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OGC Moving Features Encoding Extension - JSON

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i. Abstract

This document proposes a JavaScript Object Notation (JSON) encoding representation of movement of geographic features as an encoding extension of OGC Moving Features ([OGC 14-083r2] and [OGC 14-084r2]). A moving feature, typically a vehicle and pedestrian, can be express as a temporal geometry whose location continuously changes over time and contains dynamic non-spatial attributes whose value varies with time. It is Best Practice to share moving feature data based on JSON and GeoJSON (a JSON format for encoding a variety of geographic data structures). In addition, this document provides an example of RESTful approaches as a Feature Service Interface that has the potential for simplicity, scalability, and resilience to exchange moving feature data across the Web.

ii. Keywords

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

ogcdoc, OGC document, moving features, encoding, JSON, REST

iii. Preface

This best practice document basically follows the abstract data model defined in ISO 19141:2008 [ISO 19141:2008]; however, the encoding method refers to the expression of IETF GeoJSON Format [draft-ietf-geojson-04]. The draft format covers the movements of 0-dimensional Point, 1-dimensional curve LineString, and 2-dimensional surface Polygon due to the application requirements (disaster risk management, traffic information services, geo-fencing services, etc.) to represent various spatiotemporal geometries for moving features considered from OGC Moving Features Encoding: XML Core [OGC 14 083r2] and Simple CSV [OGC 14 084r2] that have focused on the movement of 0-dimensional geometric primitive (Point), called trajectories.

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iv. Submitting organizations

The following organizations have submitted this Document to the Open GeoSpatial Consortium, Inc.:

- Artificial Intelligence Research Center, National Institute of Advanced Industrial Science and Technology

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vi. Future Work

Among the topics for future development are the following items:

- Implementation of RESTful API
- Moving features in an indoor space
- Representation of three-dimensional moving features

Chapter 1. Scope

This Best Practice provides a format for encoding moving features using JavaScript Object Notation (JSON) [IETF RFC7159] and an example of interfaces of the RESTful service of moving features. The format defined this document is an alternative to the OGC® Moving Features Encodings: XML [OGC 14 083r2] and Simple Comma Separated Values (CSV) [OGC 14 084r2] standards. Even though this document uses different terms from the expression in the OGC Moving Features Encodings ([OGC 14 083r2] and [OGC 14 084r2]), Moving Feature JSON encoding basically refers to the abstract data model of moving features is defined in ISO 19141:2008 [ISO 19141:2008] as shown in [Figure 1](#) with the concepts of foliation, prism, trajectory, and leaf.

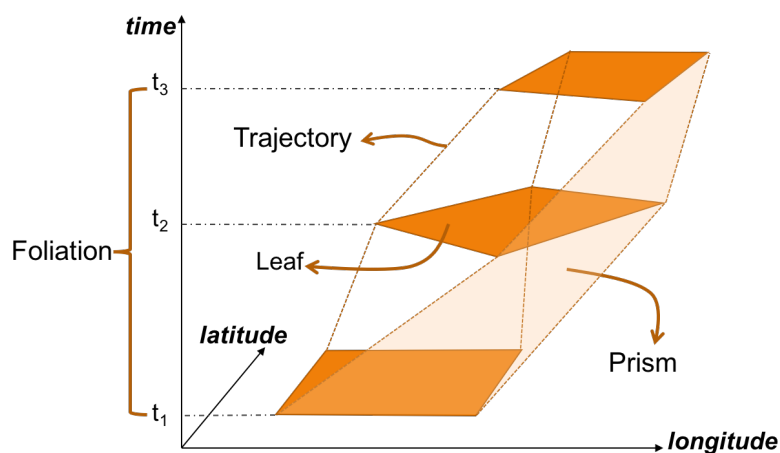


Figure 1. Conceptual Model of a Moving Feature: Foliation, Prism, Leaf, and Trajectory

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 (and by each of its other points) 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, meaning that there is a complete and separate representation of the geometry of the feature for each specific time. 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.

In general, Moving Feature JSON encoding applies to representations and formats of IETF GeoJSON [draft-ietf-geojson-04]; however, new terms are added to specify dynamic attributes of moving features:

- *Temporal geometric objects* whose location changes over time: Movements of 0-dimensional, 1-dimensional, 2-dimensional geometric primitives, and their collections.
- *Dynamic non-spatial attributes* whose value varies with time: Changes of a quantity.

This document also describes based on the data format:

-
- *RESTful APIs* for handling moving feature data over HTTP: Create, Read, Update, and Delete (CRUD) operations.

This Best Practice document has left many issues out of its scope. Design issues with complex interpolation methods and service capabilities were not considered.

Chapter 2. Conformance

Not applicable for this Best Practice document.

Chapter 3. References

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

- [OGC 06-121r9](#), *OGC Web Services Common Standard*, version 2.0.0
- [OGC 14-083r2](#), *Moving Features Encoding Part I: XML Core*. 2015
- [OGC 14-084r2](#), *Moving Features Encoding Extension: Simple Comma Separated Values (CSV)*. 2015
- [OGC 15-078r6](#), *OGC SensorThings API Part 1: Sensing*. 2016
- [ISO/IEC Directives](#), *Part 2. Rules for the structure and drafting of International Standards*
- [ISO 8601:2004](#), *Data elements and interchange formats - Information interchange - Representation of dates and time*
- [ISO 19101:2014](#), *Geographic information — Reference model — Part 1: Fundamentals*
- [ISO 19103:2015](#), *Geographic information — Conceptual schema language*
- [ISO 19107:2003](#) *Geographic Information - Spatial schema*
- [ISO 19119:2006](#), *Geographic information - Services*
- [ISO 19141:2008](#), *Geographic information - Schema for moving features*
- [IETF RFC 3986](#), *Uniform Resource Identifier (URI): Generic Syntax*.
- [IETF RFC 2616](#), *Hypertext Transfer Protocol — HTTP/1.1*.
- [IETF RFC 7159](#), *The JavaScript Object Notation (JSON) Data Interchange Format*.
- [IETF RFC 7464](#), *JavaScript Object Notation (JSON) Text Sequences*.
- [IETF RFC 7946](#), *The GeoJSON Format*.
- [OData-Part1](#), *OData Version 4.0. Part 1: Protocol Plus Errata 03*. Edited by Michael Pizzo, Ralf Handl, and Martin Zurmuehl. 02 June 2016. OASIS Standard incorporating Approved Errata 03.

Additionally the following informative documents are addressed:

- [OGC 15-052r1](#), *OGC Testbed 11 REST Interface Engineering Report*
- [OGC 16-120r2](#), *OGC Moving Features Access* [candidate standard]

Chapter 4. Terms and definitions

This document uses the specification terms defined in Subclause 5.3 of [OGC 06-121r9], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular: - SHALL is the verb form used to indicate a requirement to be strictly followed to conform to this specification, from which no deviation is permitted - MAY is the verb form used to indicate an action permissible within the limits of this specification

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

4.1. API

An interface that is defined in terms of a set of functions and procedures, and enables a program to gain access to facilities within an application. (Definition from Dictionary of Computer Science - Oxford Quick Reference, 2016)

4.2. client

software component that can invoke an operation from a server
[OGC 06-121r9]

4.3. dynamic attributes

characteristic of a feature in which its value varies with time

4.4. feature

abstraction of real world phenomena
[ISO 19101:2014]

4.5. 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]

4.6. geometric object

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

4.7. geometric primitive

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

[ISO 19107:2003]

4.8. interface

named set of operations that characterize the behaviour of an entity

[ISO 19119:2006]

4.9. leaf

<one parameter set of geometries> geometry at a particular value of the parameter

[ISO 19141:2008]

4.10. moving feature

feature whose location changes over time

[ISO 19141:2008]

NOTE Its base representation uses a local origin and local coordinate vectors, of a geometric object at a given reference time.

4.11. 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]

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

4.12. period

one-dimensional geometric primitive representing extent in time

[ISO 19141:2008]

4.13. 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

4.14. request

invocation of an operation by a client

[OGC 06-121r9]

4.15. resource

any addressable unit of information or service

[IETF RFC 3986]

4.16. response

result of an operation, returned from a server to a client

[OGC 06-121r9]

4.17. server

a particular instance of a service

[OGC 06-121r9]

4.18. service

distinct part of the functionality that is provided by an entity through interfaces

[ISO 19119:2006]

4.19. temporal geometry

one parameter set of geometries in which the parameter is time

4.20. trajectory

path of a moving point described by a one parameter set of points

[ISO 19141:2008]

Chapter 5. Conventions

This sections provides details and examples for conventions used in the document. All examples illustrated by gray or orange boxes are informative only.

5.1. JSON notation

The notation of JSON in this document is based on the specification of [RFC 7159].

The ordering of the members of any JSON object **MUST** be considered irrelevant. Some examples use a JavaScript single line comment (//) and an ellipsis (...) as placeholder notation for a specific JSON instance. Whitespace is used in the examples inside this document to help illustrate the data structures, but is not required. Unquoted whitespace is not significant in JSON.

5.2. UML notation

Unified Modeling Language (UML) static structure diagrams appearing in this document are used as described in Subclause 5.2 of OGC Web Services Common [OGC 06-121r9].

5.3. Abbreviated terms

The following symbols and abbreviated terms are used in this best practice paper:

API	Application Program Interface
CRS	Coordinate Reference Systems
CRUD	Create, Read, Update, Delete
CSV	Comma Separated Values
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
OASIS	Organization for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
REST	Representational State Transfer
UML	Unified Modeling Language

URI	Uniform Resource Identifiers
URL	Uniform Resource Locators
WKT	Well Known Text
XML	Extensible Markup Language
1D	One Dimensional
2D	Two Dimensional

Chapter 6. JSON Encoding

This clause specifies the data format for encoding moving features by using the JSON objects.

6.1. Overview

Moving Features JSON (MF-JSON) is designed by extending "foreign members" of GeoJSON [draft-ietf-geojson-04]. MF-JSON defines several types of JSON objects to represent movements about moving features, their dynamic properties, and their spatiotemporal extents based on the coordinate reference system of World Geodetic System 1984 (WGS84) and Coordinated Universal Time (UTC).

Figure 2 compares the difference of members between GeoJSON and MF-JSON.

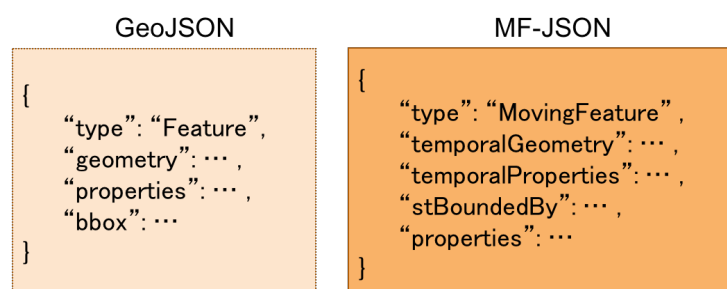


Figure 2. JSON Objects in the Moving Features JSON format

Example:

```

{
  "type": "MovingFeature", // (REQUIRED) Moving Feature Type
  "temporalGeometry": { // (REQUIRED) temporal geometric object, extended from 'geometry'
    "type": "MovingPoint", // a geometry type to represent a trajectory
    "coordinates": [ [100.0, 0.0], [101.0, 0.0], [101.0, 1.0], [100.0, 1.0] ],
    "datetimes": [ "2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z", "2011-07-15T01:01:01Z" ],
    "interpolations": "Linear" // an pre-defined interpolation method
  },
  "temporalProperties": [ // (OPTIONAL) dynamic non-spatial attributes, extended from 'properties'
    {
      "name": "length",
      "uom": "http://www.qudt.org/qudt/owl/1.0.0/quantity/Length", // a URI denoting a unit-of-measure
      "values": [1.0, 2.4, 1.0],
      "datetimes": [ "2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z" ],
      "interpolations": "Stepwise"
    },
    {
      "name": "discharge",
      "uom": "m^3/s", // a symbol from UCUM
      "values": [3.0, 2.4, 4.0],
      "datetimes": [ "2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z" ],
      "interpolations": [
        {
          "coefficients": [1.0, 3.0, 4.1], //  $v = at^2 + bt + c$ 
          "period": {
            "begin": "2011-07-14T22:01:01Z",
            "end": "2011-07-14T23:01:01Z"
          }
        },
        {
          "coefficients": [5.0, 8.0], //  $v = at + b$ 
          "period": {
            "begin": "2011-07-14T23:01:01Z",
            "end": "2011-07-15T00:01:01Z"
          }
        }
      ]
    }
  ],
  "stBoundedBy": { // (OPTIONAL) spatiotemporal bounding box to include the moving feature
    "bbox": [100.0, 0.0, 101.0, 1.0],
    "period": {
      "begin": "2011-07-14T22:01:00Z",
      "end": "2011-07-15T01:14:00Z"
    }
  },
  "properties": { // (OPTIONAL) static non-spatial attributes regardless of time: the same representation of GeoJSON
    "name": "bus1",
    "state": "test1"
  }
}

```

6.2. Types

```
{  
  "type": ...  
}
```

In [IETF GeoJSON format](#), types are not extensible. GeoJSON allows only the fixed types: FeatureCollection, Feature, Point, LineString, MultiPoint, Polygon, MultiLineString, MultiPolygon, and GeometryCollection. Even though the type extension occurs contravention of GeoJSON, this document extends new types for representing moving features with time-varying geometries and properties.

6.2.1. Moving Feature Types

In this format, two moving feature types are added as follows:

- **MovingFeature**: a moving feature instance

```
{  
  "type": "MovingFeature",  
  "temporalGeometry": ...,  
  "temporalProperties": ...,  
  "stBoundedBy": ...,  
  "properties": ...  
}
```

A moving feature instance shall contain a **"temporalGeometry"** field as described in the Temporal Geometries section. A moving feature may contain a **"temporalProperties"**, **"stBoundedBy"**, **"properties"** fields depending on the application requirements.

- **MovingFeatureCollection**: a collection of moving feature instances

```

{
  "type": "MovingFeatureCollection",
  "features": [
    {
      "type": "MovingFeature",
      "temporalGeometry": ...,
      "temporalProperties": ...,
      ...
    },
    {
      "type": "MovingFeature",
      "temporalGeometry": ...,
      "temporalProperties": ...,
      ...
    }
  ],
  "stBoundedBy": ...
}

```

A collection of moving features shall contain a **"features"** field as an array object of moving features. A collection of moving features may contain a **"stBoundedBy"** field for the spatiotemporal bounding box to cover all of features.

6.2.2. Temporal Geometry Types

The movement of a moving feature is represented as a JSON object where the type members value shall be one of the following strings: *"MovingPoint"*, *"MovingLineString"*, *"MovingPolygon"*, *"MultiMovingPoint"*, *"MultiMovingLineString"*, *"MultiMovingPolygon"*, or *"MovingGeometryCollection"*. It is modeled as a mapping function from time to a geometric object: *temporalGeometry: timePosition → Geometry (Point, LineString, Polygon, MultiPoint, MultiLineString, MultiPolygon, or GeometryCollection)*. It represents time-varying locations of a moving feature.

- **MovingPoint:** A temporal geometry represents a trajectory of a time-parametered 0-dimensional geometric primitive (Point), representing a single geographic position at a time position (instant) within its temporal domain. Intuitively this type depicts a set of curves in a spatiotemporal domain. It is used to express [mf:AbstractTrajectory](#) in the OGC® Moving Features standard. For example, the movement information of people, vehicles, or hurricanes can be shared by instances of the MovingPoint type.
- **MovingLineString:** A temporal geometry represents the prism of a time-parametered 1-dimensional (1D) geometric primitive (LineString), whose leaf at a time position is 1-dimensional linear object in a particular time period. Intuitively this type depicts a set of surfaces in a spatiotemporal domain. For example, the movement information of weather fronts or traffic congestion on roads can be shared by instances of the MovingLineString type.
- **MovingPolygon:** A temporal geometry represents the prism of a time-parametered 2-dimensional (2D) geometric primitive (Polygon), whose leaf at a time position is 2-dimensional

polygonal object in a particular time period. Intuitively this type depicts a set of polyhedrons that are the convex hulls of two congruent polygons in a spatiotemporal domain. For example, the changes of flooding areas or the movement information of air pollution can be shared by instances of the `MovingPolygon` type.

- **MultiMovingPoint**: A temporal geometry represents a set of moving points.
- **MultiMovingLineString**: A temporal geometry represents a set of moving linestrings.
- **MultiMovingPolygon**: A temporal geometry represents a set of moving polygons.
- **MovingGeometryCollection**: It represents a collection of temporal geometries that have time-varying locations. Each object in this array belongs to one of the above types.

6.3. Temporal Geometries

A moving feature has only one temporal geometry whose type is one of "MovingPoint", "MovingLineString", "MovingPolygon", "MultiMovingPoint", "MultiMovingLineString", "MultiMovingPolygon", and "MovingGeometryCollection". The temporal geometry is conceptualized as a prism of the set of points contained in all of the leaves (a foliation) and trajectories. In this draft, a temporal geometry is represented by a sequence of pairs (g, t) , where g is a leaf geometry and t is a sampling time position, with an interpolation method. The leaves of simple geometries is described by the same number of elements in the lists of "coordinates" and "datetimes" which ordered sets that preserves the given order. The interpolation approximates geographic positions at non sampling time instants for constructing the trajectory or prism of the moving feature in a spatiotemporal domain. A collection of temporal geometries consists of several prisms of geometry primitives in the "members" field.

6.3.1. Simple

A simple temporal geometry represents the movement of one geometric primitive that is non-decomposed objects. There are three types of temporal geometry: a moving point, moving linestring, and moving polygon. If viewed in a 4-dimensional spatio-temporal coordinate system, the simple temporal geometry is a single continuum. A moving point, linestring, polygon is a spatio-temporal curve, surface, solid, respectively.

```
{
  ...,
  "temporalGeometry": {
    "type": "MovingPoint | MovingLineString | MovingPolygon", // vbar | as a means to select ONE type.
    "coordinates": [...],
    "datetimes" : [...],
    "interpolations": ...
  },
  ...
}
```


- **"coordinates"**: The object SHALL be an array of geographic positions to construct a leaf geometry at a time position.

Types	Formats	Comments
MovingPoint	[[x1, y1], [x2, y2], ...]	<i>a list of points at each leaf, increasing time order</i>
MovingLineString	[[[x11, y11], [x12, y12], ...], [[x21, y21], [x22, y22], ...], ...]	<i>a list of linestrings at each leaf, increasing time order</i>
MovingPolygon	[[[[ox11, oy11], [ox12, oy12], ...], [[ix11, iy11], [ix12, iy12], ...], ...], [[[ox21, oy21], [ox22, oy22], ...], [[ix21, iy21], [ix22, iy22], ...], ...], ...]	<i>a list of polygons at each leaf, increasing time order</i>

- **"datetimes"**: The object SHALL be an array of instants of time encoded as a character string of [ISO 8601:2004](<http://www.iso.org/iso/home/standards/iso8601.htm>) date-time formatter.

Types	Formats	Comments
DateTime	["yyyy-MM-dd'T'HH:mm:ss'Z'", "yyyy-MM-dd'T'HH:mm:ss'Z'", ...]	<i>a list of monotonic increasing instants</i>

- **"interpolations"**: The object SHALL be a character string of pre-defined interpolation methods or an array object of interpolation formulas in time. [Interpolation](#) is a method of finding new values for any function using the given set of values. The unknown position at a particular point can be found using many interpolation methods. Here, there are two expressions for an interpolation instance as follows:

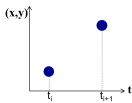
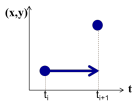
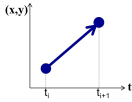
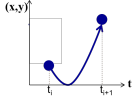
```

--- Predefined Interpolation Methods
--- Interpolation Formulas

```

[Predefined Interpolation Methods]

The new position is differently derived by each method. For the predefine method, there is the restriction to have the same number of positions of each leaf geometry.

Types	Descriptions	Comments
Discrete		<i>There is no interpolation position between two successive positions.</i>
Stepwise		<i>The interpolation position between two successive positions equals to the first position.</i>
Linear		<i>The new position is found from the linear interpolation formula with the two successive positions. *Default</i>
Spline		<i>An interpolation position is derived from a cubic spline function on each interval between data positions.</i>

```
{
  "type": "MovingPoint",
  "coordinates": [ [100.0, 0.0], [101.0, 0.0], [101.0, 1.0]],
  "datetimes": ["2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z"],
  "interpolations": "Linear" // an interpolation method
}
```

[Interpolation Formulas]

A temporal geometry may have a several interpolation formulas within its temporal domain. An element of interpolation formulas is represented by field **"coefficients"** and **"period"**. The new position at a given time position is derived from a **"coefficients"** instance as a multidimensional array of **polynomial interpolation formulas** of (x, y, z) coordinates during a particular time period. If the time position does not belong to any time period of the elements of formula, there is no interpolation position at that time. The order of each formula array SHALL follow x (longitude), y (latitude), z (altitude) order. The number of elements in each formula during a particular time period is the same. The time periods between any two elements of formulas only allows empty or 0-dimensional intersection. In order to compute a value of each axis of coordinates at an arbitrary time position formatted by a character string of [ISO 8601:2004], this practice converts the time position to a signed 64-bit integer(long) value to represent milliseconds.

$$[x(t) = a_{n-1}t^{n-1} + a_{n-2}t^{n-2} + \dots + a_0t^0$$

$$[y(t) = b_{n-1}t^{n-1} + b_{n-2}t^{n-2} + \dots + b_0t^0$$

$$[z(t) = c_{n-1}t^{n-1} + c_{n-2}t^{n-2} + \dots + c_0t^0$$

```

{
  "type": "MovingPoint",
  "coordinates": ...,
  "datetimes": ...,
  "interpolations": [
    {
      "coefficients": [[1.0, 3.0, 4.1], [2.0, 2.1, 3.0]],
      // x = 1.0*t^2 + 3.0*t + 4.1 , y = 2.0*t^2 + 2.1*t + 3.0
      "period": {
        "begin": "2011-07-14T22:01:01Z",
        "end" : "2011-07-14T23:01:01Z"
      }
    },
    {
      "coefficients": [[4.0, 2.0], [1.0, 2.0]],
      // x = 4.0*t + 2.0 , y = 1.0*t + 2.0
      "period": {
        "begin": "2011-07-14T23:01:01Z",
        "end" : "2011-07-15T00:01:01Z"
      }
    }
  ]
}

```

```

{
  "type": "MovingLineString",
  "coordinates": ...,
  "datetimes": ...,
  "interpolations": [
    {
      "coefficients": [[[1.0, 3.0, 4.1], [2.0, 2.1, 3.0]], [[2.0, 1.0, 1.2], [1.0, 0.1, 2.0]]],
      // x1 = 1.0*t^2 + 3.0*t + 4.1 , y1 = 2.0*t^2 + 2.1*t + 3.0
      // x2 = 2.0*t^2 + 1.0*t + 1.2 , y2 = 1.0*t^2 + 0.1*t + 2.0
      "period": {
        "begin": "2011-07-14T22:01:01Z",
        "end" : "2011-07-14T23:01:01Z"
      }
    },
    {
      "coefficients": [[[4.0, 2.0], [1.0, 2.0]], [[2.0, 3.0], [2.0, 1.0]]],
      // x1 = 4.0*t + 2.0 , y1 = 1.0*t + 2.0
      // x2 = 2.0*t + 3.0 , y2 = 2.0*t + 1.0
      "period": {
        "begin": "2011-07-14T23:01:01Z",
        "end" : "2011-07-15T00:01:01Z"
      }
    }
  ]
}

```

6.3.2. Collection

A temporal geometry is represented as an array object of a set of simple temporal geometry instances.

```

{
  ...
  "temporalGeometry": {
    "type": "MultiMovingPoint | MultiMovingLineString | MultiMovingPolygon | MovingGeometryCollection",
    "members": [
      {
        // Simple temporal geometry instance
        "type": "MovingPoint | MovingLineString | MovingPolygon",
        "coordinates": [...], // COORDINATES expression
        "datetimes" : [...], // DATETIMES expression
        "interpolations": ... // INTERPOLATIONS expression
      }
    ]
  },
  ...
}

```

- **MultiMovingPoint:** The **"members"** element SHALL be an array of instances of type **"MovingPoint"**. The leaf geometry at a time position must be an instance of type **"MultiPoint"**, which is the union of each leaf of moving point members at the same time.
- **MultiMovingLineString:** The **"members"** element SHALL be an array of instances of type **"MovingLineString"**. The leaf geometry at a time position must be an instance of type **"MultiLineString"**, which is the union of each leaf of moving linestring members at the same time.
- **MultiMovingPolygon:** The **"members"** element SHALL be an array of instances of type **"MovingPolygon"**. The leaf geometry at a time position must be an instance of type **"MultiPolygon"**, which is the union of each leaf of moving polygon members at the same time.
- **MovingGeometryCollection:** Each element of **"members"** can be an instance of different moving types. The leaf geometry at a time position must be an instance of type **"GeometryCollection"**, which is the union of each leaf of any temporal geometries at the same time.

6.4. Temporal Properties

A moving feature can have more than zero time-varying properties, such as the velocity of vehicles or wind speed of hurricanes. A temporal property represents a dynamic measure that the result of ascertaining the value of a characteristic of a moving feature changes over time and/or location. Even though the value of temporal property is depending on the spatiotemporal location, this draft only considers the temporal dependencies of their changes of value.

```
{
  ...
  "temporalProperties": [
    {
      "name": "any string",
      "uom": ...,
      "values": [...],
      "datetimes": [...], // same expression of temporal geometry
      "interpolations": ...
    }
  ],
  ...
}
```



If a property has a static value, it is represented with the member "properties" as same as GeoJSON.

- **"name"**: The name of property is always a string.
- **"uom"**: A unit of measure is a quantity adopted as a standard of measurement [ISO 19103:2015]. The unit of a temporal property is represented as a URI denoting a unit-of-measure defined in a web resource or a string of print symbol from the Unified Code for Units of Measure (UCUM)[1].
- **"values"**: Each member of values is a string, number, or one of the literals: true and false.
- **"interpolations"**: The temporal property also needs to define an interpolation method like the temporal geometry. The object SHALL be a character string of pre-defined interpolation methods: Discrete, Stepwise, Linear (default), and Spline or an array of interpolation formulas used for polynomial interpolation in time.

```
{
  ...,
  "interpolations": [
    {
      "coefficients": [1.0, 3.0, 4.1], // v = at^2 + bt + c
      "period": {
        "begin": "2011-07-14T22:01:01Z",
        "end" : "2011-07-14T23:01:01Z"
      }
    },
    {
      "coefficients": [5.0, 8.0], // v = at + b
      "period": {
        "begin": "2011-07-14T23:01:01Z",
        "end" : "2011-07-15T00:01:01Z"
      }
    }
  ]
}
```

6.5. Spatiotemporal Bounding Box

A moving feature may have a member named `"stBoundedBy"`, which indicate the boundary containing moving features in a spatiotemporal domain. To represent information on the coordinate range for moving features, this MF-JSON format follows GeoJSON's `"bbox"` field. The value of the `bbox` member must be a $2*n$ array where n is the number of dimensions. The temporal boundary is a temporal period of `"begin"` and `"end"` expressed in ISO 8601:2004.

```
{
  ...,
  "stBoundedBy": {
    "bbox": [-10.0, -10.0, 10.0, 10.0],
    "period": {
      "begin": "1994-11-05T13:15:30Z",
      "end" : "1994-11-05T13:15:30Z"
    }
  },
  ...
}
```

6.6. Application Domain Variables (Foreign Members)

MF-JSON uses annotations to represent foreign members which are not described in this document and their semantics are dependent on a domain or application specific requirement. It is the reason why MF-JSON defines their elements by extending the foreign member of GeoJSON. On the name/value pair of a foreign member, the name always starts with the at sign (@), such as `"@id"`, `"@context"`, and so on.

6.7. Discussions



Coordinate Reference System

The IETF GeoJSON format recommends a single coordinate reference system based on WGS84[2]. In this version of MF-JSON, CRSs are fixed to WGS84 for space and ISO 8601:2004 for time; still they need to be indicated in the request of application demands. If the application requires to define an alternative CRS, the CRS of a GeoJSON object can be represented with its `"crs"` field as described in GeoJSON(2008)[3].



Geometry Object

A moving feature may have a member named `"geometry"`, which may represent its projection in coordinate space as points, curves, or surfaces. The representation of Geometry objects is same as GeoJSON.

Chapter 7. RESTful API

This Clause provides a design example of the RESTful API as a form of service interfaces to handle moving features on the Web with ease of development, access, robustness, and scalability in server/client distributed environments. In general, Representational State Transfer (REST) focuses on resources and how to access to these resources over Hypertext Transfer Protocol (HTTP). A few use cases of RESTful approaches for OGC web service interfaces are analyzed in the OGC Testbed 11 REST Interface Engineering Report [OGC 15-052r1]. Since OGC still consider a common guidance to define RESTful interfaces and JSON encodings, this work refers to the OGC SensorThings API [OGC 15-078r6], which provides a good example to follow the RESTful principle and is approved as official OGC standard. However, this document contains a minimal description to implement RESTful API using the Moving Features JSON (MF-JSON) encoding.

7.1. General Information

Clients and servers exchange representations of resources via HTTP messages as shown in [Figure 3](#). Clients send a request against the resources to the server in the form of a HTTP verb, Uniform Resource Identifier (URI), protocol version, and request content (header and body). The server replies with a response message consisting of the protocol version followed by a status code and content.

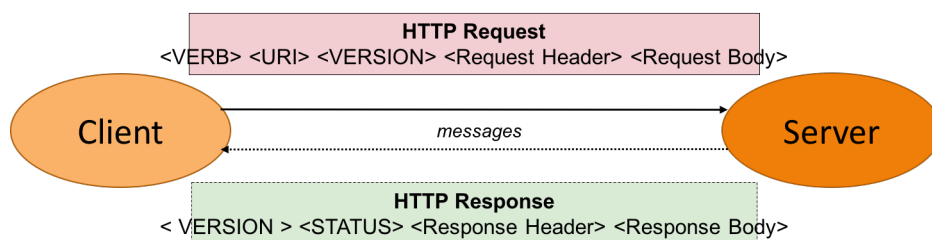


Figure 3. Client/Server Communication based on RESTful API

7.1.1. Verb

Verb is an HTTP method: POST, GET, PUT/PATCH, and DELETE corresponding to create, read, update, and delete (CRUD) operations, respectively. A client make a request with one of the following method to be applied to the resource.

POST	Creates a new resource.
GET	Retrieves a resource.
PUT	Updates/Replaces an existing resource.
PATCH	Updates/Modifies an existing resource.

DELETE	Deletes a resource.
--------	---------------------

7.1.2. URI

A Uniform Resource Identifier (URI) provides a simple and extensible means for identifying a resource as being a locator, a name, or both. The general rules of URIs are defined in [IETF RFC 3986]. The RESTful API to support moving feature data uses a Uniform Resource Locator (URL) for location and access of resources via the HTTP protocol. The basic components of URLs can be defined as follows:

URL = *SERVICE_ROOT* ["/" *RESOURCE_PATH* ["?" *QUERY_OPTIONS*]]

- *SERVICE_ROOT*: the identification of service endpoints for clients, usually formed as "http://"["host":["port"]]["/"*version*]. The "http" scheme is used to locate network resources via the HTTP protocol. The host is a domain name of a network host, or its IPv4 address as a set of four decimal digit groups separated by ".". The version is a API version.
- *RESOURCE_PATH*: the representation of a particular resource. By attaching the resource path after the service root URI, clients can address to different types of resources. (sub-clause 7.2).
- *QUERY_OPTIONS*: clients can apply query options after the resource path to further process the addressed resources, such as sorting by properties or filtering with criteria (sub-clause 7.3).

7.1.3. Version

The service implementation shall support a HTTP version. This document assumes the protocol referred to as "HTTP/1.1" [IETF RFC 2616].

7.1.4. Status

The response message should contain a status code of the attempt to understand and satisfy the request. Depending on the first digit of a 3-digit integer code, it is classified into five roles:

1xx	Informational - Request received, continuing process
2xx	Success - The action was successfully received, understood, and accepted
3xx	Redirection - Further action must be taken in order to complete the request
4xx	Client Error - The request contains bad syntax or cannot be fulfilled
5xx	Server Error - The server failed to fulfill an apparently valid request

Full list of status codes are defined in [IETF RFC 2616], Section 10. This document suggests usages of

the following specific codes:

- **200 OK** : General success status code.
- **201 CREATED**: Successful creation of resources for POST or PATCH.
- **204 NO CONTENT**: Successful operation for DELETE or PUT. There is nothing in the response body.
- **400 BAD REQUEST**: General error of client request, such as a wrong parameter, missing data, etc.
- **404 NOT FOUND**: The requested resource is not found.
- **406 Not Acceptable**: The media type given in the Content-Type header field is not `"application/geo+json"` or `"application/geo+json-seq"`.
- **500 Internal Service Error**: Unexpected condition during the request operations in a server side.
- **501 Not Implemented**: The server does not support the functionality required to fulfill the request.

7.1.5. Header

A general HTTP request/response message contains header fields consisting of a name, followed by a colon (":") and the field value. Detail information of HTTP header fields are also described in [IETF RFC 2616], Section 4.5 (General Header Fields), Section 5.3 (Request Header Fields), Section 6.2 (Response Header Fields), and Section 7.1 (Entity Header Fields). The RESTful API of moving features in this document concerns only the Content-Type field, and the other fields are charged to the implementation of domain applications.

- **Content-Type**: All request/response message SHALL contain the Content-Type field to indicate the media type of the entity-body. The Content-Type field has one of media types of `"application/geo+json"` and `"application/geo+json-seq"` to interpret Moving Features JSON (MF-JSON) entities in the message body.
- **Transfer-Encoding**: A web server serves content as a stream (dynamically-generated content) with the Transfer-Encoding field set by `"chunked"`. The size of each chunk is sent right before the chunk itself, the representation of content is recommended to use the JSON Text Sequence format [IETF RFC 7464] for the streaming transfer. Content transfer is terminated by a final chunk of length zero.



The Host request-header field specifies the Internet host and port number of the resource being requested. If the service_root omits the request, the client needs to include this field.

7.1.6. Body

The entity-body (if any) sent with an request or response is in the JSON format. If the entities represent moving feature data, it is encoded by MF-JSON. More examples are given the next sub-clause.

7.2. Resources

A request URI is constructed with a resource path for a corresponding resource item. Resources are the fundamental elements of the RESTful API. This API is designed by the resource classes and their relationships as shown in [Figure 4](#).

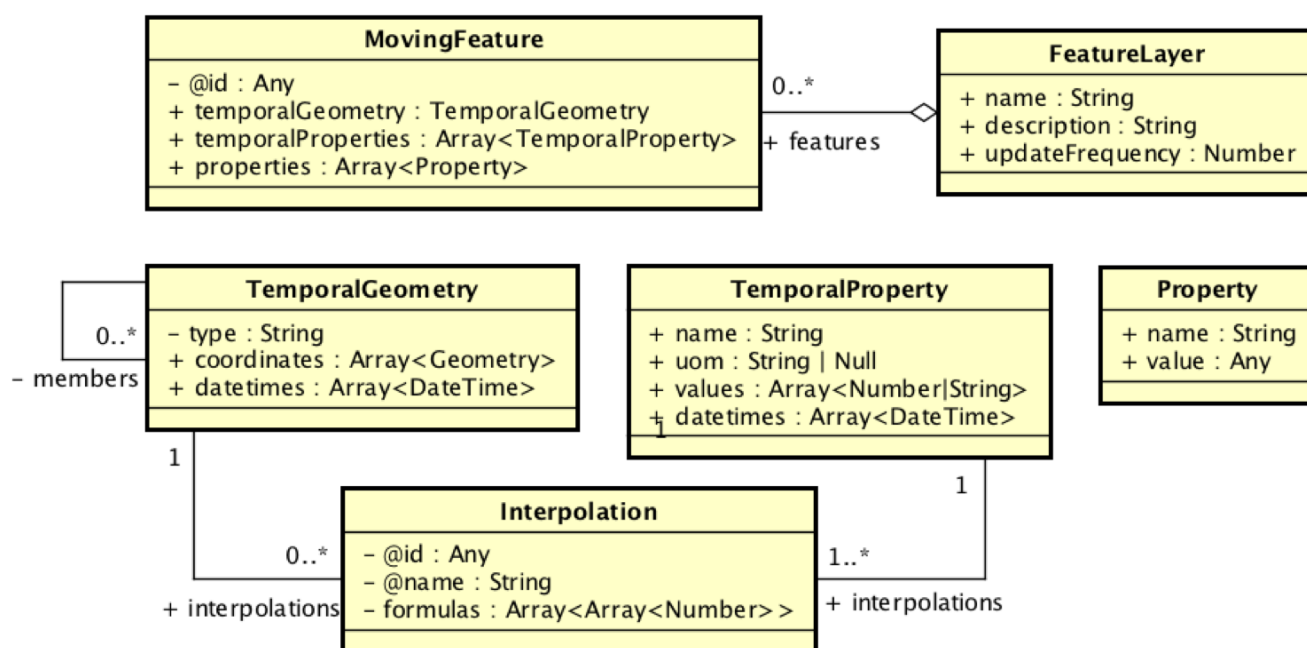


Figure 4. REST Resource Classes of a Moving Feature Service

7.2.1. Resource Classes

- **MovingFeature Class:** It is for the root resource to enable the client to access other resources as its properties. A MovingFeature resource is **mandatory** to be implemented with the following properties in a moving-feature service:

Name	Description	Data type	Multiplicity and use	Editable
@id	It is the unique and system-generated identifier. Clients cannot edit its value.	JSON Any (Null is not allowed)	One (mandatory)	NO

Name	Description	Data type	Multiplicity and use	Editable
temporalGeometry	A resource representing a temporal geometry.	JSON Object<TemporalGeometry> (Null is not allowed)	One (mandatory)	YES
temporalProperties	A resource containing temporal properties.	JSON Array<TemporalProperty> or Null	Zero-to-one	YES
properties	A resource containing static properties as name-value pairs.	JSON Array<Property> or Null	Zero-to-one	YES



JSON Any = False / Null / True / Object / Array / Number / String

A resource instance whose type is specified, such as Geometry, DateTime, TemporalGeometry, TemporalProperty, Property, and so on, is a JSON Object.

- **TemporalGeometry Class:** It is for accessing the temporal geometry of moving features. A TemporalGeometry resource is **mandatory** to be implemented with the following properties in a moving-feature service:

Name	Description	Data type	Multiplicity and use	Editable
type	Its value is one of "MovingPoint", "MovingLineString", "MovingPolygon", "MultiMovingPoint", "MultiMovingLineString", "MultiMovingPolygon", and "MovingGeometryCollection".	JSON String	One (mandatory)	NO
coordinates	A collection of geometries represented by lists of sampled positions.	JSON Array<Geometry> (or Null for collection types)	Zero-to-one (mandatory for simple types)	YES
datetimes	A collection of datetimes when the coordinates are sampled.	JSON Array<DateTime> (or Null for collection types)	Zero-to-one (mandatory for simple types)	YES

Name	Description	Data type	Multiplicity and use	Editable
members	A navigation property to address temporal-geometry elements of the collection types such as "MultiMovingPoint", "MultiMovingLineString", "MultiMovingPolygon", and "MovingGeometryCollection".	TemporalGeometry (or Null for simple types)	Zero-to-many	NO
interpolations	A navigation property to address the interpolation methods.	Interpolation (or Null for collection types)	Zero-to-many (mandatory for simple types)	YES

- **TemporalProperty Class:** It is for accessing the temporal properties of moving features. A TemporalProperty resource is optional to be implemented in a moving-feature service. The minimum properties for the implementation are defined by:

Name	Description	Data type	Multiplicity and use	Editable
name	A name of dynamic attribute of feature.	JSON String	One (mandatory)	YES (but, no duplication within a moving feature.)
uom	A symbol or URI to address the unit of measurement.	JSON String or Null	Zero-to-one	YES
values	A collection of sampled values to represent dynamic changes of feature attribute.	JSON Array<Number/String>	One (mandatory)	YES
datetimes	A collection of datetimes when the values are sampled.	JSON Array<DateTime>	One (mandatory)	YES
interpolations	A navigation property to address the interpolation methods.	Interpolation	One-to-many (mandatory)	YES

- **Interpolation Class:** It is for accessing an interpolation method. An Interpolation resource is

mandatory to be implemented with the following properties in a moving-feature service:

Name	Description	Data type	Multiplicity and use	Editable
@id	It is the unique and system-generated identifier.	JSON Any	One (mandatory)	NO
@name	A name of interpolation.	JSON String	One (mandatory)	NO
formulas	A collection of formulas to estimate arbitrary values at time.	JSON Any	Zero-to-one	NO

For pre-defined methods such as Discrete, Stepwise, and Linear, the client cannot edit the names of methods. This practice assumes that the name of a user-defined interpolation formula is automatically assigned by the service when moving features are inserted.

- **Property Class:** It is for accessing the static properties of moving features. A Property resource is optional to be implemented in a moving-feature service. The minimum properties for the implementation are defined by:

Name	Description	Data type	Multiplicity and use	Editable
name	A name of feature attribute.	JSON String	One (mandatory)	YES (but, no duplication within a moving feature.)
value	A value of feature attribute.	JSON Any	One (mandatory)	YES

- **FeatureLayer Class:** It is for a collection of moving features to manage data in a distinct (physical or logical) space; however, it is an optional resource and can be replaced by an Application-dependent feature. When the service considers the implementation, the following properties may be required:

Name	Description	Data type	Multiplicity and use	Editable
name	A property indicates the label of a FeatureLayer resource	JSON String	One (mandatory)	YES (but, no duplication.)
description	A property describes a short comment about the layer	JSON String	One (mandatory)	YES
updateFrequency	A property provides the connectivity of movement within a time interval (second)	Integer	One (mandatory)	YES (but, the previous data are not affected.)
features	A navigation property to address each moving feature	MovingFeature	Zero-to-many	YES



The moving-feature service needs to manage the connectivity of features' movement by using the updateFrequency interval.

7.2.2. Resource Path Patterns

Each resource in the service has at least one URL. The recommendation pattern of resource URL paths to address a collection of MovingFeature entities, a MovingFeature entity, and its properties may be formed as:

URL patterns without a FeatureLayer resource

- SERVICE_ROOT/MovingFeatures
- SERVICE_ROOT/MovingFeatures(@id)
- SERVICE_ROOT/MovingFeatures(@id)/temporalGeometry
- SERVICE_ROOT/MovingFeatures(@id)/temporalProperties
- SERVICE_ROOT/MovingFeatures(@id)/properties



@id is the identifier of moving feature; therefore, the server needs to return its identifier when a client inserts a new feature or provide a way to access each identifier.

If the server implements the FeatureLayer resource, it is recommend that the path pattern of resource be formed as:

URL patterns with FeatureLayer resources

- SERVICE_ROOT/FeatureLayers/
- SERVICE_ROOT/FeatureLayers(\$NAME)/features
- SERVICE_ROOT/FeatureLayers(\$NAME)/features(@id)
- SERVICE_ROOT/FeatureLayers(\$NAME)/features(@id)/temporalGeometry
- SERVICE_ROOT/FeatureLayers(\$NAME)/features(@id)/temporalProperties
- SERVICE_ROOT/FeatureLayers(\$NAME)/features(@id)/properties



\$NAME is replaced by a string of layer name.

7.2.3. Resource Path Examples

A client can make a request against the resources via URL using various HTTP methods: POST, GET, PUT/PATCH, and DELETE.

Example: To insert a moving feature data into the service.

```
>>> Request
POST SERVICE_ROOT/MovingFeatures HTTP1.1
Content-Type: application/geo+json
{
  "type": "MovingFeature",
  "temporalGeometry": {
    "type": "MovingPoint", // a geometry type to represent a trajectory object
    "coordinates": [ [100.0, 0.0], [101.0, 0.0], [101.0, 1.0], [100.0, 1.0] ],
    "datetimes": ["2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z", "2011-07-15T01:01:01Z"],
    "interpolations": "Linear", // an interpolation method
  },
  "temporalProperties": [ //(optional)
    { "name": "length",
      "uom": "http://www.qudt.org/qudt/owl/1.0.0/quantity/Length", // a URL denoting a unit-of-measure
      "values": [1.0, 2.4, 1.0],
      "datetimes": ["2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z"],
      "interpolations": "Stepwise"
    }
  ]
}

<<< Response
201 CREATED
{
  @id : mf0001",
  @created : "2012-07-14T22:01:01" // Application-defined property
}
```

Example: To add new trajectory data into a stored moving feature.

```
>>> Request
POST SERVICE_ROOT/MovingFeatures('mf0001')/temporalGeometry HTTP1.1
Content-Type: application/geo+json
{
  "type": "MovingPoint", // a geometry type to represent a trajectory object
  "coordinates": [ [100.0, 0.0], [101.0, 0.0] ],
  "datetimes": ["2011-07-16T02:01:01Z", "2011-07-16T06:01:01Z"],
  "interpolation": "Linear", // an interpolation method
}

<<< Response
201 CREATED
{
  @modified : "2012-07-14T22:01:01" // Application-defined property
}
```

Example: To get the list of all the temporal property information.

```
>>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalProperties HTTP1.1

<<< Response
200 OK
[ {
  "name": "length",
  "uom": "http://www.qudt.org/qudt/owl/1.0.0/quantity/Length", // a URL denoting a unit-of-measure
  "values": [1.0, 2.4, 1.0],
  "datetimes": ["2011-07-14T22:01:01Z", "2011-07-14T23:01:01Z", "2011-07-15T00:01:01Z"],
  "interpolations": "Stepwise"
} ]
```

Example: To retrieve a temporal property information whose name(key) is 'dose'.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalProperties('dose') HTTP1.1

<<< Response
200 OK
{
  "name": "dose",
  "uom": "http://www.qudt.org/qudt/owl/1.0.0/quantity/AbsorbedDose", // a URL denoting a unit-of-
measure
  "values": [0.003, 0.003],
  "datetimes": ["2011-07-14T22:32:00Z", "2011-07-15T10:15:00Z"],
  "interpolations": "Discrete"
}
```


Example: To modify the name of a property.

```
>>> Request
PUT  SERVICE_ROOT/MovingFeatures('mf0001')/properties#name='title'  HTTP1.1

<<< Response
204 NO CONTENT
```

7.3. Access Interfaces

The OGC Moving Feature Access [OGC 16-120r2] document requires three types of operations for accessing moving feature data: Type A, Type B, and Type C as follows:

- Type A: Retrieval of feature attribute
For example, these operations retrieve positions, trajectories, and velocities of a moving feature such as a car, a person, a vessel, an aircraft, and a hurricane.
- Type B: Operations between one trajectory object and one or more geometry objects
An example of these operations is “intersection” between a geometry object like an administrative boundary and a trajectory of a moving feature like a car, a person, a vessel, an aircraft, and a hurricane.
- Type C: Operations between two trajectory objects
An example of these operations is to calculate a distance of the nearest approach of a trajectory to another trajectory. The case studies are distance between a criminal agent and a police agent for predicting crime patterns or distance between soccer players for making proper tactics.

OGC Moving Feature Access provides a guideline for implementing interfaces to support moving feature data into a database, data service, or an application using various programming languages or protocols (e.g., SQL functions, Java APIs, and Web APIs). This sub-clause exemplifies how to realize those operations using RESTful API based on a resource URL, followed by the query option parts. The client is able to retrieve a resource representation using a HTTP GET request.

```
"GET" SERVICE_ROOT "/" RESOURCE_PATH "?" QUERY_OPTIONS "HTTP/1.1"
```

This document basically follows the usage of query options (\$filter, \$count, \$orderby, \$skip, \$stop, \$select, and \$search) to be considered in OGC SensorThings API standard [OGC 15-078r6]. The OGC SensorThings API shows a good example of adaptation in OData protocols [OData-Part1] and extension of geospatial query functions. This practice employs the **\$select**, **\$filter**, and **\$search** options in moving feature operations. In order to make a simple rule of the query options, the abstract operations of moving features as identified in [OGC 16-120r2] are re-categorized into three interfaces as shown in [Figure 5: Harvest, Relation, and Analysis](#). Interface **GeoSpatial** and **Temporal** are additionally defined to access derived properties from a TemporalGeometry and

TemporalProperty resource.



The Figure 5 omits the information of parameters and return types of Type A, B, and C operations not to bring misunderstanding the OGC Moving Feature Access specification and ambiguous type definition. The detail specification of each operation in Type A, B, and C (gray color boxes) is described by the OGC Moving Feature Access. The other interfaces (yellow color boxes) are not related to the OGC Moving Feature Access specification.

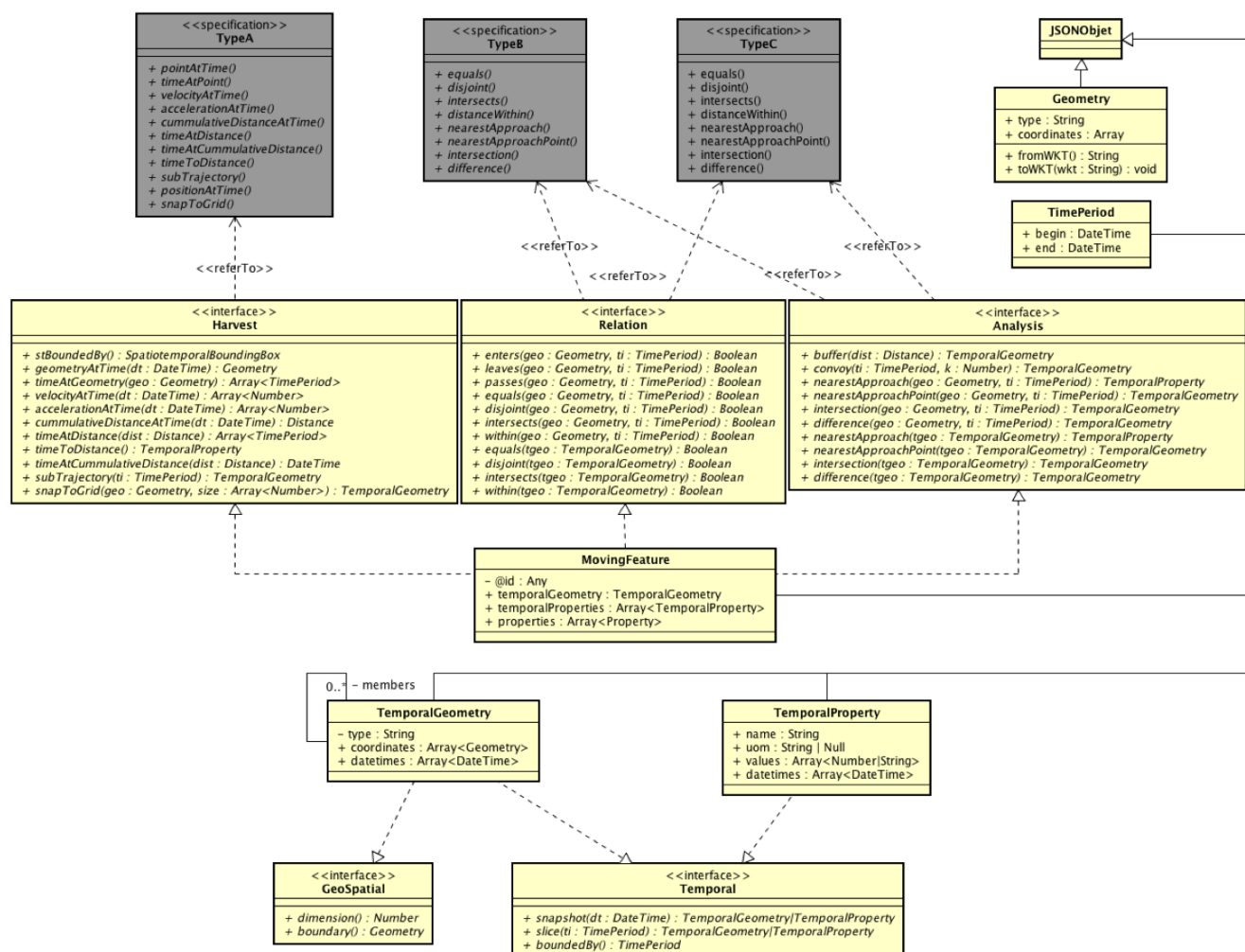


Figure 5. Interface Types of RESTful API

- **Harvest Interface:** This interface mostly implements the Type A operations to retrieve feature attributes. The practice uses `geometryAtTime` and `timeAtGeometry` to extend the geometry types not only 0-dimensional geometry objects but also 1- and 2-dimensional geometry objects instead of `pointAtTime` and `timeAtPoint` in the Moving Features Access document. In addition, operation `stBoundedBy` is added to return the boundary object containing moving features in a spatiotemporal domain. This interface is realized with `Query Option $select`.

- **Relation Interface:** This interface implements the topological relationship operations in Type B (between trajectory and geometry objects) and Type C (between two trajectory objects), such as *disjoint* and *intersects*. The practice changes the name of *distanceWithin* to *within* to exclude the distance parameter. Moreover, new relations of *enters*, *leaves*, and *passes* are defined to clarify its temporal order of topological changes of relation from *intersects*.

Figure 6 shows the examples of each relation. This interface is realized with [Query Option \\$filter](#).

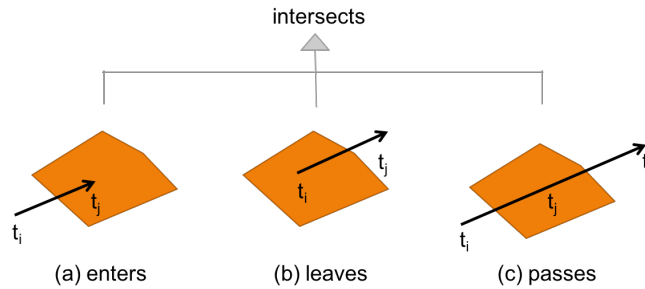


Figure 6. Specialized Relations of Moving Features from *intersects* ($t_i < t_j < t_k$ for time instant t_i, t_j, t_k)

- **Analysis Interface:** This interface implements the analysis operations in Type B (between trajectory and geometry objects) and Type C (between two trajectory objects), such as *nearestApproach* and *difference*. The operations return a new object as a computation result. For example, operation "nearestApproach" with geometric object calculates the distance between a trajectory and the geometry or between two trajectories, and returns a distance in time. This practice additionally defines two more operations: *buffer* and *convoy*. The *buffer* operation returns a temporal geometry (simple or collection) covering all points within a given distance from a target temporal geometry (simple or collection). The *convoy* operation returns the minimum bounding temporal geometry enclosing a group of moving features such that these features are consecutively closed each other (the k-nearest neighbors from a target) during a given time period. Figure 7 shows the result examples of *buffer* and *convoy* operations. This interface is realized with [Query Option \\$search](#).

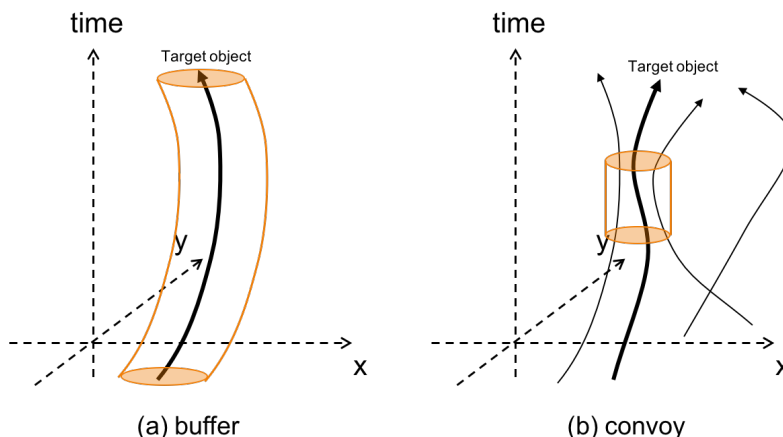


Figure 7. Examples of Analysis Operations

- **GeoSpatial Interface:** This interface provides function **dimension** that returns the maximum dimension of leaf geometry objects and **boundary** that returns the closure of the combinatorial geospatial boundary of all leaves (a foliation) for a temporal geometry resource. This interface is realized with **Query Option \$select**.
- **Temporal Interface:** This interface provides function **snapshot** and **slice** that returns a sub-object of a temporal geometry/property at a given time instant and time period, respectively. The **boundedBy** function returns the temporal range covering its prism. This interface is realized with **Query Option \$select**.

7.3.1. Query Option \$select

The **\$select** query option requests the service to harvest the properties or return a value derived from properties. The operations of **Harvest**, **GeoSpatial**, and **Temporal** are realized with the **\$select** query option corresponding to a **MovingFeature** or **FeatureLayer** resource.

Example: geometryAtTime of a moving feature with ID.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')?$select=geometryAtTime(2008-02-04T00:00:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "pointAtTime" : {
    "type" : "POINT",
    "coordinates" : [ 116.35072, 39.96354 ]
  }
}
```

Example: geometryAtTime of all moving features.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures?$select=geometryAtTime(2008-02-04T00:00:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
[
  {
    "@id" : "mf0001",
    "pointAtTime" : {
      "type" : "POINT",
      "coordinates" : [ 116.35072, 39.96354 ]
    }
  },
  {
    "@id" : "mf0002",
    "pointAtTime" : {
      "type" : "POINT",
      "coordinates" : [ 116.01843751281389, 39.909385232047136 ]
    }
  }
]
```

Example: timeAtGeometry of a moving feature with ID.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')?$select=timeAtGeometry(POINT(116.4%2039.8)) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "timeAtPoint" : [ "2008-02-07T13:00:37Z", "2008-02-07T13:00:51Z", "2008-02-08T13:35:57Z", "2008-02-08T13:36:06Z", "2008-02-06T13:08:32Z", "2008-02-06T13:08:29Z", "2008-02-07T23:04:51Z", "2008-02-07T23:04:55Z", "2008-02-06T23:09:41Z", "2008-02-06T23:09:56Z", "2008-02-04T00:36:14Z", "2008-02-04T00:36:23Z", "2008-02-05T13:17:28Z", "2008-02-05T13:17:39Z" ]
}
```

Example: timeAtGeometry of all moving features.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures?$select=timeAtGeometry(POINT(116.4%2039.8)) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
[
  {
    "@id" : "mf0001",
    "timeAtPoint" : [ "2008-02-07T13:00:37Z", "2008-02-07T13:00:51Z", "2008-02-08T13:35:57Z", "2008-02-08T13:36:06Z", "2008-02-06T13:08:32Z", "2008-02-06T13:08:29Z", "2008-02-07T23:04:51Z", "2008-02-07T23:04:55Z", "2008-02-06T23:09:41Z", "2008-02-06T23:09:56Z", "2008-02-04T00:36:14Z", "2008-02-04T00:36:23Z", "2008-02-05T13:17:28Z", "2008-02-05T13:17:39Z" ]
  },
  {
    "@id": "mf0002",
    "timeAtPoint": ["2013-05-01T10:33:45Z"]
  }
]
```

Example: velocity of the all moving feature.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures?$select=velocity(2008-02-04T00:00:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
[
  {
    "@id" : "mf0001",
    "velocity" : [ 0.0, 0.0 ]
  },
  {
    "@id" : "mf0002",
    "velocity" : [ -5.42125853725347E-4, 1.0906301588750913E-4 ]
  }
]
```

Example: timeAtCummulativeDistance of a moving feature with ID.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')?$select=timeAtCummulativeDistance(1,%22km%22) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "timeAtCummulativeDistance" : "2008-02-02T22:35:04Z"
}
```

Example: subTrajectory of a moving feature with ID.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')?$select=subTrajectory(2008-02-03T23:00:00Z,2008-02-03T23:05:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "subTrajectory" : {
    "type" : "MovingPoint",
    "datetimes" : [ "2008-02-03T23:00:00Z", "2008-02-03T23:04:34Z", "2008-02-03T23:03:49Z", "2008-02-03T23:03:04Z", "2008-02-03T23:02:19Z", "2008-02-03T23:01:29Z", "2008-02-03T23:00:44Z", "2008-02-03T23:00:04Z", "2008-02-03T23:04:39Z", "2008-02-03T23:03:54Z", "2008-02-03T23:03:09Z", "2008-02-03T23:02:24Z", "2008-02-03T23:01:34Z", "2008-02-03T23:00:49Z", "2008-02-03T23:00:09Z", "2008-02-03T23:04:44Z", "2008-02-03T23:03:59Z", "2008-02-03T23:03:14Z", "2008-02-03T23:02:29Z", "2008-02-03T23:01:39Z", "2008-02-03T23:00:54Z", "2008-02-03T23:00:14Z", "2008-02-03T23:04:49Z", "2008-02-03T23:04:04Z", "2008-02-03T23:03:19Z", "2008-02-03T23:02:34Z", "2008-02-03T23:01:49Z", "2008-02-03T23:00:59Z", "2008-02-03T23:00:19Z", "2008-02-03T23:04:56Z", "2008-02-03T23:04:09Z", "2008-02-03T23:03:24Z", "2008-02-03T23:02:39Z", "2008-02-03T23:01:54Z", "2008-02-03T23:01:04Z", "2008-02-03T23:00:24Z", "2008-02-03T23:04:14Z", "2008-02-03T23:03:29Z", "2008-02-03T23:02:49Z", "2008-02-03T23:01:59Z", "2008-02-03T23:01:09Z", "2008-02-03T23:00:29Z", "2008-02-03T23:04:19Z", "2008-02-03T23:03:34Z", "2008-02-03T23:02:54Z", "2008-02-03T23:02:04Z", "2008-02-03T23:01:19Z", "2008-02-03T23:00:34Z", "2008-02-03T23:04:29Z", "2008-02-03T23:03:44Z", "2008-02-03T23:02:59Z", "2008-02-03T23:02:09Z", "2008-02-03T23:01:24Z", "2008-02-03T23:00:39Z", "2008-02-03T23:05:00Z" ],
    "coordinates" : [ [ 116.35079, 39.96372 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35102, 39.96422 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96372 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35102, 39.96421 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35107, 39.96425 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35106, 39.96425 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35105, 39.96424 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35104, 39.96424 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35104, 39.96423 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ] ],
    "interpolations" : "Linear"
  }
}
```

The subTrajectory operation can also be realized by using the slice interface of temporal geometry as follows:

Example: slice of the temporal geometry of the moving feature whose identifier is 'mf0001'.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalGeometry?$select=slice(2008-02-03T23:00:00Z,2008-02-03T23:05:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "slice": {
    "type": "MovingPoint",
    "datetimes": [ "2008-02-03T23:00:00Z", "2008-02-03T23:04:34Z", "2008-02-03T23:03:49Z", "2008-02-03T23:03:04Z", "2008-02-03T23:02:19Z", "2008-02-03T23:01:29Z", "2008-02-03T23:00:44Z", "2008-02-03T23:00:04Z", "2008-02-03T23:04:39Z", "2008-02-03T23:03:54Z", "2008-02-03T23:03:09Z", "2008-02-03T23:02:24Z", "2008-02-03T23:01:34Z", "2008-02-03T23:00:49Z", "2008-02-03T23:00:09Z", "2008-02-03T23:04:44Z", "2008-02-03T23:03:59Z", "2008-02-03T23:03:14Z", "2008-02-03T23:02:29Z", "2008-02-03T23:01:39Z", "2008-02-03T23:00:54Z", "2008-02-03T23:00:14Z", "2008-02-03T23:04:49Z", "2008-02-03T23:04:04Z", "2008-02-03T23:03:19Z", "2008-02-03T23:02:34Z", "2008-02-03T23:01:49Z", "2008-02-03T23:00:59Z", "2008-02-03T23:00:19Z", "2008-02-03T23:04:56Z", "2008-02-03T23:04:09Z", "2008-02-03T23:03:24Z", "2008-02-03T23:02:39Z", "2008-02-03T23:01:54Z", "2008-02-03T23:01:04Z", "2008-02-03T23:00:24Z", "2008-02-03T23:04:14Z", "2008-02-03T23:03:29Z", "2008-02-03T23:02:49Z", "2008-02-03T23:01:59Z", "2008-02-03T23:01:09Z", "2008-02-03T23:00:29Z", "2008-02-03T23:04:19Z", "2008-02-03T23:03:34Z", "2008-02-03T23:02:54Z", "2008-02-03T23:02:04Z", "2008-02-03T23:01:19Z", "2008-02-03T23:00:34Z", "2008-02-03T23:04:29Z", "2008-02-03T23:03:44Z", "2008-02-03T23:02:59Z", "2008-02-03T23:02:09Z", "2008-02-03T23:01:24Z", "2008-02-03T23:00:39Z", "2008-02-03T23:05:00Z" ],
    "coordinates": [ [ 116.35079, 39.96372 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35102, 39.96422 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96372 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35102, 39.96421 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35107, 39.96425 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35106, 39.96425 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35105, 39.96424 ], [ 116.35079, 39.96373 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35104, 39.96424 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35076, 39.96383 ], [ 116.35104, 39.96423 ], [ 116.35079, 39.96374 ], [ 116.35079, 39.96373 ], [ 116.35076, 39.96383 ] ],
    "interpolations": "Linear"
  }
}
```

However, the slice operation is for only one MovingFeature resource. This practice restricts the use of GeoSpatial and Temporal interface to only TemporalGeometry or/and TemporalProperty resource type. The following examples show the use cases of each operation.

Example: snapshot of the temporal property whose name is 'length' of the moving feature whose identifier is 'mf0001'.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalProperties(name=@title)?$select=snapshot(2013-05-01T10:33:41Z)&@title='length' HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "snapshot": {
    "name": "length",
    "uom": "http://www.qudt.org/qudt/owl/1.0.0/quantity/Length", // a URL denoting a unit-of-measure
    "values": [1.2],
    "datetimes": ["2013-05-01T10:33:41Z"],
    "interpolations": "Discrete"
  }
}
```

Example: boundedBy of the temporal geometry of the moving feature whose identifier is 'mf0001'.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalGeometry?$select=boundedBy() HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "boundedBy": {
    "begin" : "2008-02-03T23:00:00Z",
    "end" : "2008-02-03T23:05:00Z"
  }
}
```

Example: boundary of the temporal geometry of the moving feature whose identifier is 'mf0001'.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')/temporalGeometry?$select=boundary() HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "boundary": {
    "type": "LineString",
    "coordinates": [ [100.0, 0.0], [101.0, 0.0], [101.0, 1.0], [100.0, 1.0] ]
  }
}
```

7.3.2. Query Option \$filter

The **\$filter** query option allows clients to filter a collection of moving features that are addressed by a request URL. It can be applied to a specific moving feature and a collection of moving features. The **\$filter** option is evaluated for each moving features in the collection, and returns the features where the expression of the Relation interface is **true** in the response. For a specific feature, it returns **true** or **false**. The **Relation** interface is realized with the **\$filter** query option.

Example: The disjoint operation returns true or false corresponding to a moving feature.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures('mf0001')?$filter=disjoint(LINESTRING(1%202,3%204,5%206),2008-02-02T22:31:00Z,2008-02-02T22:40:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "disjoint": true
}
```

Example: The intersects operation returns the identifiers of moving features whose trajectory intersects with the parameter geometry object for a particular period of time in the collection.

```
>>> Request
GET
SERVICE_ROOT/MovingFeatures?$filter=intersects(POLYGON((30%2010%2C40%2040%2C20%2040%2C10%2020%2C30%2010)),
2013-05-01T10:33:50Z,2013-05-01T10:36:41Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "intersects": [ "mf0001", "mf0003" ]
}
```

Example: The distanceWithin operation returns the identifiers of moving features which are located within 100km from the given position during the parameter time period.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures?$filter=distanceWithin(POINT(103%201.0),2013-05-01T10:33:50Z,2013-05-01T10:36:41Z,100;km) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "distanceWithin ": null
}
```

The operations of Type C between two trajectory objects provide spatiotemporal relations (e.g., intersects). The current API tries to realize the Type C operation by a temporary method until the expression way for parameter moving features becomes clear in a request URL, such as the Well-Known Text (WKT) format for a geometry object.

(1) Create a temporal resource of FeatureLayer as follows:

```
>>> Request
POST SERVICE_ROOT/FeatureLayers HTTP1.1
Content-Type: application/geo+json
{
  "name": "queryfeatures",
  "description": "temporal feature layer for query parameters"
  "updateFrequency": 0
}

<<< Response
201 CREATED
{
  @id : "queryfeatures",
  @created : "2012-07-14T22:01:01"
}
```



(2) Insert a query object into the feature layer as follows:

```
>>> Request
POST SERVICE_ROOT/FeatureLayers('queryfeatures')/features HTTP1.1
Content-Type: application/geo+json
{
  "type": "MovingFeature",
  "temporalGeometry": {
    ....
  }
}
<<< Response
201 CREATED
{
  @id : "mf9999999",
  @created : "2012-07-14T23:01:01"
}
```

(3) Search intersected moving features from the bus layer with the query feature.

```
>>> Request
GET
SERVICE_ROOT/FeatureLayers('bus')/features?$filter=intersects(@id)&@id='mf9999999'
HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "intersects": [ "mf0001", "mf0003" ]
}
```

7.3.3. Query Option \$search

The **\$search** query option allows clients to analyze moving features or a specific moving feature, and returns a new object as a computation result. The **Analysis** interface is realized with the **\$search** query option.

Example: To search the nearest approach point with ID.

```
>>> Request
GET
SERVICE_ROOT/MovingFeatures('mf0001')?$search=nearestApproachPoint(LINESTRING(116.35%2039.8,116.36%2040),2
008-02-04T00:00:00Z,2008-02-04T00:10:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
{
  "nearestApproachPoint" : {
    "type" : "MovingPoint",
    "datetimes" : [ "2008-02-04T00:06:14Z", "2008-02-04T00:06:19Z" ],
    "coordinates" : [ [ 116.35089, 39.96329 ], [ 116.35814635910225, 39.962927182044886 ] ],
    "interpolations" : "Linear"
  }
}
```

Example: To search the nearest approach distance for all moving features.

```
>>> Request
GET SERVICE_ROOT/MovingFeatures?$search=nearestApproach(LINESTRING(116.35%2039.8,116.36%2040),2008-02-
04T00:00:00Z,2008-02-04T00:10:00Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
[
  {
    "@id" : "mf0001",
    "nearestApproach" : {
      "name" : "distance",
      "uom" : "m",
      "values" : [ 7.265423889165578, 7.265423889165578 ],
      "datetimes" : [ "2008-02-04T00:06:14Z", "2008-02-04T00:06:19Z" ],
      "interpolations" : "Linear"
    }
  }
]
```

Example: To compute each intersection object of the temporal geometry from a collection of moving features with a parameter geometry object for a particular period of time.

```
>>> Request
GET
SERVICE_ROOT/MovingFeatures?$search=intersection(POLYGON((30%2010%2C40%2040%2C20%2040%2C10%2020%2C30%2010)
),2013-05-01T10:33:50Z,2013-05-01T10:36:41Z) HTTP1.1

<<< Response
200 OK
Content_Type: application/geo+json
[
  {
    "@id": "mf001",
    "intersection": {
      "type": "MovingPoint",
      "coordinates": [...],
      "datetimes" : [...],
      "interpolations": ...
    }
  },
  {
    "@id": "mf003",
    "intersection": {
      ...
    }
  }
]
```

In the OData protocol, the **\$search** query option is used to restrict the result to include only those entities matching the specified search expression.

For example,



- [http://host/service/Products?\\$search=bike](http://host/service/Products?$search=bike) //return all Products that match the search term "bike"
- [http://host/service/Products?\\$search=\(mountain%20OR%20bike\)%20AND%20NOT%20clothing](http://host/service/Products?$search=(mountain%20OR%20bike)%20AND%20NOT%20clothing) //return all Products that match either "mountain" or "bike" and do not match clothing

Bibliography

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- [2] EPSG Geodetic Parameter Dataset, www.epsg.org
- [3] The GeoJSON Format Specification. 2008, geojson.org

Annex A: Revision History

Date	Release	Author	Paragraph modified	Description
2016-08-29		Kyoung-Sook KIM, Hirotaka OGAWA	All	Created
2016-09-27		Kyoung-Sook KIM	RESTful APIs: Resource types and interfaces	Revised
2016-10-23		Kyoung-Sook KIM	Interpolation formulas, RESTful APIs	Revised