Towards An Ontology-Based Pivot Model for Spatio-Temporal Sources

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Abstract

The spectacular evolution of sensor networks and the proliferation of location-sensing devices in daily life activities are leading to an explosion of disparate spatio-temporal data. The collected data describes the movement of mobile objects used to construct what we call *trajectory data*. The diversity of these generated data has led to a variety of spatio-temporal models. In fact, the conceptual design can be achieved using either enhanced classical models such as spatio-temporal unified modeling language, spatio-temporal entity relationship, or ontological models such as web ontology language. Moreover, the diversity of conceptual formalisms highly increases the heterogeneity of sources as well as the difficulty of interoperating between them.

To reduce this complexity, we set up a high level formalism that covers the most important existing conceptual and ontological models. In fact, current abstract formalisms left out the representation of spatio-temporal properties. In this paper, we present a preliminary work that proposes an ontology-based pivot model for representing spatio-temporal sources.

Keywords: Ontology, pivot model, spatio-temporal sources, trajectory.

1 Introduction

Current advances in remote sensors and sensor networks in daily life activities are leading to an explosion of disparate, dynamic, and geographically distributed spatio-temporal data. Actually, information sources hold data which correspond to the activity of a mobile object traveling in space during a time interval and is called as well *Trajectory data*. The diversity of these generated data has led to a variety of spatio-temporal formalisms. The conceptual design can be achieved either classical models or ontological ones. The most well known classical models are inter alia, Spatio-Temporal Unified Modeling Language (STUML) and Spatio-Temporal Entity Relationship (STER) having a graphical notation and a specific syntax. Despite efforts, they are still limited to understanding moving object's goals neither his activity during the travel. *Ontological based models* are defined as conceptual semantic models covering a sphere among concepts and properties. They have been proposed to reduce syntactic and semantic heterogeneity that may exist among sources [19]. Actually, *OWL* is the standard recommended by World Wide Web Consortium *(W3C)* for the definition of ontologies. OWL is based on description logic (*DL*) formalism. It provides a set of operators which cover several formalisms such that *RDF, RDFS, DAML+OWL*. Also, *Time-OWL* holds temporal information in [12]. *SOWL* a spatio-temporal ontology extends the OWL with spatio-temporal concepts and relations [5]. The diversity of conceptual formalisms highly increases the heterogeneity of sources as well as the difficulty of interoperating between them. The exploitation of this mine of data may be ensured either by integrating or exchanging them.

The emergence of systems like e-government, e-learning, and electronic libraries needs to share information between different systems. Informations, designed and developed by different organizations, are generally sources of autonomous and heterogeneous data. Data source integration problem has been largely studied in the literature [17]. Several factors increase the complexity of sources interoperability: (i) the large number of designers involved in developing the target system, (ii) the diversity of formalisms followed by designers (iii) the heterogeneity of vocabularies and syntaxes, (iv) the autonomy of designers [7].

An artless solution can be applied by putting up $n*(n-1)/2$ mappings between n formalisms. This solution requires a high number of mappings between each pair of models mainly as there are many. To reduce this complexity, setting up a global conceptual pivot model is more suitable. Consequently, the number of mappings will be reduced to n. Conceptual data models advocate as well the use of abstract formalisms for describing data using DL. A unified formalism were advanced for ER model and object oriented data models in [9]. However, current abstract formalisms left out the representation of concepts involved in a spatio-temporal mid and expelled spatio-temporal roles. In order to propose a pivot model, a roadmap including the following steps is needed: (i) understanding the state of art related to trajectory data models, (ii) the fundamental characteristics of spatial and temporal relations that may exist between concepts, (iii) a formalism of the pivot model and (iv) its instantiation.

The outline of this paper is structured as follows: In Section 2, we review main works on trajectory data modeling approaches. Section 3 presents spatial and temporal relations that should be taken into consideration. In Section 4, we describe the pivot model where some existing formalisms are instantiated. Section 5 concludes the paper.

2 Trajectory data models: state of the art

Mainly, trajectory data is the evolution of the position of a moving object traveling in space during a time interval in order to achieve a given goal [10]. Yet, the notion of trajectory has evolved over the time and various models were proposed. In the sequel, we review and classify trajectory data models into classical and semantic models.

2.1 Classical trajectory data models

Many approaches to model trajectories considered as a set of spatio-temporal data were defined [8], [22], [21] [20] [11]. These data were stored and manipulated in Spatio-Temporal Databases (STDB) and Moving Object Databases (MOD). However, current DBMS ability is limited only on storing raw data which is not bearing any semantic information about moving object behavior.

2.2 Semantic trajectory data models

The latest years, a big interest has been shown to the semantic approach for modeling spatio-temporal data. Recently, likely semantic models were in many cases as in the works of [3] [4] [24] [23]. *SMoT* in [3] annotated trajectory data by geographical points of interest. In [4] trajectory data were modeled based on trajectory ontology. In [24], the semantic model was a modular approach provided by three sub-ontologies. The geometric trajectory module holds trajectory's components. The geography module describes points of interest. The application-domain module includes all concepts related to the sphere. As well, mammals trajectory was modeled in [23] through an ontology modular approach that brings out thematic, spatial and temporal components.

Table 1: Classical Vs semantic trajectory data models

	Trajectory	Semantic enrichment
[21]	geospatial lifelines	NA
[22]	abstract data type	NA
[11]	abstract data type	NA
[8]	raw data	NA
[15]	stops and moves	NA
[3]	stops and moves	location
[4]	stops and moves	trajectory ontology
[24]	generic trajectory	modular ontology
[23]	seals trajectory	modular ontology

2.3 A taxonomy for trajectory data models

The aforementioned trajectory data models fall into two categories (Figure 1) (a) classical models and (b) semantic models. (a) Classical models [8] [22] [21] [20] [11] hinge on conceptual models based on STUML or STER. These models are busy of constructs and stereotypes as well as inapprehensible. Despite efforts, they are still limited to understanding moving object goals neither his activity during the travel. (b) Semantic models rely on algorithm based and ontology based models. Algorithm based models [3] extend stop and moves with semantic geographical information. Ontological ones [4] [24] [23] offer a global ontology for trajectory data.

As a matter of fact, ontology models are similar to conceptual models, but in many aspects of knowledge representation the former exceeds the latter. Among

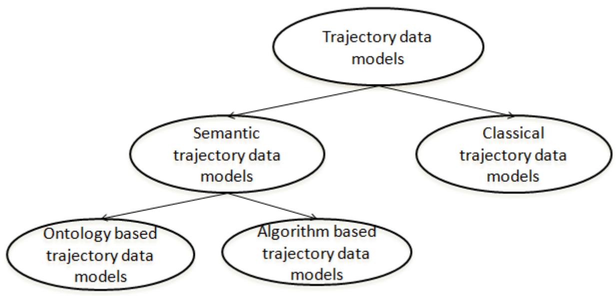

Figure 1: A taxonomy for trajectory data models

which we mention here the ones that are most relevant for the pivot model:

- *Consensuality*: To hold out a global and universal view of trajectory data whose purpose is taking off ambiguity. The latter results from heterogeneous formalisms and syntaxes. The diversity of formalisms used by designers increases the heterogeneity of vocabularies. Therefore, semantic must be defined straightforwardly.
- *Interoperability*: To offer a hardware and software independent model. The pivot model plays the role of a global conceptual model with a shared vocabulary of a universe of discourse which is trajectory.
- *Transformation*: To provide transformation model techniques between the pivot model and the local models which will reduce the complexity of mappings between different formalisms.
- *Reasoning*: To apply reasoning mechanisms on the trajectory model in order to deduce new informations from existing concepts and relations.

3 Background

The proposed pivot model is an ontological OWL model based on DL which is a formal mathematical language. A DL knowledge base is composed of two components a *TBOX* and an *ABOX*. The *TBOX* contains general knowledge about the domain in the form of a terminology. It is built through declarations that describe general properties of concepts. Besides, it includes concepts definition with the definition of new concepts thanks to DL constructors. The *ABOX* contains extensional knowledge which provides assertions about concepts and roles [14]. *OWL-DL* stands on the fragment *SHOIND(D)* which provides a set of constructors like intersection ($\cap$), union ($\cup$), complement ($\neg$), universal quantification ($\vee$), existential quantification (($\exists$)), enumeration, equal value, minimal cardinality, maximal cardinality and exact cardinality. For the aim of extending the model with spatio-temporal properties, we summarize the representation standard of temporal and spatial informations in the litterature.

3.1 Representing temporal information

Time-OWL[1] is a temporal ontology standard developed by the *W3C* thanks to the definition of temporal concepts and properties as defined by Allen algebra [2, 1]. The latter manages a set of relations between *time intervals* which are defined as a starting and ending *instants*. Let $i1 = [s1; e1]$ and $i2 = [s2; e2]$ be two

[1] http://www.w3.org/TR/owl-time/

intervals $i1, i2$ with starting and ending instants $s1, s2$ and $e1, e2$ respectively. Allen algebra depicts the following relations *Before, Overlaps, Meets, During, Starts, Finishes, Equals* and their inverse relations *After Overlappedby, Metby, Contains, Startedby Finishedby* (Table 2).

Table 2: Matching of DL constructors with Time-owl constructors

DL constructor	OWL-Time relation
i1 before i2	intervalBefore
i1 equals i2	intervalEqual
i1 overlaps i2	intervalOverlaps
i1 meets i2	intervalMeets
i1 during i2	intervalDuring
i1 starts i2	intervalStarts
i1 finishes i2	intervalFinishes

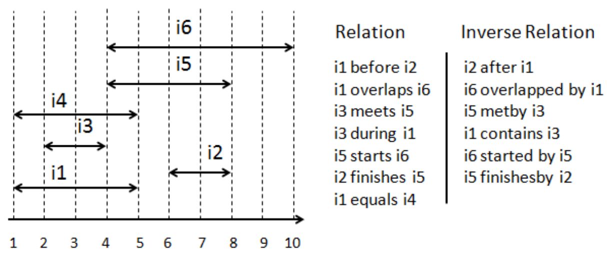

Figure 2: An example of Allen's temporal interval relations

We provide an example for temporal relations (Figure 2). Then, we can deduce the following assumptions:

- i_1 equals $i_4 \wedge i_1$ before $i_2 \rightarrow i_4$ before i_2
- i_5 during $i_6 \wedge i_2$ during $i_5 \rightarrow i_2$ during i_6
- i_3 meets $i_5 \rightarrow i_5$ started by $i_6 \rightarrow i_3$ meets i_6

3.2 Representing spatial information

SOWL offers a representation for spatial objects in [6]. Spatial objects are typically formalized using *point*, *line*, *polyline*, and *Minimum Bounding Rectangle (MBR)*. *Point* represents point location having two or three numerical attributes. *Line* represents line location. It has two points as attributes representing the starting and ending points of a line segment. *PolyLine* represents the surrounding contour of an object as a set of consecutive line segments [6]. An object may also be represented by its (MBR) specified by the four numerical attributes $Xmax$, $Ymax$, $Xmin$ and $Ymin$. Relations connecting two spatial objects fall into three categories: topological, directional, and distance relations.

Topological Relation : based on RCC-8 standard in [13] represents a set of relations namely *connects with (C)*, *parts of (P)*, *overlaps (O)*, *disconnected (DC)*, *externally connected (EC)*, *equal (EQ)*, *tangential proper part (TPP)*, *non-tangential proper part (NTPP)*, and *partially overlapping (PO)*. These latter can be written in *DL* as indicated in (Table 3). Then, inverse relations are omitted. From these defined relations, we can deduce new relations such as:

- NTPP(X,Y) $\wedge$ EC(Y,Z) $\rightarrow$ DC(X,Y)
- EQ(X,Y) $\wedge$ EQ(Y,Z) $\rightarrow$ EQ(X,Z)

Table 3: Matching of topological relations

DL constructor	SOWL relation
Connects with	C(x,y)
Parts of	P(x,y)
Overlaps	O(x,y)
Externally connected	EC(x,y)
Disconnected	DC(x,y)
Equal	EQ(x,y)
Tangential proper part	TPP(x,y)
Non-tangential proper part	NTPP(x,y)
Partially overlapping	PO(x,y)

Directional relations : presented in [16] respectively North (N), North-East (NE), East (E), South East (SE), South (S), South West (SW), West *(W)* and North West (NW).

Distance Relations : based on the *W3C* standard and represents an object with attributes as (3 Km away) representing their distance or with qualitative attribute like (Far and Near).

4 Our proposal

In section 2, we analyzed most of the works in the literature related to trajectory data conceptual modeling. In here, our goal is to find a high level formalism that covers the most important existing static conceptual models like STUML class diagram, STER models and OWL ontological models. STER extended the ER model with spatio-temporal constructs. STUML is the extension of UML class diagram with spatio-temporal features. OWL is a standard ontology embedding classes and properties. We choose DL formalism. DL is able to capture the most popular data class-based modeling formalisms frequently used in databases and information system analysis [9].

In (Figure 3) we define the meta-model for the pivot model extended by spatio-temporal concepts and properties as follows:
PivotMetaModel:< Concept, Role, Resource, Relation >, such as:

- *Concept*: denotes atomic and derived concepts of the model.
- *Role*: denotes properties (roles) of the model.
- *Resource*: denotes references of concepts and roles of the model.
- *Relation*:< Basic Relation, Spatial Relation, Temporal Relation > denotes spatio-temporal relations of the model used to deduce new informations.
  - *Basic Relation* : regroups basic relations such union, intersection covered by the basic *DL* fragment.
  - *Spatial Relation* : regroups spatial relations based on *W3C* standard.
  - *Temporal Relation* : regroups temporal relations based on Allen relations.

The pivot meta-model manages a reference relationship between resources and extended relations in order to deduce new resources (concepts and roles).

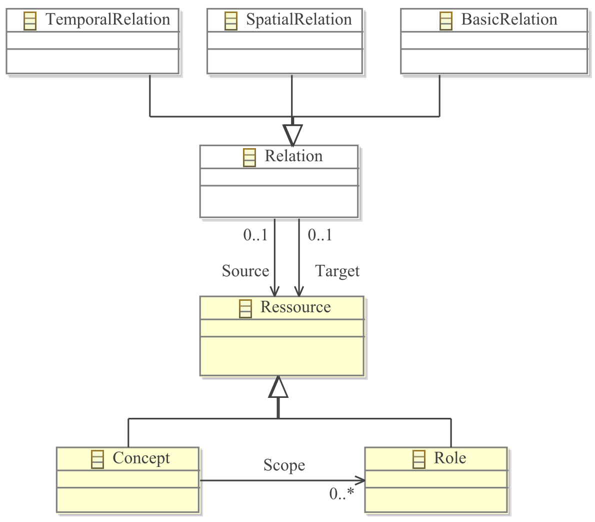

Figure 3: Meta-model of the pivot model

4.1 Representing spatio-temporal information

A spatio-temporal information is the junction of a spatial and a temporal information. To formalize the later, we give basic spatio-temporal concepts (Table 4).

Table 4: A definition of spatio-temporal concepts

Concept	Definition in DL
Timepoint	Point ∩ Instant
Timeline	Line ∩ Instant
Timeregion	Region ∩ Interval

In addition, through spatial and temporal relations presented above, we can make relations between concepts (Figure 4).

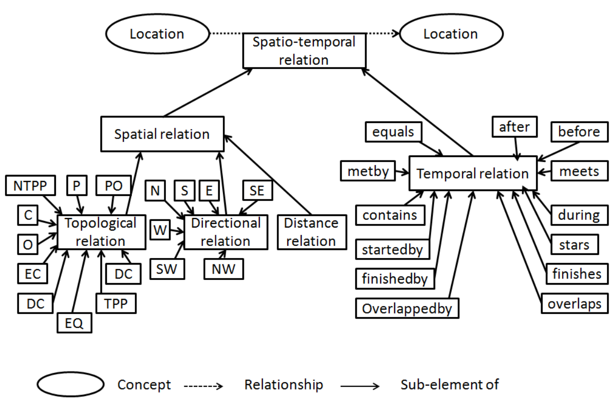

Figure 4: Schema of spatio-temporal relations

4.2 Formalization of the pivot model

A formalization for conceptual static and ontological models were presented in [18]. This formalization left out the representation of concepts involved in a spatio-temporal mid and expel spatio-temporal roles. We propose an enrichment with spatio-temporal concepts and properties as follows:

PivotModel: $< C, R, Ref(C, R), Formalism >$, such as:

- C : denotes *concepts* of the model (atomic concepts and concept descriptions) extended with spatio-temporal concepts.
- R : denotes *properties (roles)* of the model. Roles can be presented as relationships relating concepts to other concepts or relationships relating concepts to data-values.
- $Ref(C, R)$: C ∪ R→ (*Operator*, *Exp*(*C, R*)) is a function representing the various correlations between concepts and roles.
- *Operator* can be inclusion (⊑) or equality (≡).
- *Exp(C,R)* is an expression over concepts and roles of the model using constructors such as union, intersection, restriction, extended by spatial and temporal constructs.

For example concept Begin in the Trajectory Spatio-temporal ontology [24] is defined as all Point having a time Instant.
i.e. Ref(Begin)→(⊑, Point ∩ ∨ has time (Point, Instant))).

- *Formalism* : represents the formalism ensuing by the spatio-temporal conceptual model like STER, STUML, SOWL, RDF, etc.

4.3 Instantiation of the pivot model

To illustrate our proposal, we instantiate the pivot model over a set of well known spatio-temporal models (Table 5); class based models such as *STUML STER* in [22], *Time-owl*, and *Trajectory ontology*.
STER is based on entities described by attributes and relationships. To reference entities we use the relation *is-a* so called equivalence (≡) in *DL*.
Then, *STUML* is based on classes described by attributes and associations. Rather than *STER*, we can reference classes using *is-a* and *type-is* relations so called respectively equivalence ≡ and inclusion ⊑ in *DL*.
Also, *Time-owl* is an *owl* ontology embedding classes defined by *object properties* and *data type properties*. To reference individuals, we use operators based on basic and temporal *DL* relations.
Regarding, *Trajectory ontology* is based on *OWL-DL* and includes a set of classes defined by *object properties* and *data type properties*. To reference individuals, we use operators based on temporal, spatial, and basic *DL* relations.

5 Conclusion

In this paper, we proposed a preliminary work described by an ontology-based model destined to define and represent spatio-temporal data. To do so, we formalized concepts, relations and structures of the most important existing models.
The analysis of these models allowed us to define our global pivot model. To show its importance and genericity, we instantiated four main important models which are: OWL-Time, STER, STUML, and trajectory owl ontology.
Currently, we are developing a Model Driven Approach (MDA) to ensure an automatic interoperability of these models and to exploit the reasoning mechanisms offered by ontologies to detect conflicts and anomalies between models.

Table 5: An instantiation for spatio-temporal data models

Formalism	Presentation of spatio-temporal model
STER	**Concepts** Entities **Roles** Attributes / Relationships **Ref(C, R): C ∪ R →(operator, Exp(C,R))** *Operator* Inclusion ⊑ *Exp(C, R)* expression between entities and (attributes, relationship) to define new concepts and relations.
STUML	**Concepts** Classes **Roles** Attributes / Associations **Ref(C, R): C ∪ R →(operator, Exp(C,R))** *Operator* Equivalence ≡ or inclusion ⊑ *Exp(C, R)* expression between classes and (attributes, associations) to define new concepts and relations.
Time-OWL	**Concepts** Classes **Roles** Object properties / Data type properties **Ref(C, R): C ∪ R →(operator, Exp(C,R))** *Operator* Operator of*SHOIN(D)* and temporal DL constructs *Exp(C, R)* expression between (classes and (object properties, data type properties) to define new concepts and relations.
Trajectory OWL	**Concepts** Classes **Roles** Object properties / Data type properties **Ref(C, R): C ∪ R →(operator, Exp(C,R))** *Operator* *SHOIN(D)* and spatio-temporal DL constructs *Exp(C, R)* expression between classes and (object properties, data type, properties) to define new concepts and relations.

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