ISO 19141:2008]

4.7
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]

4.8
period
one-dimensional **geometric primitive** representing extent in time

[ISO 19141:2008]

4.9
point
0-dimensional **geometric primitive**, representing a position

[ISO 19107:2003]

4.10
geometric primitive
geometric object representing a single, connected, homogeneous element of space

[ISO 19107:2003]

4.11
vector
quantity having direction as well as magnitude

[ISO 19123:2005]

5 Conventions

5.1 Symbols (and abbreviated terms)

ISO	International Organization for Standardization
OGC	Open Geospatial Consortium
UML	Unified Modeling Language
XML	Extensible Markup Language
1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
CSV	Comma Separated Values

5.2 UML Notation

The diagrams that appear in this standard are presented using the Unified Modeling Language (UML) static structure diagram. The UML notations used in this standard are described in the diagram below.

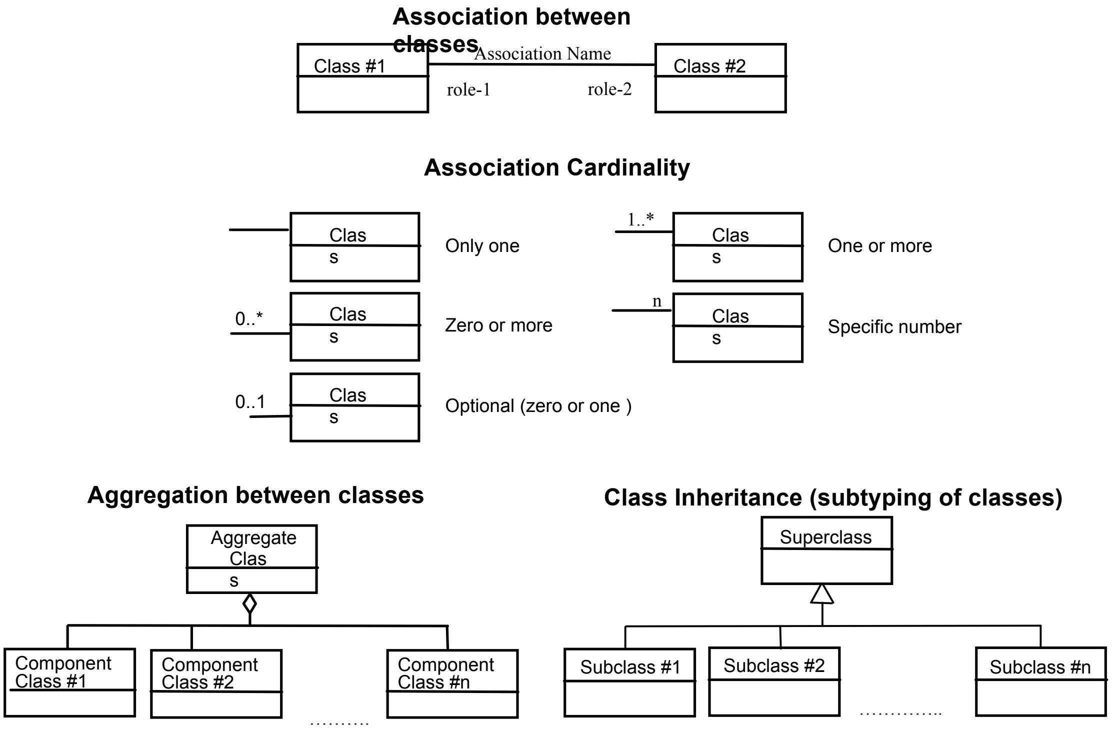


Figure Error! Bookmark not defined. — **UML notation**

In this standard, the following three stereotypes of UML classes are used:

a) <<Interface>> A definition of a set of operations that is supported by objects having this interface. An Interface class cannot contain any attributes.

b) <<DataType>> A descriptor of a set of values that lack identity (independent existence and the possibility of side effects). A DataType is a class with no operations whose primary purpose is to hold the information.

c) <<CodeList>> is a flexible enumeration that uses string values for expressing a list of potential values.

In this standard, the following standard data types are used:

a) CharacterString – A sequence of characters

b) Integer – An integer number

c) Double – A double precision floating point number

d) Float – A single precision floating point number

5.2 XML Namespaces

All components of the Moving Feature XML schema are defined in the namespace with the identifier "http://www.opengis.net/movingfeatures/1.0", for which the prefix mf or the default namespace is used within this Standard.

6 Data Model Overview

6.1 Concepts and standard modularity

Figure 1 illustrates the standard components for encoding and communicating Moving Features data. The four boxes drawn in the figure portray the four modules defined in the OGC® Moving Features standard.

OGC® Moving Features Simple CSV Encoding and Simple Binary Encoding are fundamental and are data formats to describe moving points and their trajectories. The formats are designed to encode trajectories of moving points compactly as application schemas of IETF RFC 4180 (CSV), NetCDF Discrete Sampling Geometry and so on.

OGC® Moving Features Core, defined in this document, is represented by an XML data encoding for moving points and their trajectories. The format is an extensible format to model and encode movement data for features encoded as point geometries .

OGC® Moving Features 1D/2D Geometry and OGC® Moving Features 3D Geometry are defined to encode moving features that have more complex geometries.

Two UML packages are defined in ISO 19141:2008 [ISO 19141:2008]: "Geometry Types" and "Prism Geometry". "Geometry Types" defines the description model of movements including the paths. "Prism Geometry" defines the moving geometry. The two squares drawn with broken lines in Fig. 1 correspond to these packages. The square labeled as "<<Prism Geometry>>" is an implementation of "Prism Geometry"; the square labeled as "<<Geometry Types>>" is an implementation of "Geometry Types."

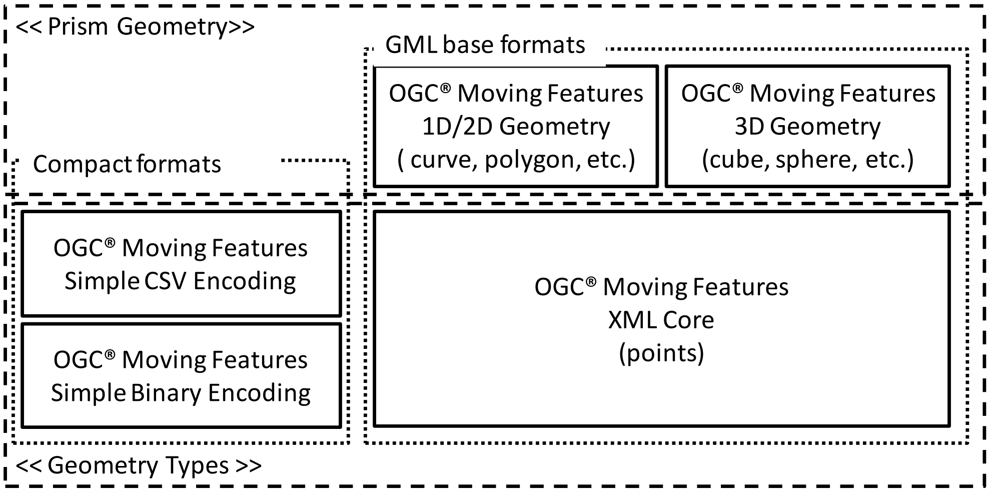

<< Prism Geometry>>
GML base formats
OGC® Moving Features 1D/2D Geometry (curve, polygon, etc.)
OGC® Moving Features 3D Geometry (cube, sphere, etc.)
Compact formats
OGC® Moving Features Simple CSV Encoding
OGC® Moving Features Simple Binary Encoding
OGC® Moving Features XML Core (points)
<< Geometry Types >>

Figure 1. OGC® Moving Features modularity

6.2 Foliation and prisms

Figure 2 illustrates the concepts of foliation, prism, trajectory, and leaf, which are defined in ISO19141:2008[ISO 19141:2008]. In this illustration, a 2D rectangle moves and rotates. Each representation of the rectangle at a given time is a leaf. The path traced by each corner point of the rectangle is a trajectory. The set of points contained in all of the leaves, and in all of the trajectories, forms a prism. The set of leaves also forms a foliation.

The prism of the moving feature can be viewed as a bundle of trajectories of points on the local engineering representation of the feature's geometry. If viewed in a 4 dimensional spatio-temporal coordinate system, the points on the feature at different times are different points.

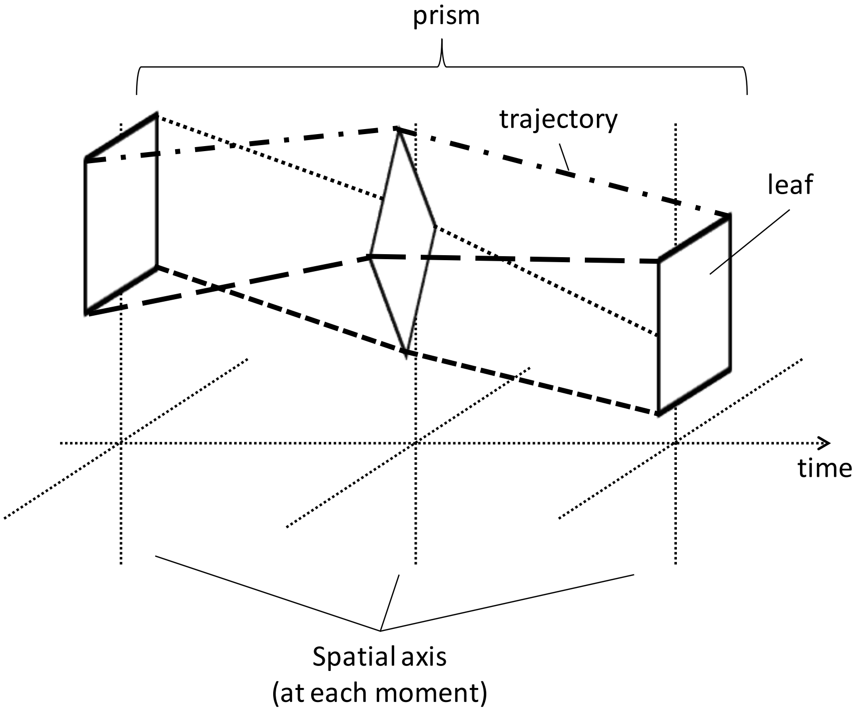


Figure 2. Foliation, prism and trajectory

6.3 XML Implementation

An XML data encoding is defined in this standard for implementing the foliation data model. Note that massive amounts of moving feature data may need to be described with this format. Therefore, the data encoding should be compact and easy to handle. Figure 3 illustrates an importing process for a document written in the XML data format. When dealing with massive numbers of moving features, the entire data set may not be able to be loaded into memory. Therefore, the XML data should be parsed on-the-fly. This means that all information needed for interpretation of the XML data should appear at the head of the document. Thus, the XML document written has two main parts: *header part* and *body part*. The header part, which is implemented as meta elements, includes meta information for the XML data. The body part, which is implemented as foliation elements, includes the movement information for moving features.

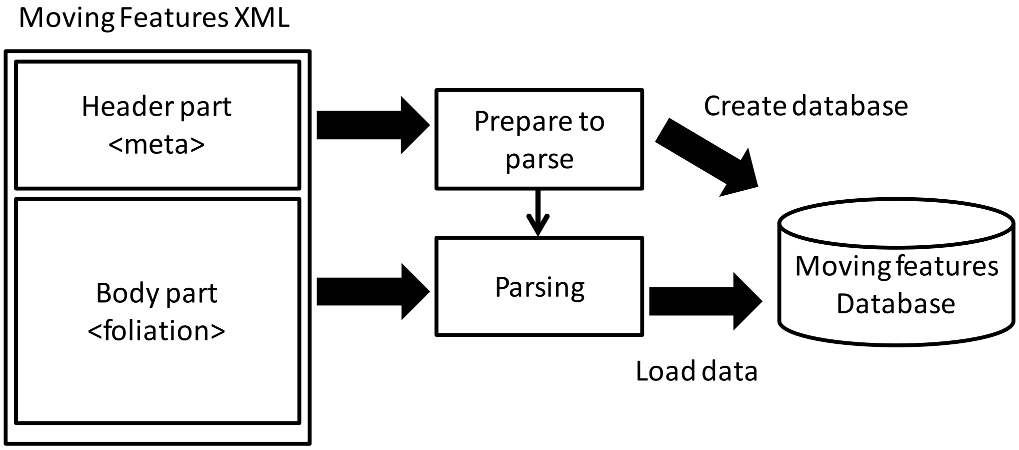


Figure 3. XML parsing

6.4 Time ordered encoding

Figure 4 shows an example for trajectories of three moving points A, B and C. Each trajectory has the start time and the end time. At t=0 (start of all data), all points start moving. Then, at t =1, the movement of A is changed. In the case, the trajectory of A from t=0 to t=1, the trajectory of A from t=1 to t=2, the trajectory of B from t=0 to t=2, and the trajectory of C from t=0 to t=2 are encoded. This means that only changes of state, including moving-speed, direction, existence, and attributes, are encoded in the format. The encoded changes of state are ordered by time in order to determine the states of all features even if only the first half of data is loaded.

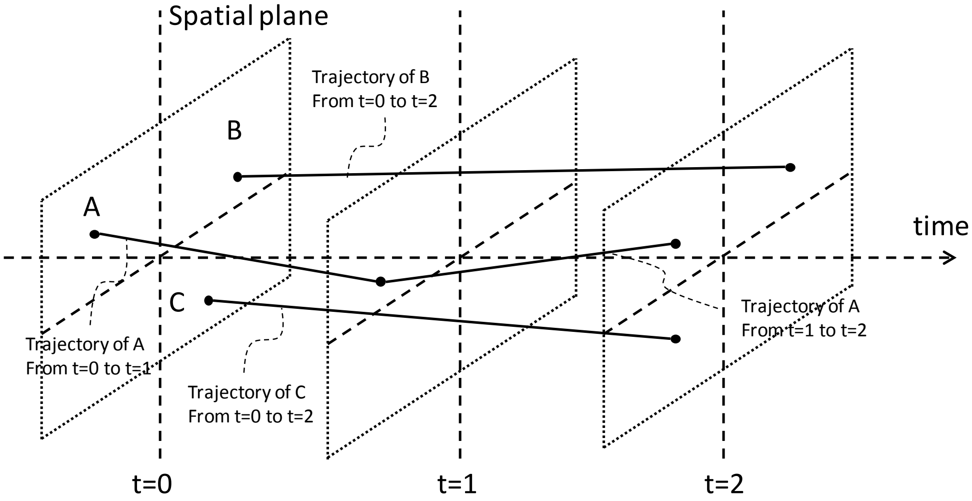


Figure 4. Example of trajectories

7 Root Element

7.1 mf:MovingFeatures

7.1.1 Structure

```
<mf:MovingFeatures gml:id="ID">
   <mf:sTBoundedBy>   ...</mf:sTBoundedBy>[1]
   <mf:member> ...</mf:member>[0,..,n]
   <mf:Header> ...</mf:Header>[0,1]
   <mf:Foliation> ...</Foliation>[0,1]
</mf:MovingFeatures>
```

Superclass: `gml:AbstractFeature` [OGC 07-036]

7.1.2 Description

The root element is named `mf:MovingFeatures`. The `mf:MovingFeatures` element consists of `mf:sTBoundedBy, mf:member`(optional)`, mf:Header` and `mf:Foliation`. The `mf:sTBoundedBy` states the spatio-temporal bound of the trajectories. The `mf:Header` element has meta-information about the moving features, for example, attribute definition. The `mf:Foliation` element, which is the main part of the moving feature data, contains moving geometries.

Requirement 7.1 (req/xmlcore/movingfeatures)
The root element **shall** be `mf:MovingFeatures`.

The class diagram of the `mf:MovingFeatures` is shown below.

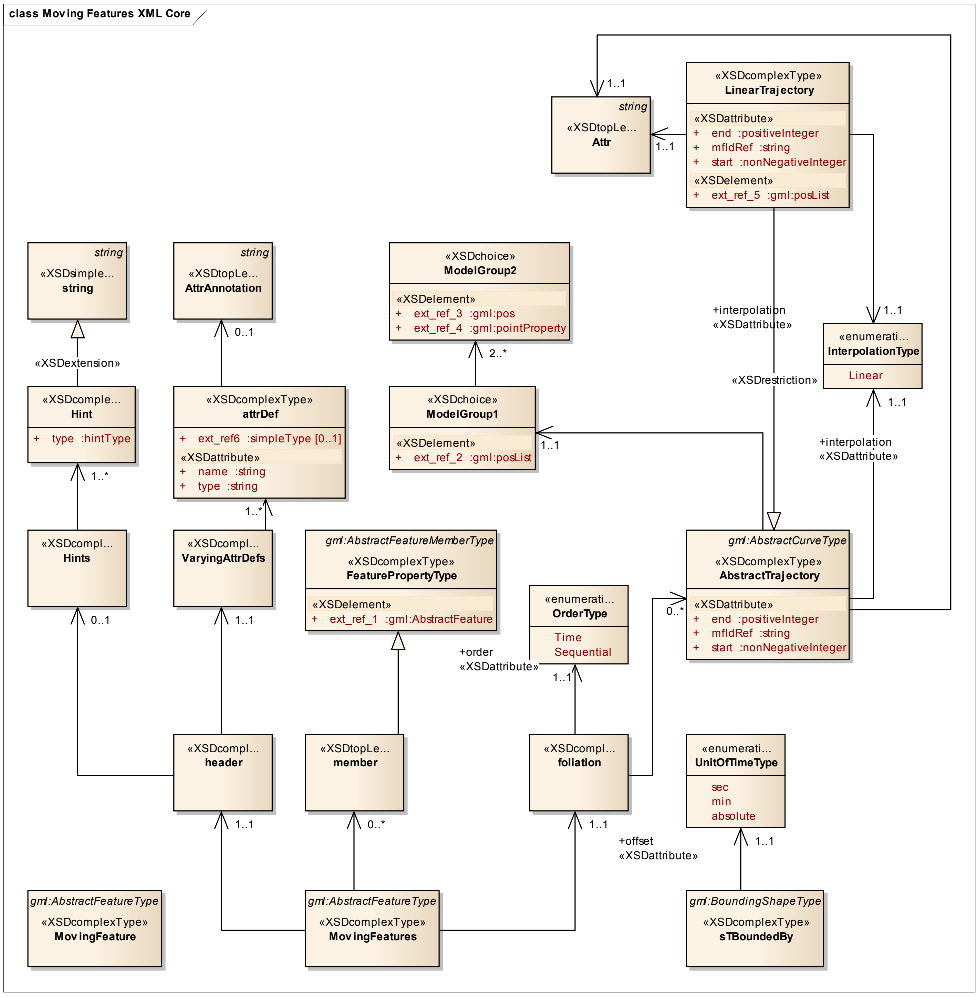


Figure 5. Class diagram of `mf:MovingFeatures`

7.1.3 Content

7.1.3.1 mf:sTBoundedBy

This element regulates the spatio-temporal region where the trajectories described in the foliation exist. Times used in trajectories are described in offset time, that is, duration in seconds or minutes or hours from the time origin defined here is shown in the trajectory elements. The `mf:STBoundedBy` element inherits `gml: BoundingShapeType`, and include `gml:EnvelopeWithTimePeriod` [OGC 07-036].

7.1.3.2 mf:member (optional)

`mf:member` elements give the properties of moving features.

7.1.3.3 mf:Header

`mf:Header` element describes the meta information of the XML document.

7.1.3.4 mf:Foliation

`mf:Foliation` includes movements of moving features. The movements are expressed as spatio-temporal curves, which are included in trajectory elements.

7.2 mf:sTBoundedBy

7.2.1 Structure

```
<mf:sTBoundedby offset=”time unit”>
   <gml:EnvelopeWithTimePeriod>...</gml:EnvelopeWithTimePeriod>
</mf:sTBoundedBy>
```

Superclass: `gml: BoundingShapeType` [OGC 07-036]

7.2.2 Description

The `mf:sTBoundedBy` element indicates the boundary of the moving features. All trajectories are contained in the spatio-temporal boundary specified at `mf:sTBoundedBy`.

7.2.3 Content

7.2.3.1 gml:EnvelopeWithTimePeriod

The `gml:EnvelopeWithTimePeriod` [OGC 07-036] specifies the envelope of the boundary. All moving features included in the foliation should be in the envelope. The used spatial reference system in the envelope (specified by `srsName` and `srsDimension` attributes) is default in the foliation. The coordinate system used for the trajectories should be specified by `srsName`

7.2.4 Attributes

7.2.4.1 offset

The *offset* attribute shows the unit of time used in the mf:Foliation. "start" attribute and "end" attribute of mf:AbstractTrajectory is described the offset from the gml:beginPosition. The unit of time is defined as the offset attribute.

Attribute values	Definitions	Default
sec	the offset described in seconds is encoded in xsd:decimal style	yes
minute	the offset described in minutes is encoded in xsd:decimal style	
absolute	an absolute time description used in the gml:beginPosition	

7.3 mf:member

7.3.1 Structure

```
<mf:member>
  <gml:AbstractFeatureType gml:id="ID">
   ...
  </gml:AbstractFeatureType>
</mf:member>

<mf:member xlink:href="URI" />
```

7.3.2 Description

The contents of mf:member specifies properties of moving features.

7.3.3 Content

7.3.3.1 gml:AbstractFeature

The gml:AbstractFeature gives the properties of the moving feature. The gml:id can be referred to associate the element with mf:mfIdRef.

7.3.4 Attributes

7.3.4.1 xlink:href (optional)

The attribute specifies an URI at which mf:AbstractFeature is given.

7.4 mf:MovingFeature

7.4.1 Structure

```
<mf:MovingFeature gml:id=”ID”>
  <gml:name>...</gml:name>
</mf:MovingFeatue>
```

Superclass: `gml:AbstractFeature` [OGC 07-036]

7.4.2 Description

The **`mf:MovingFeature`** specifies the property of moving features as a kind of `gml:AbstractFeature`. Normally, elements inheriting `gml:AbstractFeature` are defined in an application of Moving Feature XML Core, for example, `app:Vehicle`, `app:Pedestrian`, and so on. The **`mf:MovingFeature`** is predefined for ease to providing properties of features.

8. Header data

8.1 mf:Header

8.1.1 Structure

```
<mf:Header>
   <mf:VaryingAttrDefs>  ...</mf:VaryingAttrDefs>[0,1]
   <mf:Hints> ... </mf:Hints> [0,1]
</mf:Header>
```

8.1.2 Description

The `mf:Header` element contains the meta-information for the XML data.

Requirement 8.1 (req/xmlcore/header/structure):
The contents of `mf:Header` **shall** be `mf:VaryingAttrDefs` or `mf:Hints` or both. If both are included, `mf:VaryingAttrDefs` **shall** appear earlier then `mf:Hints`.

8.1.3 Content

8.1.3.1 mf:VaryingAttrDefs

This element defines attributes used in the foliation (see 8.3). If the moving features do not have any variable attributes, this element can be omitted.

8.1.3.2 mf:Hints

Hints element shows the optional information which is helpful for data processing.

8.2 **mf:VaryingAttrDefs**

The `mf:VaryingAttrDefs` element specifies the available attributes in the XML document. The `mf:VaryingAttrDefs` element contains `mf:AttrDef` elements to enumerate the attribute name and the type of contents.

8.2.1 Structure

```
<VaryingAttrDefs>
   <AttrDef ... />[0...*]
</VaryingAttrDefs>
```

8.2.2 Description

`mf:VaryingAttrDefs` states the definition of attributes used in the foliation.

Requirement 8.2 (req/xmlcore/varyingattrdefs):
`mf:VaryingAttrDefs` **shall** include `mf:AttrDef`, otherwise the content is empty.

8.2.3 Content

8.2.3.1 **mf:AttrDef**

The element indicates a definition of an attribute used in the foliation.

8.3 **mf:AttrDef**

8.3.1 Structure

```
<mf:AttrDef>
   <xsd:simpleType name="">
    ...
     <xsd:annotation> ... </xsd:annotation>
   </xsd:simpleType>
</mf:AttrDef>

<mf:AttrDef name="name of attribute" type="type string">
   <mf:AttrAnnotation>
   ...
   </mf:AttrAnnotation>
</mf:AttrDef>
```

8.3.2 Description

The AttrDef element defines the attribute name and the type of contents.

Requirement 8.3 (req/xmlcore/attrdef/attributes)
Any attributes of moving features appearing in mf:Foliation **shall** be defined by `mf:AttrDefs` element.

Requirement 8.4 (req/xmlcore/attrdef/datatypes)
The types of the attributes **shall** be consistent with the data descriptions of the attributes.

8.3.3 Content

The type of the attribute is defined in `mf:AttrDef` by `xsd:simpleType`. An example is following.

```
<mf:AttrDef>
   <xsd:simpleType name=”speed_meter_record”>
      <xsd:union>
         <xsd:simpleType name=”km_per_hour”>
            <xsd:restriction base="xsd:positiveInteger">
               <xsd:minInclusive value="0"/>
               <xsd:maxInclusive value="100"/>
            </xsd:restriction>
         </xsd:simpleType>
         <xsd:simpleType name=”speed_rank”>
            <xsd:restriction base="xsd:NMTOKEN">
               <xsd:enumeration value="slow"/>
               <xsd:enumeration value="medium"/>
               <xsd:enumeration value="fast"/>
            </xsd:restriction>
         </xsd:simpleType>
      </xsd:union>
   </xsd:simpleType>
</mf:AttrDef>
```

The attributes `name` and `type` can be used instead of the content for ease of the description.

```
<mf:AttrDef name=”speed_meter_km_per_hour”
 type=”xsd: positiveInteger” />
```

Either of the two styles should be used to define the type of attributes.

Requirement 8.5 (req/xmlcore/attrdef/datatypes_definition)
A `xsd:simpleType` **shall** be contained by `mf:AttrDef` if the attributes `name` and `type` of `mf:AttrDef` are omitted.

8.3.4 Attributes

8.3.4.1 `name` (optional)

The name attribute shows the name of the attribute defined in the `mf:AttrDef` element.

8.3.4.2 `type` (optional)

The type attribute shows the data type of the attribute defined in the `mf:AttrDef` element. The data type is specified by xsd data type. Examples of the data types are listed in the following table.

#	Type	Contents
1	`xsd:boolean`	“True” or “false”
2	`xsd:decimal`	Real number
3	`xsd:integer`	Integer number
4	`xsd:string`	Text data like “I am here.” with double quotation marks (“) are replaced by “&quot;”.
5	`xsd:dateTime`	Text specifying the date time like “1999-05-31T13:20:00.000-05:00”.
6	`xsd:AnyURI`	URI style text

8.4 `mf:AttrAnnotation`

8.4.1 Structure

```
<mf:AttrAnnotation>
Annotation Text
</mf:AttrAnnotation>
```

8.4.2 Description

The contents of `mf:AttrAnnotation` is the detailed text for describing the attribute.An example of the attnotaions is following.

```
<mf:AttrDef name=”speed_meter_record” type=”xsd:string”>
  <mf:AttrAnnotation>
    This attribute shows the speed meter records of the vehicles.
   Slow : less than 20km/h
   Medium: more than or equal to 20km/h, and less than 100km/h
   Fast: more than or equal to 100km/h
  </mf:AttrAnnotation>
</mf:AttrDef>
```

Note that `xsd:Annotation` is also available if `xsd:simpleType` is used.

8.5 `mf:Hints`

8.5.1 Structure

```
<mf:Hints>
  <mf:Hint> - </mf:Hint>[0...*]
</mf:Hints>
```

8.5.2 Description

The `mf:Hints` element includes the information helpful for processing. If the dataset is huge, special techniques to handle the dataset are needed. For such case, the `mf:Hints` element provides the additional information. For example, the size of dataset is helpful for determining whether the entire data are loadable on the DRAM.

Requirement 8.6 (req/xmlcore/hints):
Contents of the `mf:Hints` element **shall** be `mf:Hint` describing hints for interpretation processes.

8.5.3 Content

8.5.3.1 `mf:Hint`

`mf:Hint` gives predefined hints to process the dataset.

8.6 `mf:Hint`

8.6.1 Structure

```
<mf:Hint name=”hintname”>value text</mf:Hint>
```

8.6.2 Description

The `mf:Hint` element includes the information helpful for processing. Pair of name attribute and text describes one hint (this is a key-value-pair data).

Requirement 8.7 (req/xmlcore/hint):
Any hints specified by `mf:Hint` **shall** be consistent with the contents of `mf:Foliation`.

8.6.3 Content

The `mf:Hint` element value provides the value of the “key-value-pair”.

8.6.4 Attributes

8.6.4.1 `name`

The name attribute specifies the key of the key-value pair. The content shows the value related to the key. For example, if name is “`TrajectoryAppearance`” and content is “`periodic`” like

```
<mf:Hint name=” TrajectoryAppearance”>periodic</mf:Hint>,
```

the trajectory elements will appear periodically. The defined pairs of name and value are listed in the **table 1**.

Table 1. Key-value pairs for mf:Hint element

Name	Value

`TrajectoryAppearance`	`periodic: rajectory elements appear periodically.`
	`random: trajectory elements appear randomly.`

`TrajecotryLifetime`	`The maximal time length of the trajectories is shown.`

9. Foliations

9.1 `mf:Foliation`

9.1.1 Structure

```
<mf:foliation order=”...”>
   <mf:AbstractTrajectory>  ...</mf: AbstractTrajectory>[0...*]
</mf:foliation>
```

9.1.2 Description

The foliation element, which contains the spatio-temporal geometries for moving features, supports a foliation structure.

Requirement 9.1 (req/xmlcore/foliation)
The foliation element **shall** include `mf:STBoundedBy` with a `srsName` attribute and elements inheriting `mf:AbstractTrajectory` using a coordinate system specified by the `srsName` of `mf:sTBoundedBy`.

Requirement 9.2 (req/xmlcore/foliation/order)
`mf:sTBoundedBy` **shall** be the first element in `mf:Foliation`. The following elements **shall** be ordered by the rule specified by `order` attribute of the

mf:Foliation.

9.1.3 Contents

9.1.3.1 mf:AbstractTrajectory

Trajectories of moving features are expressed as subclasses of the mf:AbstractTrajectory. Because the subclasses of mf:AbstractTrajectory will be defined in the later versions of OGC Moving Features XML Core, softwares supporting the current version should work correctly even if any subclasses of mf:AbstractTrajectory are used (i.e. the unsupported types might be ignored),

9.1.4 Attributes

9.1.4.1 "order"

"order" defines appearing order of mf:AbstractTrajectory elements. The possible values are enumerated in the following code table.

Table 2. code-table for "order" attribute

Attribute values	Definitions	Default
Time	mf:AbstractTrajectory elements ordered by time strictly	yes
Sequential	mf:AbstractTrajectory elements which are parts of one track are ordered by time	

9.2 mf:AbstractTrajectory

9.2.1 Structure

```
<mf:AbstractTrajectory mfIdRef="id" start="t1" end="t2"
interpolation="interpolation type">
   <mf:Attr>Attributes text</mf:Attr> [0, 1]
</mf:AbstractTrajectory>
```

Superclass: gml:AbstractCurve [OGC 07-036]

9.2.2 Description

mf:AbstractTrajectory is an abstract class to implement the trajectory.

mf:AbstractTrajectory, of which superclass is gml:AbstractCurve [OGC 07-036], has an attribute to specify the method for temporal interpolation.

Requirement 9.3 (req/xmlcore/abstracttrajectory):
All elements in `mf:Foliation` **shall** be inheritances of `mf:AbstractTrajectory`.

Each `mf:AbstractTrajectory` describes a segment consisting of a trajectory. If the `mf:AbstractTrajectory` elements with common “`mfid`” attribute are collected and sorted by time, the sequence of the segments constitutes the entire spatio-temporal trajectory of the moving feature identified by the “`mfid`” attribute.

9.2.2 Contents

9.2.2.1 `mf:Attr`

Attributes variable by time are described in this element. The values of the attributes are constant while the feature moves along the `mf:AbstractTrajectory`.

9.2.3 Attributes

9.2.3.1 “`mfIdRef`”

The text specifying the moving feature (i.e. person ID, vehicle ID, etc.)

9.2.3.2 “`start`”

“start” attribute specifies the start time of the segment.

9.2.3.3 “`end`”

“end” attribute specifies the end time of the segment.

9.2.3.2 “`interpolation`” (optional)

The attribute specifies the interpolation method.

“`linear`” (default): The point during the movement is linearly interpolated. The linearly interpolated points between two end points P1 and P2 are derived by:

(1-t)*P1+t*P2, where $0 < t < 1$.

9.3 `mf:LinearTrajectory`

9.3.1 Structure

```
<mf:LinearTrajectory>
   <gml:PosList>...</gml:PosList>[0, 1]
   <mf:Attr>Attributes text</mf:Attr>[0, 1]
</mf:LinearTrajectory>
```

Superclass: `mf:AbstractTrajectory`

9.4.2 Description

`mf:LinearTrack` element is the spatio-temporal line string, which is similar to `gml:LineString` [OGC 07-036]. The `mf:LinearTrack` is a special trajectory that consists of a single segment with linear interpolation.

Requirement 9.4 (req/xmlcore/lineartrajectory):
`mf:LinearTrajectory` **shall** include `gml:PosList` having more than two points (their dimension is specified by `gml:EnvelopeWithTimePeriod` in `mf:sTBoundedBy`).

9.4.3 Contents

9.4.3.1 gml:posList

Two or more coordinate tuples are specified in `gml:posList`, with linear interpolation between them. The described line string is the trajectory of the moving featrure.

9.4.3.2 mf:Attr

Attributes variable by time are described in this element. The values of the attributes are constant while the feature moves along the `mf:LinearTrajectory`.

9.5 mf:Attr

9.5.1 Structure

```
<mf:Attr>Attributes Text</mf:Attr>
```

9.5.2 Description

The `mf:Attr` element contains the attribute information as a text.

Requirement 9.5 (req/xmlcore/attr):
`mf:Attr` **shall** include a CSV text line of which columns are consistent with `mf:AttrDefs`.

9.5.3 Contents

A CSV text which describes the attribute values is contained. An example is the following:

12.0,313.1,,4,5,a&lt;b,123

Some characters may need to be escaped here. < (less than), > (greater than), ‶ (double quotation), ‵ (single quotation), and & (ampersand) must be replaced with the entity references defined in XML. Space, tab, and comma are written in escape sequences \s, \t, and \b, respectively. If the value equals the previous value, the text for the value can be omitted.

Requirement 9.6 (req/xmlcore/attr/entity):
< (less than), > (greater than), ‶ (double quotation), ‵ (single quotation), and & (ampersand) contained by `mf:Attr` **shall** be replaced with the entity references.

10 Example instances

10.1 Example 1 Pedestrian's tracks

```
<?xml version="1.0" encoding="UTF-8"?>
<mf:MovingFeatures xmlns:mf="http://schemas.opengis.net/mf-
      core/1.0"
  xmlns:xlink="http://www.w3.org/1999/xlink"
      xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:gml="http://www.opengis.net/gml/3.2"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://schemas.opengis.net/mf-core/1.0
      moving_features_gml_app.xsd"
  gml:id="MFC_0001">
  <mf:sTBoundedBy offset="sec">
    <gml:EnvelopeWithTimePeriod srsName="urn:x-
      ogc:def:crs:EPSG:6.6:4326">
      <gml:lowerCorner>50.23 9.23</gml:lowerCorner>
      <gml:upperCorner>50.31 9.27</gml:upperCorner>
      <gml:beginPosition>2012-01-17T12:33:41Z
      </gml:beginPosition>
      <gml:endPosition>2012-01-17T12:37:00Z </gml:endPosition>
    </gml:EnvelopeWithTimePeriod>
  </mf:sTBoundedBy>
  <mf:member xlink:href="#pointerToGmlIdOfMovingFeature_a"/>
  <mf:member xlink:href="#pointerToGmlIdOfMovingFeature_b"/>
  <mf:member>
    <mf:MovingFeature gml:id="a">
      <gml:name>Joe Blow</gml:name>
    </mf:MovingFeature>
  </mf:member>
  <mf:member>
    <mf:MovingFeature gml:id="b">
      <gml:name>Jane Doe</gml:name>
    </mf:MovingFeature>
  </mf:member>
  <mf:header>
    <mf:VaryingAttrDefs>
```

```
      <mf:attrDef>
        <xsd:simpleType name="state">
          <xsd:restriction base="xsd:NMTOKEN">
            <xsd:enumeration value="walking"/>
            <xsd:enumeration value="staying"/>
            <xsd:enumeration value="running"/>
          </xsd:restriction>
        </xsd:simpleType>
      </mf:attrDef>
      <mf:attrDef>
        <xsd:simpleType name="typecode">
          <xsd:restriction base="xsd:integer">
            <xsd:enumeration value="1"/>
            <xsd:enumeration value="2"/>
            <xsd:enumeration value="97"/>
          </xsd:restriction>
        </xsd:simpleType>
      </mf:attrDef>
    </mf:VaryingAttrDefs>
  </mf:header>
  <mf:foliation>
    <mf:LinearTrajectory gml:id="LT0001" mfIdRef="a" start="10"
     end="150">
      <gml:posList>11.0 2.0 12.0 3.0</gml:posList>
      <mf:Attr>walking,1</mf:Attr>
    </mf:LinearTrajectory>
    <mf:LinearTrajectory gml:id="LT0002" mfIdRef="b" start="10"
     end="190">
      <gml:posList>10.0 2.0 11.0 3.0</gml:posList>
      <mf:Attr>walking,2</mf:Attr>
    </mf:LinearTrajectory>
    <mf:LinearTrajectory gml:id="LT0003" mfIdRef="a" start="150"
     end="190">
      <gml:posList>12.0 3.0 10.0 3.0</gml:posList>
      <mf:Attr>walking,2</mf:Attr>
    </mf:LinearTrajectory>
  </mf:foliation>
</mf:MovingFeatures>
```

10.2 Example 2 Vehicles

```
<?xml version="1.0" encoding="UTF-8"?>
<mf:MovingFeatures xmlns:mf="http://schemas.opengis.net/mf-
      core/1.0"
  xmlns:xlink="http://www.w3.org/1999/xlink"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:gml="http://www.opengis.net/gml/3.2"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://schemas.opengis.net/mf-core/1.0
      moving_features_gml_app.xsd"
  gml:id="MFC_0002">
```

```
<mf:sTBoundedBy offset="sec">
  <gml:EnvelopeWithTimePeriod srsName="urn:x-
   ogc:def:crs:EPSG:6.6:4326">
    <gml:lowerCorner>150 0</gml:lowerCorner>
    <gml:upperCorner>250 50</gml:upperCorner>
    <gml:beginPosition>2013-05-01T10:33:41Z
   </gml:beginPosition>
    <gml:endPosition>2013-05-01T10:37:41Z </gml:endPosition>
  </gml:EnvelopeWithTimePeriod>
</mf:sTBoundedBy>

<mf:member  xlink:href="#pointerToGmlIdOfMovingFeature_a"/>
<mf:member  xlink:href="#pointerToGmlIdOfMovingFeature_b"/>
<mf:member>
  <mf:MovingFeature gml:id="a">
    <gml:description>Nissan Sentra - License plate ABC 123.
   Five passengers.</gml:description>
    <gml:name>NissanA</gml:name>
  </mf:MovingFeature>
</mf:member>
<mf:member>
  <mf:MovingFeature gml:id="b">
    <gml:description>Nishiki 21 speed racer</gml:description>
    <gml:name>BicycleB</gml:name>
  </mf:MovingFeature>
</mf:member>
<mf:header>
  <mf:VaryingAttrDefs>
    <mf:attrDef name="direction" type="xsd:double">
      <mf:AttrAnnotation>
          The direction of the vehicle: the attribute value is
   the angle between the north direction and the vehicle
   direction. Unit of angle is radian.
          For example, North is 0[rad], East is 1.57[rad] and
   West is -1.57[rad].
        </mf:AttrAnnotation>
    </mf:attrDef>
  </mf:VaryingAttrDefs>
</mf:header>
<mf:foliation>
  <mf:LinearTrajectory gml:id="LT0001" mfIdRef="a" start="0"
   end="50">
    <gml:posList>161 5 172 5</gml:posList>
    <mf:Attr>0.0</mf:Attr>
  </mf:LinearTrajectory>
  <mf:LinearTrajectory gml:id="LT0002" mfIdRef="b" start="0"
   end="50">
    <gml:posList>158 20 158 50 159 60</gml:posList>
    <mf:Attr>1.57</mf:Attr>
  </mf:LinearTrajectory>
  <mf:LinearTrajectory gml:id="LT0003" mfIdRef="a" start="50"
   end="100">
```

```
      <gml:posList>172 5 172 1</gml:posList>
      <mf:Attr>-1.57</mf:Attr>
    </mf:LinearTrajectory>
    <mf:LinearTrajectory  gml:id="LT0004" mfIdRef="b" start="50"
     end="100">
      <gml:posList>159 60 166 50</gml:posList>
      <mf:Attr>0</mf:Attr>
    </mf:LinearTrajectory>
  </mf:foliation>
</mf:MovingFeatures>
```

Annex A
(Normative)

Abstract test suite

This Annex specifies an Abstract Test Suite which shall be passed in completeness by any implementation claiming conformance with this Moving Features XML Core. Test identifiers below are relative to

http://www.opengis.net/spec/MovingFeatures/1.0/conf/

A.1 Conformance Class:

The OGC URI Identifier of this conformance classes is

http://www.opengis.net/spec/MovingFeatures/1.0/conf/xmlcore.

A.1.1 XML Validity

Test id: conf/xmlcore/xmlcore-valid

Requirements:

- **8.1 req/xmlcore/header/structure**
- **8.2 req/xmlcore/varyingattrdefs**
- **8.6 req/xmlcore/hints**
- **9.1 req/xmlcore/foliation**
- **9.3 req/xmlcore/abstracttrajectory**
- **9.6 req/xmlcore/attr/entity**

Test purpose:

Verify that any XML element defined in namespace “mf” is well-formed and valid.

Test method:

Validate the XML document using the XML schema document http://schemas.opengis.net/MovingFeatures/1.0/xmlcore.xsd. Pass if no errors reported. Fail otherwise.

A.1.2 Root Element

Test id: conf/xmlcore/movingfeatures

Requirements:

- **7.1 req/xmlcore/movingfeatures**

Test purpose:

Verify that the root element is “`mf:MovingFeatures`”.

Test method:

Validate that the root element of the document is `mf:MovingFeatures`.

A.1.3 Attribute Definition

Test id: conf/xmlcore/attributes

Requirements:

- **8.3 req/xmlcore/attrdef/attributes**
- **8.4 req/xmlcore/attrdef/datatypes**
- **8.5 req/xmlcore/attrdef/datatypes_definition**
- **9.5 req/xmlcore/attr**

Test purpose:

Verify that attribute definitions are consistent with the attributes shown in the trajectories.

Test method:

At First, the contents of mf:AttrDef is checked. If it is empty, the attributes of mf:AttrDef are checked. If either the name attribute or the type attribute is empty, the test is failed.

After that mf:AttrDef is checked, the contents of mf:attr are parsed as a CSV data. Then the number of columns and the datatype of the columns are checked. If they are consistent with the definition in mf:attrdefs, the test is passed. If not, it is failed.

A.1.3 Time order

Test id: conf/xmlcore/order

Requirements:

- **9.2 req/xmlcore/foliation/order**

Test purpose:

Verify that "order" attribute of mf: foliation is consistent with the contents of the foliation.

Test method:

The "start" attributes of mf:AbstractTrajectory (and the inheritances) are checked. If the order is consistent with the "order" attributes, the test passes.

A.1.4 Hints

Test id: conf/xmlcore/hints

Requirements:

- **8.7 req/xmlcore/hint**

Test purpose:

Verify that mf:Hints is consistent with the contents of the foliation.

Test method:

The contents of mf:Hint are checked.

- If TrajectoryAppearance is specified, the "start" and "end" attributes of mf:AbstractTrajectory (and the inheritances) are checked. If they are consistent, the test passes.
- If TrajectoryLifetime is specified, the difference between "start" and "end" attributes of mf:AbstractTrajectory (and the inheritances) are checked. If they are less than the specified life time, the test passes.

A.1.5 sTBoundedBy

Test id: conf/xmlcore/lineartrajectory

Requirements:

- **8.7 req/xmlcore/lineartrajectory**

Test purpose:

Verify that the mf:LinearTrajectory is vaild.

Test method:

If gml:PosList included by mf:LinearTrajectory has more than two points which are contained by the spatio-temporal envelope determined by mf:sTBoundedBy, the test passes.

Annex B
(Informative)

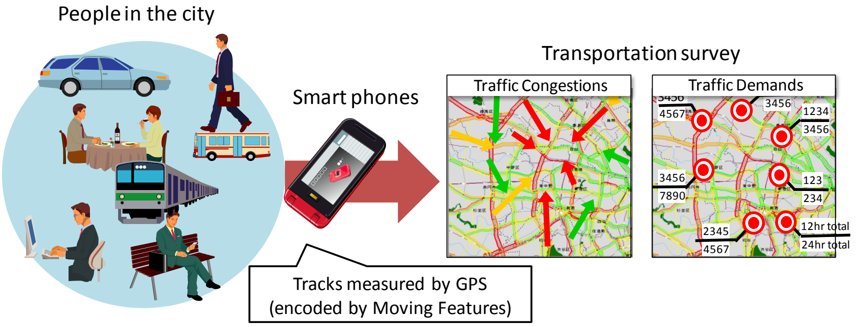
Application examples

B.1 Transportation survey with smart phones

Traffic congestion is a serious problem in many cities. Basically, two types of solutions are applied to resolve congestion: road-construction and enhancement of public transportation systems. Both of the solutions require information on trip demands: the number of people's movements between two places, because roads and public transportation systems should make connection between the pairs of places that have the highest trip demand. Therefore, the trip demands should be figured out by transportation survey.

Questionnaires are traditionally used to survey trip demands. However, because GPS enabled smart-phones are now available, GPS based research is applicable as a sampling alternative. The GPS tracks are encoded by Moving Features standard in order to be shared by many stakeholders like local governments, bus companies, and so on.

Features				
Objects	**Detail**	**Movement properties**		**Attributes**
Pedestrians	Walking people to go somewhere	Speed: 4km/h		State: Stay or Walking
Vehicles	People driving his/her vehicle	Speed: 60km/h		
Data sources				
Data sources	**Localization method**	**Sampling rate**	**Accuracy**	**Number of data**
Smart phones	GPS/Wi-Fi positioning	1 point per 1s	100-10m	Over 100 tracks



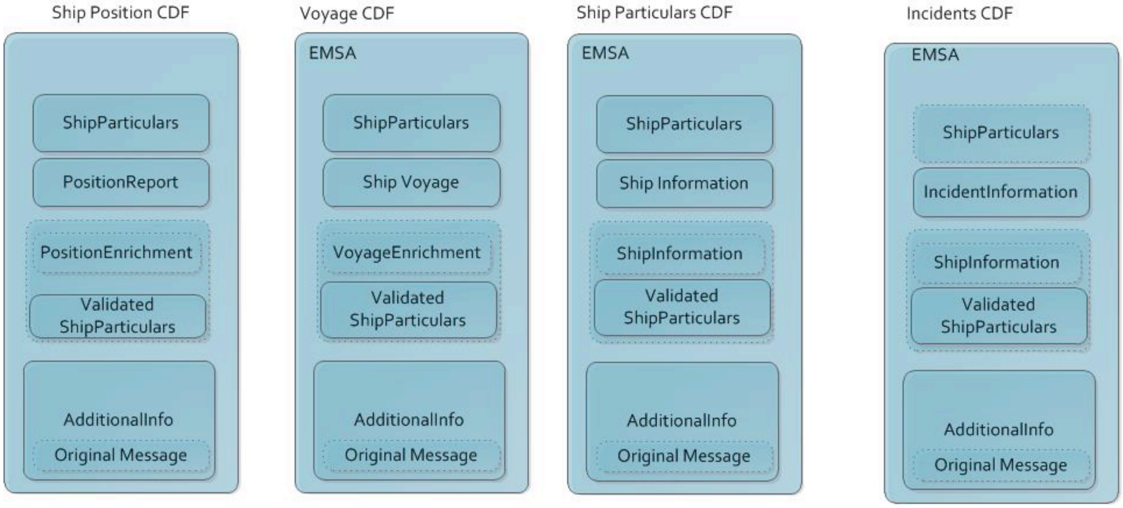
Background map: ©Open Street Map

B.2 Maritime sector use case

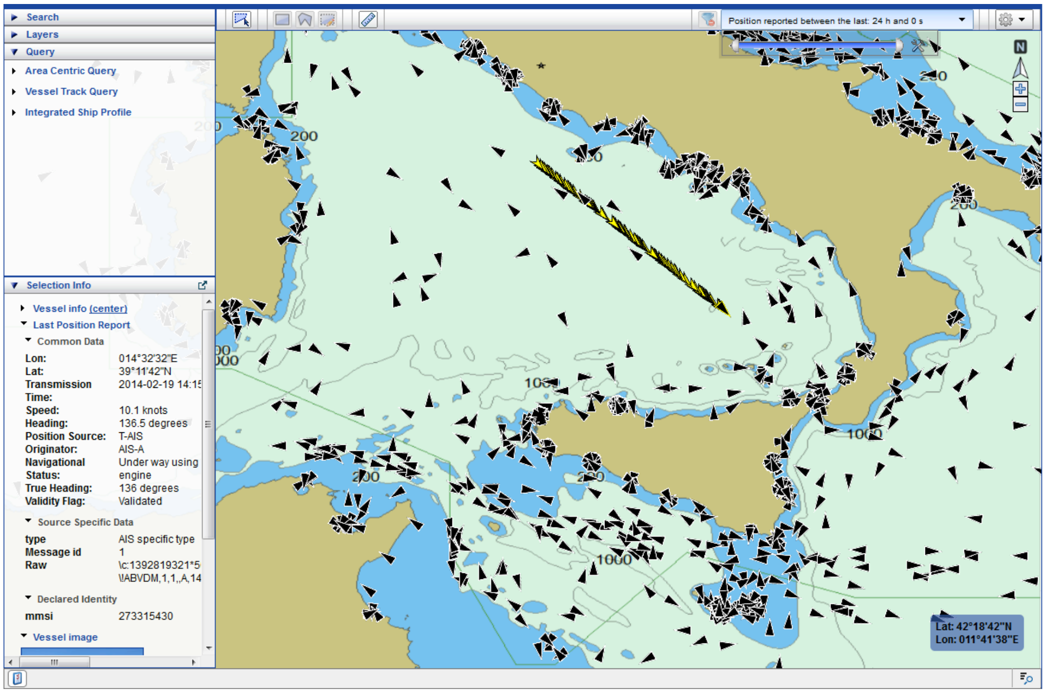
Several devices have been used by vessels to track their positions. Some of these devices are mandatory as required by regional/international standardization initiatives (i.e. EU Directives, IMO conventions, etc …).

The scope to track the position of the vessels is twofold: increase the safety and security within the maritime sector.

In order to address maritime use cases the Moving Feature standard has to include at least the following information: (i) ship position, which can be provided by different data source (AIS, LRIT, etc …); and (ii) ship voyage, which describe the track of vessels. Additional information about the vessel incidents and the ship particulars has to be considered complementary, therefore as possible extensions to the Moving Feature standard. For example the following figure summarize the information collected by the Canonical Data Format produced by the European Maritime Safety Agency



The following picture reports the last position of vessels within a specific area (black triangle), and the track of a specific vessel (yellow triangles). In this case the yellow triangles report the position of a specific vessel every 6 minutes in the last 24 hours. Furthermore additional information as: heading, true heading and speed is recorded for enrich the description of the vessel track.



Lon: 014°32'32"E
Lat: 39°11'42"N
Transmission Time: 2014-02-19 14:15
Speed: 10.1 knots
Heading: 136.5 degrees
Position Source: T-AIS
Originator: AIS-A
Navigational Status: Under way using engine
True Heading: 136 degrees
Validity Flag: Validated

type AIS specific type
Message id 1
Raw \c:1392819321*5 \!ABVDM,1,1,,A,14

mmsi 273315430

A vessel has a unique identification at a worldwide scale (IMO number, or MMSI), the position of a vessel (ship position) is a point feature over the time. The voyage feature of a vessel (ship voyage) is characterized by several attributes such as: speed over the ground, course over the ground, heading and true heading.

To build the trajectory of a vessel, two main abstract feature types are relevant for Moving Feature standard: ship position and ship voyage.

Possible uses of the information collected by maritime authorities are:

<table>
<tr><th colspan="5">Features</th></tr>
<tr><th>Objects</th><th colspan="2">Detail</th><th>Movement properties</th><th>Attributes</th></tr>
<tr><td>Vessels</td><td colspan="2">enter/leave/inside a particular area X</td><td>Speed 11 knots in/out a Feature of Interest</td><td></td></tr>
<tr><td>Vessels</td><td colspan="2">Suspicious manoeuvres</td><td>Change the speed rapidly and/or varying</td><td></td></tr>
<tr><td>Vessels</td><td colspan="2">Discrepancy between declared Next Port or arrival time and current position/course</td><td>Current position and voyager declared</td><td></td></tr>
<tr><td>Vessels</td><td colspan="2">Approaching dangerous Feature Of Interest</td><td>Distance from a rocks less than 3 miles</td><td></td></tr>
<tr><th colspan="5">Data sources</th></tr>
<tr><th>Data sources</th><th>Localization method</th><th>Sampling rate</th><th>Accuracy</th><th>Number of data</th></tr>
</table>

Automatic Identification System (AIS) / Satellite AIS	GPS/Wi-Fi positioning	1 point every 6 minutes	100-10m	Over 10 tracks per hour

B.3 Aviation sector use case

Aircraft and other airborne vehicles are obviously moving features as well. The aviation sector has a (large) number of methods to track aircraft and to represent their position.

The main sources of data include the following

- Primary surveillance radar: Radar equipment measuring position and heading of aircraft.
- Secondary surveillance radar: position detection is augmented with an active response from the aircraft's transponder. It supplies additional information such as its identity.
- ADS-B: aircraft with on board GPS or other GNSS equipment may also provide position information based on the GPS measurement. This mode of position and information broadcasting is called ADS-B and is seen as an important future tool for increasing air traffic capacity and safety.

The position and related data of aircraft is encoded according to different standards. One standard is Eurocontrol ASTERIX (http://www.eurocontrol.int/asterix). ASTERIX defines different categories, most categories containing position data according to a different detection method.

For instance, category 48 defines the following fields (copied from the Cat 48 specification on http://www.eurocontrol.int/services/specifications-documents)

Data Item	Description	Description System Units
I048/010	Data Source Identifier	N.A.
I048/020	Target Report Descriptor	N.A.
I048/030	Warning/Error Conditions	N.A.
I048/040	**Measured Position in Slant Polar Co-ordinates**	RHO: 1/256 NM, THETA: 360°/(2 16)
I048/042	**Calculated Position in Cartesian Co-ordinates**	X, Y: 1/128 NM
I048/050	Mode-2 Code in Octal Representation	N.A.
I048/055	Mode-1 Code in Octal Representation	N.A.
I048/060	Mode-2 Code Confidence Indicator	N.A.
I048/065	Mode 1 Code Confidence Indicator	N.A.
I048/070	Mode-3/A Code in Octal Representation	N.A.
I048/080	Mode-3/A Code Confidence Indicator	N.A.

I048/090	**Flight Level in Binary Representation**	1/4 FL
I048/100	Mode-C Code and Confidence Indicator	N.A.
I048/110	**Height Measured by a 3D Radar**	25 ft
I048/120	Radial Doppler Speed	(2-14) NM/s
I048/130	Radar Plot Characteristics	N.A.
I048/140	**Time of Day**	1/128 s
I048/161	Track/Plot Number	N.A.
I048/170	Track Status	N.A.
I048/200	**Calculated Track Velocity in Polar Representation**	Speed: (2-14) NM/s, Heading:360°/(2 16)
I048/210	Track Quality	N.A.
I048/220	**Aircraft Address**	N.A.
I048/230	Communications / ACAS Capability and Flight Status	N.A.
I048/240	**Aircraft Identification**	N.A.
I048/250	Mode S MB Data	N.A.
I048/260	ACAS Resolution Advisory Report	N.A.

The items in bold relate to the position, heading, time, and identity of the aircraft. Other information fields provide metadata on quality, data source, etc.

Other ASTERIX categories provide different sets of information where position and other information may also be encoded in different ways. Some interesting aspects to ASTERIX:

- The positions may be expressed in relation to the radar equipment position. A (separately available) position of the radar is thus needed to correctly geo-reference the aircraft.

- The data has a binary encoding optimized to obtain a small message size. Verbose GML/XML encoding may be a barrier for adoption of the Moving Feature standard for large data sets in the aviation world.

- Many data sets do not include all fields. Optional elements in the Moving Features may accommodate representing such data sets.

- Some categories or data sets do not include an identification of the moving features. Such data is often referred to as 'plots'. Since multiple plots cannot be related to a single aircraft, the data set basically is a bag of time-stamped points.

FAA has an Aircraft Situation Display to Industry (ASDI) feed, which provides aircraft position reports as a convenient data feed to industry. The feed also includes information on flight plans (the planned route of the aircraft). See http://www.fly.faa.gov/ASDI/asdi.html for more information.

In order to address aviation use cases at least this information must be managed in the moving feature standards. Other information is important as well and may be encoded as use-case specific metadata.

Possible uses of the information collected by aviation authorities are:

Features			
Objects	**Detail**	**Movement properties**	**Attributes**
Aircraft	Performing a flight	Speed: 300-1000km/h	Many
Aircraft	Taxiing on a airport	Speed: 0-300km/h	Many

Data sources				
Data sources	**Localization method**	**Sampling rate**	**Accuracy**	**Number of data**
Primary/Secondary Surv. Radar	Radar detection	1 to several seconds per position	Depends on radar & distance to radar	Thousands of concurrent flights world-wide
ADS-B	GNSS/GPS	1 to several seconds per position	100-10m	Thousands of concurrent flights world-wide

Use cases can also involve analysis afterwards (incident analysis, statistics, etc.) or simulated air traffic. The moving features standard may be useful to convert raw feeds into a standard moving features representation for use in generic analysis and processing tools.

B.4 A Use case for Hurricanes

Tropical storms, hurricanes and typhoons are extremely energetic and dangerous weather phenomena with a pronounced centre of rotation, the 'eye'. However, their position can be forecast, with increasing accuracy, several days in advance, and even more accurately only a day in advance. These forecasts are normally presented to the general public and emergency services as a simple graphical map, often using PNG or JPEG formats.

Hurricanes and typhoons are the same phenomenon, but traditionally the names in the western Pacific and western Atlantic are different. A tropical storm is a weaker version, causing less damage, but can become more energetic. Currently a wind speed threshold of 65 knots (120Km/hour, 75 miles/hour) is the only distinguishing attribute.

Typically a deterministic chart will show a single forecast storm trajectory as a single track with the location of the storm centre or 'eye' indicated at regular intervals, say every 6 or 12 hours. The location at a specific time is usually marked by specific symbols, standardised across all countries for both meteorology and aviation.

Sometimes a probabilistic chart is preferred, and a range of possible trajectories, or an envelope of these trajectories is used. The set of trajectories may come from a single forecast centre using an ensemble of possible forecasts, or the set may be from several forecast centres which all produce slightly different forecasts. Generally, if the spatial, and temporal, spread of the set of trajectories is small, then more confidence is attached to them than if the spread is great.

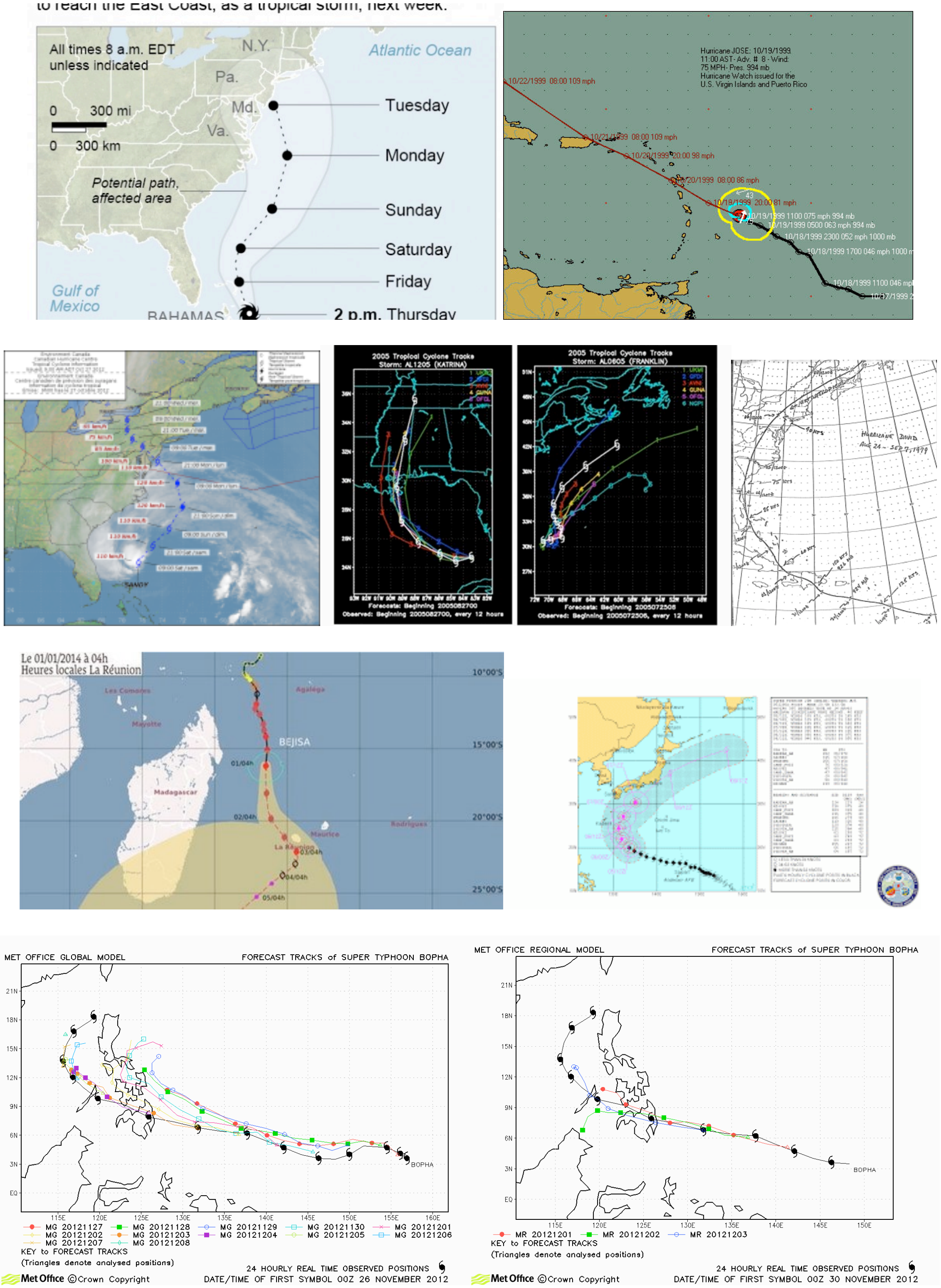
Expert users, such as forecasters, may also use a chart that displays ranges of trajectories from successive forecast times, and the actual trajectory so far. Again, similarity in these successive forecasts gives increased confidence in the accuracy of the forecasts.

If graphical output is inappropriate, there is a standardised simple text message used to transmit the current and forecast locations across emergency communications channels. These messages also include the actual and forecast wind speeds at various distances and directions from the 'eye'. The atmospheric pressure near the eye may also be included.

The central pressure is an important indicator of damage, like the wind speed, as the reduced pressure causes the local sea surface to rise by a few metres causing flooding and destructive waves.

The sea surface temperature in the path of the storm is also important, as this determines whether the storm will increase or decrease in strength.

So there are a number of changing attributes need to be associated with the storm and its trajectory.


to reach the East Coast, as a tropical storm, next week.
All times 8 a.m. EDT unless indicated
0 300 mi
0 300 km
N.Y.
Pa.
Md.
Va.
Atlantic Ocean
Tuesday
Monday
Sunday
Saturday
Friday
2 p.m. Thursday
Potential path, affected area
Gulf of Mexico
BAHAMAS
Hurricane JOSE: 10/19/1999 11:00 AST- Adv. # 8 - Wind: 75 MPH- Pres. 994 mb Hurricane Watch issued for the U.S. Virgin Islands and Puerto Rico
10/22/1999 08:00 109 mph
10/21/1999 08:00 109 mph
10/20/1999 20:00 98 mph
10/20/1999 08:00 86 mph
10/18/1999 20:00 81 mph
10/19/1999 1100 075 mph 994 mb
10/19/1999 0500 063 mph 994 mb
10/18/1999 2300 052 mph 1000 mb
10/18/1999 1700 046 mph 1000 mb
10/18/1999 1100 046 mph
2005 Tropical Cyclone Tracks Storm: AL1205 (KATRINA)
Forecasts: Beginning 2005082700 Observed: Beginning 2005082700, every 12 hours
2005 Tropical Cyclone Tracks Storm: AL0605 (FRANKLIN)
Forecasts: Beginning 2005072506 Observed: Beginning 2005072306, every 12 hours
1 UKMI
2 GFDI
3 AVNI
4 GUNA
5 OFCL
6 NGPI
Hurricane David Aug 24 - Sep 7, 1979
Le 01/01/2014 à 04h Heures locales La Réunion
Les Comores
Mayotte
Agaléga
Madagascar
BEJISA
01/04h
02/04h
03/04h
04/04h
05/04h
Maurice
La Réunion
Rodrigues
10°00'S
15°00'S
20°00'S
25°00'S
MET OFFICE GLOBAL MODEL
FORECAST TRACKS of SUPER TYPHOON BOPHA
MG 20121127
MG 20121128
MG 20121129
MG 20121130
MG 20121201
MG 20121202
MG 20121203
MG 20121204
MG 20121205
MG 20121206
MG 20121207
MG 20121208
KEY to FORECAST TRACKS
(Triangles denote analysed positions)
24 HOURLY REAL TIME OBSERVED POSITIONS
Met Office ©Crown Copyright
DATE/TIME OF FIRST SYMBOL 00Z 26 NOVEMBER 2012
MET OFFICE REGIONAL MODEL
FORECAST TRACKS of SUPER TYPHOON BOPHA
MR 20121201
MR 20121202
MR 20121203
KEY to FORECAST TRACKS
(Triangles denote analysed positions)
24 HOURLY REAL TIME OBSERVED POSITIONS
Met Office ©Crown Copyright
DATE/TIME OF FIRST SYMBOL 00Z 30 NOVEMBER 2012
BOPHA

Features

<table>
<tr><th>Objects</th><th colspan="2">Detail</th><th colspan="2">Movement properties</th><th>Attributes</th></tr>
<tr><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><th colspan="6">Data sources</th></tr>
<tr><th>Data sources</th><th>Localization method</th><th colspan="2">Sampling rate</th><th>Accuracy</th><th>Number of data</th></tr>
<tr><td></td><td></td><td colspan="2"></td><td></td><td></td></tr>
</table>

B.5 Predicting Crime patterns by simulating movement of criminals, victims and police on map

Goal: To replicate the conditions under which crime is committed and predict crime patterns, for example predicting regions more vulnerable to crime based on Routine Activity Theory.

Setup: All these phenomena move only along roads on the map. There are certain fixed marked spots on the map. These include Criminal's Home, Office, Mall, Bar, Restaurants. There is a weekly schedule and the criminal agent moves between these spots based on the schedule.

Forms of Motion:

- Beeline Movement: The agent chooses one of the shortest 3 paths between two spots randomly and moves along it. This is time bound - if there are less than 3 routes that can be covered in the amount of time the agent has - only that number of routes are considered for random selection.

- Random Movement: Agent starts from source and at each road intersection, agent chooses a road randomly and moves along it. This is also time bound - when time runs out, the agent moves to the destination along the shortest path from its current location.

- Hybrid Movement: Agent moves between source and destination along the shortest path with deviations. Agent randomly chooses two points on the shortest route and takes a longer different route between these two points. If there is time remaining, agent repeats this, otherwise moves to the destination along the shortest path.

Prediction of Crime Patterns: Criminal Agent, Victim Agents and Police all keep moving along the map as per their schedules. There are a number of designated crime spots on the map. When the criminal agent passes through the vicinity of a crime spot, it decides whether or not to commit crime based on factors like profit value associated with crime spot, risk involved, presence of police nearby, absence of guardian of spot and the number of times the spot has been visited before. Crime Patterns are predicted by running this simulation a very large number of times.

Discussion:

- The simulation needs a city description with roads and buildings of interest. CityGML could be used here.

- The simulation needs to represent the agent's trajectory in the above-cited city. Moving Features standard would be used here.

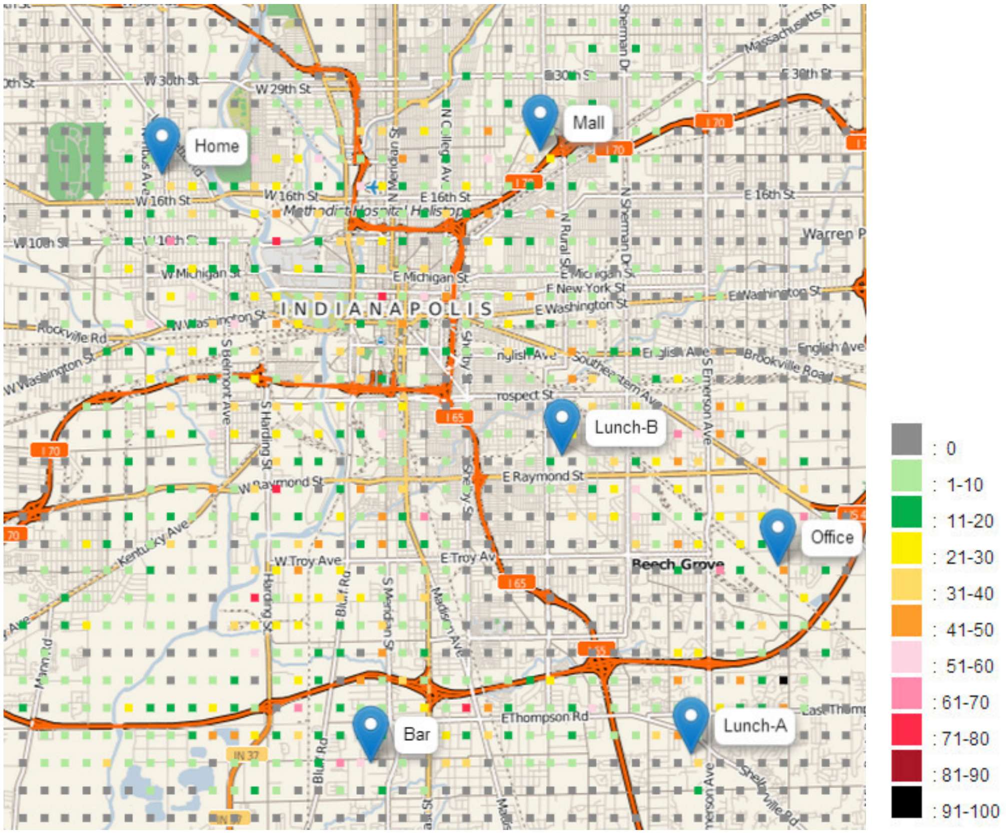
- The trajectory is repeated weekly with random variations. That may be represented as a "base line" moving feature. This base line would not describe a real moving feature, but would be used as a template.

- Interactions between the environment (CityGML) and the moving features may trigger events. For example when <mf:Trajectory> value become close to a CityGML feature or interest having a low "presence of police" attribute, a crime may occur depending on the value of that attribute and other attributes like "absence of guardian", "profit", and "risk".

Features			
Objects	**Detail**	**Movement properties**	**Attributes**
Criminal Agent	The one who commits crime		
Victim Agent	The one whose property is under risk of theft		
Police Agent	Police patrol the city to prevent crime		

Data sources				
Data sources	**Localization method**	**Sampling rate**	**Accuracy**	**Number of data**
Simulation	Movement simulation along Road map (Open Street Map)			

Example: The criminal agent moves between Home, Office, Bar, Lunch-A, Lunch-B, Mall marked on the map as per a weekly schedule. The result corresponds to the weekly schedule run for 500 times on the city: Indianapolis. The small squares on the map correspond to crime spots. The color of each crime spot represents the number of times crime has been committed at that spot, normalized on a scale of 0-100.



B.6 Use-Cases for Soccer Matches

Background: It is an important task of soccer coaches to analyze matches for developing proper tactics and preparing for future matches. With recent progress of several video analysis and sensor technologies, it is now possible to gather match data including trajectories of both players and the ball.

Feature Modelling [1]: A soccer match is composed of 23 moving features including 22 players and ball, where each moving feature has $p(x,y)$ or $p(x,y,z)$ coordinates for each time instance during a match. A sequence of moving point for a player or ball forms a trajectory. A basic feature model for soccer match in terms of moving feature is given as the following figure.

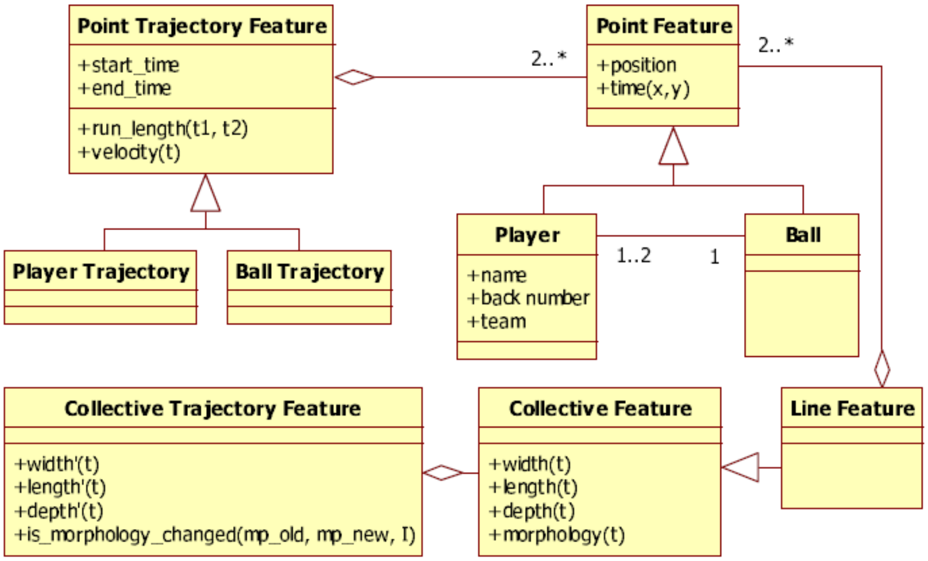


Figure B.6-1. Basic Feature Model for Soccer Match

We define two abstract feature types Point Feature and Point Trajectory Feature as the root classes of the model of figure 1, which correspond to spatial and spatiotemporal objects respectively. And Ball and Player, which inherit from Point Feature, have the coordinates of the ball and players at each sampling time instance. Ball Trajectory and Player Trajectory represent the feature types of ball and player trajectories respectively. Each object of Point Feature has (x, y) coordinates at each time instance t. Note that we employ (x, y)-coordinate reference system to specify the position of spatial objects from the left-bottom corner of the field. And we assume the continuity of temporal domain even though there may be several breaks of match such as ball-out. Due to the breaks, we cannot assure the continuity of the ball trajectory. Since soccer is a collective sport, it is required to analyze the positions of players as a collection as well as position of each individual player. For example, the defensive tactics would be better understood by analyzing the shape of the defensive players in a collective way, rather than the position of each individual defender separately. For this reason, we define Collective Feature and Collective Trajectory. We may define additional properties for player such as direction.

Based on the information of this basic feature model, we can derive more useful information from primitive behaviours such as kicks, ball possession, dribbles (see figure 2), intercepts, passes, to complicated strategies such as formation, defence or attack systems.

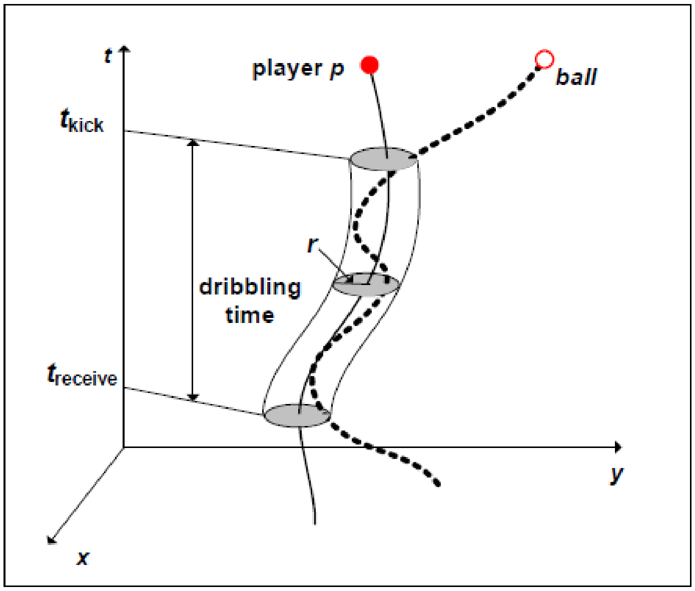


Figure B.6-2. Dribbles [2]

References

[1] Ho-Chul Kim, Oje Kwon and Ki-Joune Li, "Spatial and Spatiotemporal Analysis of Soccer", Proceedings of ACM SIGSPATIAL GIS ’11, November 1-4, 2011. Chicago, IL, USA

[2] Chan-Hyun Kang, Jung-Rea Hwang, and Ki-Joune Li, "Trajectory analysis for soccer player", Spatial and Spatio-temporal Data Mining (SSTDM), the IEEE Computer Society Press

Revision history

Date	Release	Author	Paragraph modified	Description
2014/11/13	OGC 14-084r2	Akinori Asahara	3	References were added
2014/11/18		Carl Reed	Numerous	Final edits prior to publication