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Semantic Representation of Moving Entities for Enhancing Geographical Information Systems

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ABSTRACT: Geographical Information Systems have become useful for fleet control, hurricane tracking, tourism analysis and some other critical fields that include decision making processes. The analysis have been mainly focused on historical movement, movement prediction and motion patterns detection, which have a tremendous impact in traffic analysis, finding locations of interest and most visited places, estimating hurricane damage and so more. Recently, ontology driven GIS have shown to the scientific community the advantages of making semantic analysis based in ontology models. In this work we present the advantages of using ontologies for representing moving entities and enriching information with semantics. We also present some experimental results of using an ontological model and making semantic queries over the laying information, encouraging on several obtained benefits and aiming to state a basis for enhanced ontology driven GIS.

KEYWORDS: GIS, ontologies, moving objects, semantics, hurricane tracking.

1 INTRODUCTION

Based on needs, researchers have been focusing they efforts on developing algorithms and techniques for facing challenges like: the analysis of data concerning on trajectory or historical trajectories of moving entities given by GPS feeds, finding movement patterns for predicting future movement or change, or water level change on river margins or inundations, or dealing uncertainty associated to unpredicted movement of hurricanes.

The Geographical Information Systems(GIS) developing area is growing fastly, supporting such enhanced functionalities for decision making systems. There are many GIS applications that allow processing of moving entities information, examples of this are fleet control and hurricane tracking. The utility is related to up-to-date position visualization, traffic control, efficient resource assignation, path optimization and trajectory analysis among others. The problem arises when analyzing the laying representation models, that falls short for considering deeper semantic elements.

The real fact is that the answers we receive from laying spatio-temporal models are mainly based on quantitative data. The main interest is to find how elaborate more qualitative queries over spatio-temporal data, and it surely relies over a more qualitative and semantically rich representation. We actually have some notion of how representing and reasoning over spatio-temporal data, and we have (approximately) the necessary means to do that but, are they really semantically rich enough? Could we represent the information of moving entities, hurricanes for example, in a semantic way?

Related to this is the rising of the Ontology Driven Geographical Information Systems (ODGIS), as stated in [1], with a tremendous importance in GIS research and development fields. But most of existing systems only consider spatial and geographical semantics (with all aspects it involves), nothing included from the needed movement semantics, totally focused

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in the spatio-temporal domain. The solution could be to think in an enhanced kind of ODGIS, starting from new spatio-temporal ontologies for the moving objects domain, not only the existing spatial or geographical ones.

2 SEEING EVOLVING ENTITIES AS MOVING OBJECTS

In the field of GIS development for fleet control the “fleet” concept have been generalized beyond vehicles, ships or any other transportation mean. Today we can catalogue as fleet to a person moving around with his mobile phone, or a biker with his GPS device. For meteorologists the tracking of hurricanes is a key issue, mostly in the Caribbean. It does not matter which kind of moving entity we are dealing with, we can gather information and make some behavioral analysis:

- Historical movement analysis
  - Trajectory analysis
  - Movement patterns recognition
  - Outliers detection
- Future movement prediction
  - Uncertainty treatment

Thus, we can see a contact point between what we call fleet and the moving object concept given in [2], where evolving entities that can *“move or change their shape over time”* are called *moving objects*. There are three kind of moving objects: moving point, moving line and moving region. If we deeply analyze, the moving point concept entirely fits the fleet concept, so we can treat all fleet elements as *moving points* and, moreover, the aforementioned analysis is exactly the one carried out in moving objects domain. On the other hand, for hurricanes, taking into account the type of analysis we have to do, we can choose the *moving point* or a *moving region* concept. Having this, we can use in the GIS domain the results obtained in the moving objects researching field.

3 CHALLENGES ON SEMANTIC REPRESENTATION OF MOVING OBJECTS

For representing moving objects we should consider their spatio-temporal behavior. But if we need to improve GIS, we need to also consider a semantic perspective. When analyzing data models [3,4], there are some restrictions, on one hand attached to the poor location-based semantics considered and in the other hand the little consideration of semantics associated with relationships between objects. All this can be improved considering more relationships (e.g. the core three: topological, mereological and mereotopological), represented as concepts and relations between concepts. The data models mainly describe common data types and operators but have a lack on the formal definition of the motion semantics associated to moving objects. It is possible with existing techniques and data models to answer some spatial, temporal and spatio-temporal questions over spatial or geographical data, but they fall short when we need to understand the meaning of the laying information on received answers.

On the other hand, when dealing spatio-temporal information and specifically movement, there are some variables like uncertainty, tightly associated to the random nature of the movement of real entities, and motion patterns, given that common behavior is also a natural practice of humans, animals and some other tracked entities. The correct understanding of motion patterns and uncertainty as they mean remains as open issue. Data mining techniques seem to be the more suitable and useful way for dealing this problem, but there are not enough and well established approaches and sometimes to understand results or make them optimal for users presentation is a hard task.

We need more semantic approaches for achieving this goal; samples of previous efforts are [5] and [6]. Here enters ontologies and ontology based applications. Existing ontologies capture domain concepts, elements and information and link them in a very semantic way, improving humans and applications understanding. But as ontologies seem better when compared with database and logical approaches considering semantic richness, they fall short when taking into account the possibility of handling high amount of information. Thus, we see a contact point between historical researching areas: each one of them can be used as a partial component of an integrational approach that will finally solve existing problems. Database area has been considering semantic enrichment (sometimes using ontologies) of the information for better understanding and deeper analysis; ontology researchers are proposing the usage of rules for ontology reasoning capacity enhancement. On the other hand, logical approaches are applicable to all other approaches as the final goal more and more consist on logical and semantic issues. The solution then is to drive efforts to develop suites, tools or mechanisms that integrate and combine data mining, logical and ontological approaches. Then, the development of ontological approaches for moving objects domain is a primary goal.

3.1 THE FACED PROBLEM AND EXISTING SOLUTIONS

For obtaining the desired semantic representation we need to face a big challenge: finding suitable models for representing moving entities considering movement semantics that fully support semantic reasoning over the laying information. To do that, and considering ontologies as an important part of the possible solution, the researching path should be routed to one of the next tasks:

- To develop an integrational approach which merges actual geospatial ontologies with formal ones and including spatio-temporal elements.
- An improvement to previous ontologies that consider spatio-temporal aspects or the development of an Ontology for Moving Objects.
- Addition of temporal dimensions to existing spatial ontologies considering them as “snapshots” cases of a given instant in the spatio-temporal domain.

Given that we consider in this paper the second case, it is important to say that the modeling of spatio-temporal aspects using ontologies have some others problems to be solved, most of them related with the limitations of existing ontology languages. To the best of our knowledge, there is not a work that summarizes the strength or weaknesses of existing ontology languages on representing spatio-temporal issues, but for the aspect of the unsupported ternary relation, like the (x,y,t) needed for representing movement. Anyway, there are some approaches and models for solving existing problems, like reification, versioning and the 4D-fluents approach. They are mainly useful given the binary-relation-centered support of most ontology languages, like OWL. Each one have its own advantages and disadvantages. Versioning is commonly used for representing the evolution in time of an ontology. On the other hand, reification and 4D-fluents [7] are the widely used methods for representing spatio-temporal concepts.

4 PROPOSAL DESCRIPTION

We have developed an ontology for the moving objects domain, aiming to have a common vocabulary for representing moving objects and reasoning over their motion semantics. For do that, we followed the 4D-fluents approach including Semantic Web Rule Language (SWRL) rules. On this model we use a semantic representation by concepts, handling the spatial and spatio-temporal information by it meaning. This provides better results in queries, given that: (1) can be done as semantic queries (high abstraction), (2) can use inferred information, which could be not explicitly defined and (3) can integrate (or homogenize) information of several elements treated as the same concept: moving object.

4.1 EXPERIMENTAL RESULTS

We have represented data as an adaptation from a real dataset from USA NHC hurricanes database published in http://www.aoml.noaa.gov/hrd/hurdat/easyread-2011.html, using Jena[1] framework for adding individuals as moving objects. Using the Pellet reasoner[2] in a Java application, the added hurricanes were classified, demonstrating the capability of the ontology reasoners for identifying moving objects using equivalent classes, restrictions and SWRL rules.

Then, we tested the spatio-temporal analysis capacity with more specific queries (using ad-hoc queries from [8]) like:

Give me all tropical cyclones that crossed a given Region between some (or before or after) Initial date and End date (in other words, a given interval) or a given date (instant). The equivalent SPARQL query is:

```
SELECT ?hurr WHERE ?hurr rdf:type onto:MovingObject. ?hurr onto:hasTrajectory ?traj. ?traj onto:is_cross ?reg. ?trajts fluent:tsTimeSliceOf ?traj. ?trajts fluent:tsTimeInterval ?interval. ?interval time:hasEnd ?end. ?end time:inXSDDateTime ?date. FILTER (?date < “1990-07-25T18:00:00Z”xsd:dateTime)
```

[1] http://jena.apache.org/

[2] http://clarkparsia.com/pellet

After creating one special scenario using real and artificial data, the obtained output was:

```
onto:Arthur
onto:Charlie
```

For cross-field analysis we imported some data from the Geolife [9] GPS Trajectories, which includes data from several GPS devices associated with people, cars or phone users movements on real scenarios, recording their trajectories. The obtained ontology model was the same as the one for the previously analyzed dataset, which allows similar queries to be made, now also allowing mixing data of two scenarios. For example, a meteorological system could use the available information for analysis like: *"Show the number of people directly affected when Hurricane (or Tornado) X crossed Y state in 1990"*. If the trajectories of people and hurricane one are intersected or the hurricane region includes their position in the same instant, we suppose they were affected and count them.

Table 1. Comparing ontology model and conventional MOD

Criteria/Model	**Proposed model**	**Conventional MOD**
Spatio-temporal Queries Possibilities	+	+
Rapidity of Queries	+	+
Support for Querying Big Amounts of Data	-	+
Possibility of Querying Inferred Information	+	-
Less Abstraction Level	+	-
Less Cross-Domain Query Complexity	+	-

Table 1 shows a summary of comparing conventional Moving Objects Database (MOD) models with ontology models like our proposal. The plus (+) sign means *more advantageous* and minus (-) *less advantageous* for the given criteria. When analyzing the possibilities of spatio-temporal queries in both cases it is possible using several existing techniques. Those queries have similar execution time in SQL and SPARQL, but can be done in higher abstraction level using SPARQL over an ontology model, also using inferred information, which is not possible in databases. The database community has ensured the possibility of manipulating big amount of data, and querying the laying information; on the other hand, conventional ontology reasoners fail in similar cases. Even that, there are approaches like DBOWL [10] for facing this problems (because of this, the criteria appears highlighted in the table). One important application field for ontology models is the information standardization for cross-field analysis. The conventional database models imply database linking or query complexity using several joins. In the ontology models, similar real entities can be treated as the same concept, allowing query disambiguation and low complexity in cross-domain analysis.

5 CONCLUSION AND FUTURE WORK

After we have created and tested the proposed ontology model we can be sure that this can be used as the laying model in a ODGIS for moving objects representation. It can be done even if used together with a conventional MOD, as an abstraction layer for semantic integration or semantic query answering. The representation of evolving entities information as moving objects using this ontology can help on high abstraction level spatio-temporal queries, using inferred information and including information of several fields by the common moving objects representation, facts that have been demonstrated by experimental issues. For the future, remains as goal the inclusion of the presented model as a basis model inside an ODGIS. Regarding spatial representation issues for completing the elements of an enhanced ODGIS, it could be solved using the Map4RDF[3] proposal, which allows visualization of geospatial ontologies over maps.

[3] http://oeg-dev.dia.fi.upm.es/map4rdf/

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