A Semantic Modeling of Moving Objects Data to Detect the Remarkable Behaviors

Mojdeh Soltan Mohammadi
Intactile Design / UMR 228 Espace-DEV
Soltan-mohammadi.m@intactile.com

Isabelle Mougenot
UMR 228 Espace-DEV
Montpellier, France
isabelle.mougenot@umontpellier.fr

Thérèse Libourel
UMR 228 Espace-DEV
Montpellier, France
therese.libourel@umontpellier.fr

Christophe Fagot
Intactile Design
20, Carré du Roi,
Montpellier, France
Fagot.c@inatctile.com

Abstract

The recent advances in both wireless communication and tracking technologies provide new types of services and applications for a better supervision of a variety of moving objects. In order to fully capture the broadest possible range of object situations and more particularly to identify patterns of unusual behavior, we can gain valuable knowledge by analyzing object trajectories. Trajectories of moving objects are complex spatio-temporal aggregates and consequently require an expressive conceptual representation of mobile object trajectory and its related data. In this paper, we therefore propose a knowledge-based model dedicated to handle the moving objects' related data and its trajectory to detect unusual behaviors and their underlying patterns of interest. Interestingly, this model reuses parts of existing ontologies that refer to spatio-temporal knowledge and additionally considers each object as an inseparable part of its unique life trajectory. We illustrate our approach through a concrete use case in the domain of supervision and control systems.

Keywords: trajectory model; moving object; spatio-temporal data; ontology.

1 Introduction

The development of wireless communication technologies for object tracking and geographic information system (GIS) promotes new types of services and applications for real-time monitoring of mobile objects. This offers new perspectives in detecting interesting behaviors of the monitored objects by analyzing their trajectories. The challenge is to clarify the gathered data that is often voluminous, redundant or heterogeneous and also acquired in real time by the various global positioning systems (GPS) distributed in the earth's surface. Over the recent years, a variety of approaches have been proposed for analyzing the object's behavior in different contexts through an ontological trajectory modeling while the most of them are more interested in the trajectory's features than the object's characteristics.

In the current study, we focus on conceptual modeling of the data that is gathered from monitoring mobile objects as an open and flexible model representing both object's characteristics and its trajectory. So, this model must be able to represent the changes that have been applied on values of the object's properties as well as the time when the changes were made over object's movement. To this end, we propose a knowledge model that includes state-of-the-art semantic, spatial, and temporal dimensions of the data and considers only one trajectory for a mobile object throughout its lifecycle. Namely, the semantic dimension is based on the design pattern proposed in (Hu et al 2013, p.346); the spatial dimension is based on the GeoSPARQL[1] standard; the temporal dimension is based on the OWL-Time[2] standard. Later, this model can be used for enriching object's data and detecting remarkable behaviors.

2 State of the art

The real-time management and analysis of geographical, temporal, and mobility information has become a priority in several territory-related areas such as the environment, urban, maritime and air transport. Consequently, during the past decade a wide variety of ontological approaches have been proposed for conceptual modeling of data related to mobile object's trajectory based on for example context-sensitive (Das et al., 2016), activity or event aspect (Andrienko et al., 2011). In this section, we study the most relevant notions and approaches for modeling those semantic, spatial and temporal data.

2.1 Mobility

First, we introduce the "mobile object" and "trajectory" notions as the main concepts related to time and space and then we present briefly our state of the art on trajectory conceptual models.

2.1.1 Background definitions

A **spatio-temporal entity** is an entity of the real world that has a unique identity throughout its lifetime. This entity may also have one or more descriptive and spatial property, which will possibly vary over time and build the dynamic part of the entity (Harbelot et al., 2014). The classification in (Lardon et al., 1999) distinguishes the entity's dynamic capabilities between mutable or changing object, deformable object, convertible object, and mobile or moving object to better control their evolution-related phenomena. In the current study, we only focus on mobile objects and their movements in space, which is considered as their environment. We are

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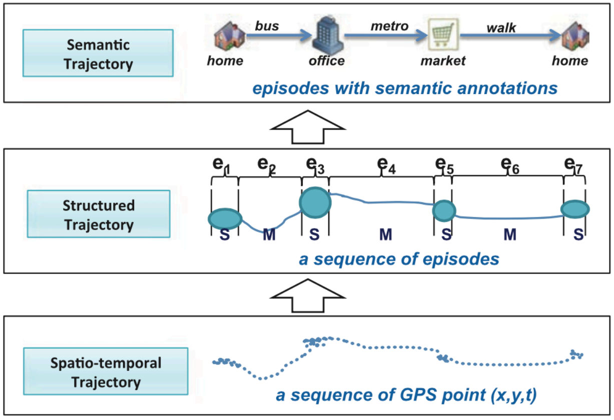
[1] http://www.opengeospatial.org/standards/geosparql

[2] https://www.w3.org/TR/owl-time/

interested in the object's motion evolving in an open and unconstraint space. The movement results in a geographical location that changes over time. A moving object has specific characteristics as well, such as its semantic category (e.g., boat, airplane), its ability to move or its geometric shape.

A **trajectory** is described by the successive positions of an object in space and time; the object's motion path is represented in three spatio-temporal fundamental scales in (Nathan, 2008). Based on (Spaccapietra, 2008) a trajectory is a segment of the spatio-temporal path of a moving object, which is travelled to achieve a given goal. It is defined from the evolution of object's position (perceived as a point) during a given time interval. The points are represented as a triple {xi; yi; ti} in a 2D geographical plane (ti represents a time stamp), or a quadruple (zi sets the altitude) if the trajectory is analyzed in a 3D space. Noël (2015) calls the trajectory as a "semantic trajectory" when it is enriched by additional information, often thematic that can be provided from distributed data sources to clarify the object's description in a given context (illustrated in figure 1).

Figure 1: From the raw trajectory to the semantic trajectory



Source: (Yan, 2013)

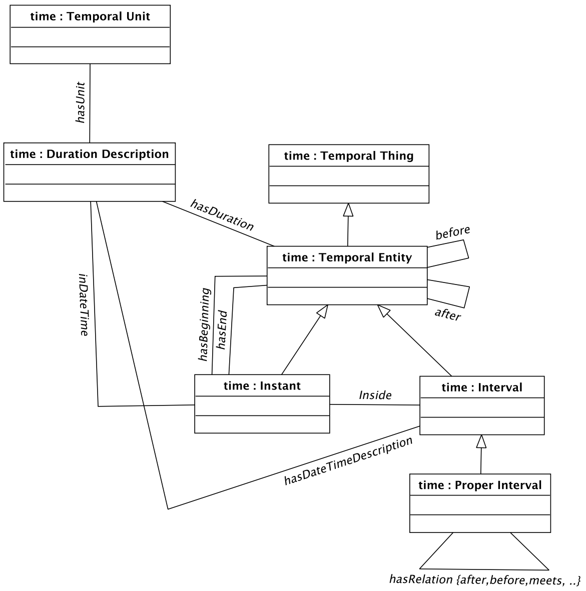
2.1.2 Study of trajectory conceptual models

The "mobile object" and "trajectory" notions are supposed to be presented by means of a generic, open and flexible model adapted to the needs of various contexts. This model must also be able to enrich object's trajectory with the required knowledge for the analysis requests, and particularly for detecting the irregularity in the object's behavior. Different conceptual models have recently attempted to better organize the prominent trajectory's elements as explained below. The conceptual model of Spaccapietra (2008) has introduced the first ideas by analyzing the trajectories of the migratory birds during their trip. This approach modeled the birds' trajectories through their movements (i.e., stops and moves), who have a given objective through each trajectory. So additionally to the geometric facet, a semantic facet resulting from the annotations is associated to the trajectory. Each trajectory's element is then bound to a time attribute. Based on the same concepts, (Baglioni et al., 2008) proposed an ontological model to show a permanent interpretation of the trajectory's objective. Afterward, Yan (2011) has introduced a modular ontology namely geometric, geographic and domain modules for constructing the semantic trajectory. Later, this ontology is reused by (Vandecasteele, 2012) to achieve the control maritime goals. The design pattern of (Hu et al., 2013) describes the human's trajectories by relying to existing ontological modules (e.g., the motion pattern of (Narock et al., 2015)). Nevertheless, following the previous models, it is possible to consider a mobile object with several trajectories or a trajectory, which belongs to different mobile objects.

2.2 Temporal dimension : OWL-Time standard

We reuse the OWL-Time ontology's main concepts (illustrated in figure 2) for modeling temporal data dimension (i.e., instant, interval, the duration measures, the clock and calendar notions representing the dates).

Figure 2: Conceptual model (UML[3]) illustrating the concepts of the OWL-Time ontology defined by DAML[4] project



2.3 Spatial dimension : GeoSPARQL standard

The Core module of the GeoSPARQL standard, illustrated in figure 3, represents the spatial dimension through a full ontology described in OWL2.

A spatial object is defined by both concepts called "Feature" and "Geometry". The feature represents an entity of real world such as a boat or a park while the geometry represents all geometric forms defined on a spatial coordinate reference system. The entity is associated to its geometry by the "hasGeometry" relation.

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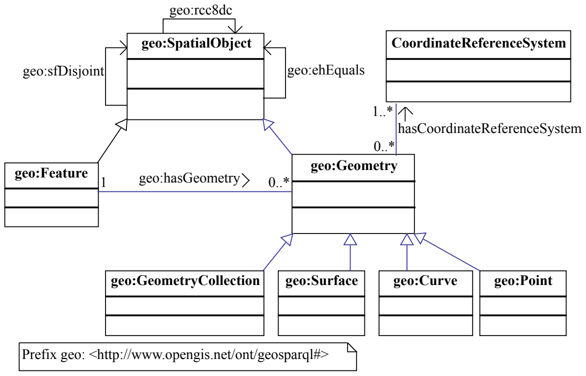
[3] Unified model language: https://en.wikipedia.org/wiki/Unified_Modeling_Language

[4] The DARPA Project or Agent Markup Language is an initiative partnered with the Semantic Web (http://www.daml.org)

Figure 3: Conceptual model (UML) describing the Core module ontology of the GeoSPARQL standard (Reverse engineering)



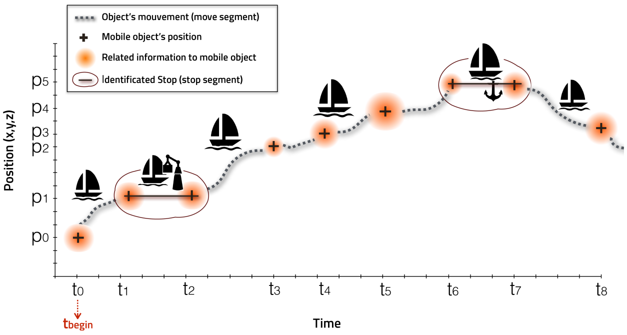
In figure 3, the illustrated reflexive associations, such as sfDisjoint, ehEquals and rss8dc are some examples of GeoSPARQL spatial relations that link at least two "SpatialObject" with type "Feature" or "Geometry". They allow clarifying the relative situation of two objects.

3 Methodological approach

3.1 Construction of a spatio-temporal model

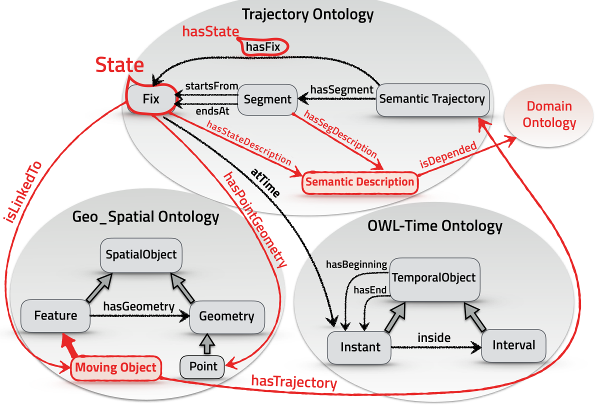
Most of the approaches of our state of the art represent the trajectory dissociable from its corresponding object and don't take into account related semantic information. In some cases, these approaches consider several trajectories for a mobile object while each trajectory is traveled to achieve a given goal. Our postulate is that a moving object has one and the same trajectory constantly evolving as time passes during its life. As shown in figure 4, we create a new state of object when a variation occurs in the value of any property of the object. So each object's state contains the properties that changed values, and is attached to the time when the change was made. The object's trajectory is in the process of being created from the identified states of object over the time.

Figure 4: A part of a boat's trajectory is defined by its states identified over time. A new state of the boat is created as soon as a change occurs in the value of any property.



The received information in real time is semi-structured and incomplete. Hence we need a model that merges and stores not only object's positions, but also various additional information related to object's characteristics and its movement (e.g., weather conditions, other near objects) over time. To this end, we propose a semantic knowledge model that ensures a unified modeling of mobile object and its trajectory and so simplifies the querying and analyzing spatio-temporal knowledge. The figure 5 illustrates a semantic view of our proposal. As shown, we reuse the existing approaches and we determine an extension of each one that is conformed to our vision. Namely, we based on the semantic trajectory's pattern defined by Hu (2013) while it reuses the OWL-Time ontology for the temporal aspect. The spatial entities are taken into account by the GeoSPARQL's core ontology. We define the three relations called "hasTrajectory", "isLinkedTo" and, "hasPointGeometry" between these three high-level ontological components that share the primitive concepts of major invested areas, namely spatial, temporal, and mobility. We refine these primitive concepts to model precisely our domain and to benefit from existing spatial relations of GeoSPARQL as well as temporal relations in OWL-time. This makes possible to extract untapped interpretations and to emerge an integrated model of the moving object and its trajectory.

Figure 5: Our proposed ontological model representing data related to the mobile object and its trajectory (the red concepts are added by our approach)

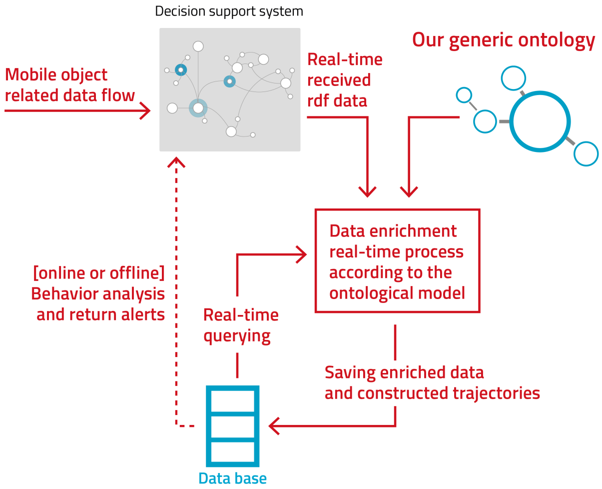


To support the mobiles entities called "Moving Object", we extend the "Feature" class of the GeoSPARQL. A mobile object has attributes like a name, the thematic characteristics and a default spatial form as a geometry point, which is associated to this one by the "hasGeometry" link. The trajectory named "Semantic Trajectory" is linked to its mobile object thanks to the "hasTrajectory" relation. This trajectory supplies the variations in the value of the object's properties and the additional gathered information during the object's lifetime. According to the pattern of Hu (2013), a new instance of "Fix" will be created when the position of the object (spatial representation) changes. But we renamed "Fix" concept to "State" (see figure 5), because we create a new state of object for each change that is done not only in the position but also in any other object's property. The "atTime" relation attaches the state to the changes' time as an instant. If the change is occurred in the position of entity then its state will be bound to a point geometry introduced by the "hasPointGeometry" link. Thanks to the "hasSegment" link, we decompose the trajectory into the smaller phases called "Segment". We create a segment between two successive states defined by the relations named "StartsFrom" (the beginning of segment) and "endsAt" (the end of segment). This segmentation makes possible to analyze the behavior of an entity during a time interval. That is way we don't need to create several trajectories for one mobile object. Therefore, the full representation of an entity's situation is the aggregation of its states resulting by the "isLinkedTo" relation over time. The trace of object's motion (part of its trajectory) in a time interval can be provided by the "hasState" link. If the object has objectives for its movements we can also attach them to the segments of its trajectory. All together, we create a real trajectory for every mobile object that will be reused during the analysis phases and behavior study.

3.2 Use case

To assess the relevance and effectiveness of our integrated model, in figure 6 we provide a general view of an application case of our model in a decision support system.

Figure 6: Illustration of real-time enrichment process of data relating to the evolution of mobile objects through our ontological model



The grey block shows a decision support system's platform available to the company Intactile DESIGN. This platform is first fed in real time by a data flow related to the monitoring of mobile objects in different contexts. We implement an enrichment process to participate to the reflections and decisions about situation of the objects presenting on this platform. This process takes in parameter our ontological model that is conformed to moving object's knowledge to enrich those data with additional semantics and construct the trajectory of each object from the object's states over time. Thereafter, the enriched RDF[5] data that is modeled to the trajectory form is stored in a persistence system. Finally, the stored data will be analyzed and queried to find the patterns of object's irregular behaviors.

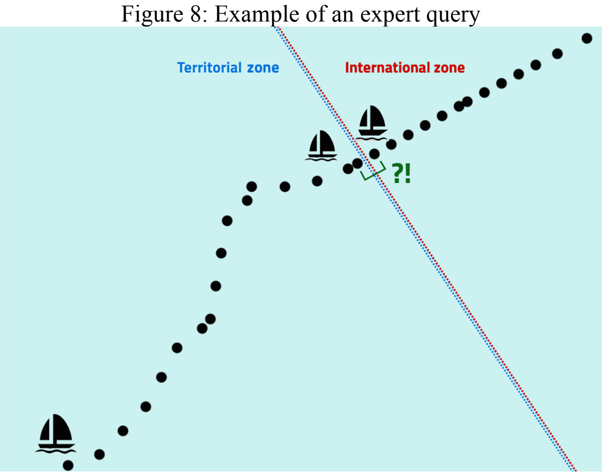
3.3 Data enrichment through proposed model

The figure 7 offers a RDF representation of the data enrichment through our model, step by step during 10 seconds from the evolution of a moving object refer to mObj_231 and illustrates how its trajectory is being created over time. First the system creates the object with an initial state containing its characteristics a priori chosen such as its identifier, name, and its start position (fig. 7.1). Expect the identifier, all other value of properties can vary with time. So, in the second step (fig. 7.2), the instances of "State" are created on the fly as soon as a change is reported at a time. Over 10 seconds, we received two set of changes means two states of this object, the first at 16:25:28 and the second at 16:25:38, each containing the values of properties which have changed since last record (e.g., waterline, speed). Yet, the "isLinkedTo" relation attaches them to the mobile object. Based on our model, from two created states, we create a segment of object's trajectory by adding additional properties to this one (fig. 7.3). We compute such properties from the value of properties in segment's associated states. For example, since both states contain the position's value, we calculate the travelled distance by the object during 10 seconds and we attach it to the segment. So the named property "isMove" has the true value that means the object has moved during this interval. Finally, thanks to the different relations in our model (e.g., hasState, hasTrajectory), we link all created elements (object, states and segment) to the object's trajectory.

3.4 Querying modeled data

Our model allows an expert to query the modeled knowledge to detect the interesting behavior's patterns. Suppose that an expert attempts to supervise the waterline property of a boat crossing the international area (see figure 8).

Figure 8: Example of an expert query



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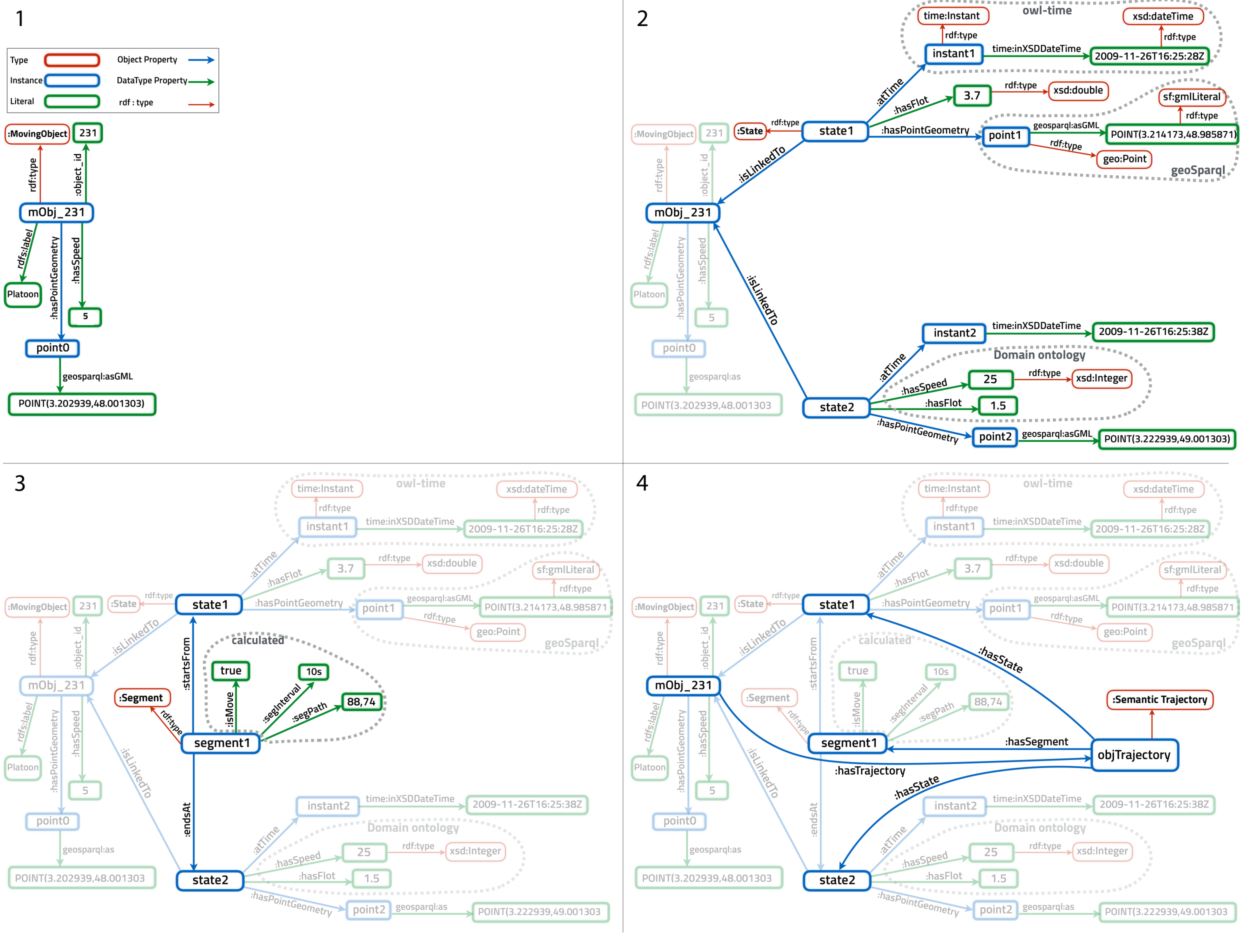
[5] Resource description framework

Figure 7: RDF representation of the received data in 10 seconds



In figure 9, we have translated this question in SPARQL query language. Through our proposed model's concepts, we first search the segment during which the boat crosses from territorial zone to international zone and as result we get the two states of boat before and after that the boat changes the border. So we can export the information about its waterline property or other properties and also the time associated to each state.

Figure 9: Expert's query translated in SPARQL language

```
SELECT DISTINCT  ?segment  ?positionB  ?flotB  ?positionE  ?flotE  ?interval
WHERE
 { ?ship     rdf:type    trajOnt:MovingObject ;
            trajOnt:Unit_id  231;
             trajOnt:hasTrajectory    ?traj .
  ?traj    trajOnt:hasSegment     ?segment .
  ?segment    trajOnt:startsFrom     ?stateB ;
          trajOnt:endsAt     ?stateE.
  ?stateB    trajOnt:hasPointGeometry  ?pointB .
  ?pointB    geosparql:asGML     ?positionB .
  ?stateE    trajOnt:hasPointGeometry  ?pointE .
  ?pointE    geosparql:asGML     ?positionE .
  ?segment    trajOnt:segInterval  ?interval.
  FILTER (
  idFuns:ZoneContainsGeometry( \"3,6010 49,3147 2,7821 49,3574 2,9821 49,5823\" , ?positionB) = true  &&
  idFuns:ZoneContainsGeometry( \"2,6283 48,5659 3,5864 48,5642 3,5562 49,0738\", ?positionE) = true
  )
  ?stateB    trajOnt:hasflot  ?flotB.
  ?stateE    trajOnt:hasflot  ?flotE.
   }
```

The filter function named "ZoneContainsGeometry" is an example of methods that we implemented and added to Jena query engine (called ARQ) such a built-in to simplify the reasoning calculations. This function takes two arguments (zone and geometry point) and returns a Boolean variable justifies whether a point is in a polygon zone or not. The result of this query, which is shown in table 1 means this boat by crossing the border has changed its waterline property's value from 3,75 meters to 1,5 meters during a segment of 10 minutes.

Table 1: Result of the expert query

Segment	**<http://www.intactile.com/ontologies/2016/TrajOntology#Segment3119>**	
interval	**10 minute**	
positionB	**3.3297269773907043, 49.3288840437939**	**flotB = 3.75m**
positionE	**3.0831988361027802, 48.81467430476564**	**flotE = 1.5m**

4 Conclusion and Future work

An ontological model representing the semantic and spatio-temporal data seems a useful contribution to analyze the mobile objects' behaviors for supervision purpose. The model first must be applicable to various incomplete and semi-structured data sets related to object's motion gathered in real time, which can simplify large-scale analysis and processing. Secondly, it must be easily extensible, in line with the standard ontologies or design patterns existing in several domains enriching the moving object's trajectory. In the current paper, we present an ontological model integrating the knowledge related to a mobile object and its trajectory. This model considers only one trajectory for each moving object over its lifeline and is based on three ontological modules. The dynamic part (mobility) related data is modeled through the semantic trajectory's pattern of Hu (2013). The GeoSPARQL ontology is reused as spatial module and the OWL-Time ontology as temporal one. The spatial and temporal relations predefined in these modules allow us to define the situation between two mobile objects. To create a true semantic trajectory, our model provides the data interoperability (facilitated by RDF syntax) and links semantically the incoming information from various data sources thanks to the relations that we have defined. This trajectory will then be used during analysis phases to detect the remarkable objects' behaviors. The first operational validation of our model is realized by inserting a RDF spatio-temporal dataset about mobile objects into a Jena-TDB[6] triple-store and by querying it with a SPARQL[7] query set.

Our future work focuses on providing a more optimal way to store massive data through our model as a solution for the problem of big data (scalability). We continue to study the different strategies of spatio-temporal analysis of the objects' trajectories to exploit remarkable or unusual behavior's patterns. For this aim, we attempt to define the new spatio-temporal operators that simplify the analysis of objects' situations and exploit the different reasoning mechanisms to define the useful supervision semantic rules.

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[6] https://jena.apache.org/documentation/tdb/

[7] Jena-TDB query language (https://www.w3.org/TR/rdf-sparql-query/)