Geographic Information Systems: a Unified Conceptual Model for Temporal Aspects

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Abstract. Time presents an important component of spatial analysis. However, conventional Geographic information systems (GIS) approaches adopt a static view to model geographic phenomena and are incapable of representing the changes and the dynamics of GIS. Building on pre-existing formalisms, a unified spatial-temporal GIS data model is developed to faithfully record all of the time-related information produced by GIS. For the temporal representation, the unified temporal model which we have represented in (Radjai and Rassoul, 2013) accommodates different temporal primitives and types. Time can be absolute and relative, certain or uncertain. Different granularities and calendars are supported. In this paper, we demonstrate that we can use this model to represent all time related data and to refer to any past state of GIS. For the spatial representation, we use the GeoProfile model (LISBOA-FILHO et al, 2010). This framework allows us to represent geographic phenomena in the object as well as in the field view.

Keywords: GIS, temporal aspects, object modeling, concepts unification, instantiation

1 INTRODUCTION

Time has become important in many areas in the society as diagnostic applications, cadastral systems, medical informatics, Computer-Aided Design, Computer-Aided Manufacturing, Computer Aided Construction and geographic information system. The automation of such applications needs temporal support. But existing models could not support temporal information well. The representation of time is still problematic. A field where the temporal component becomes very important is GIS. Spatiotemporal GIS is an active area of research within geographic information science centering on representation, management, manipulation, and analysis of spatiotemporal data. GIS collect data from diverse sources. The resulting data have both spatial and temporal features. These features are diverse and complex, and require powerful data model to adequately address the challenges posed by these data.

We have focused our design efforts on temporal aspects of data models for GIS. The new, fundamental issue of temporal GIS models consists of which modeling approaches that can adopt today or in the near future for representing the temporal needs of GIS?

The goals of this research are twofold:

- To develop a unified conceptual model for temporal aspects in GIS by combining different models.

- To demonstrate how the unified temporal model proposed by Chafiqa and Idir (2013) can be an efficient temporal formalism for modeling the dynamic aspect of GIS.

The rest of the paper is organized as follows: Section 2 will explain and discuss the dynamic aspects of spatial information in GIS applications. Section 3 will give an overview of spatial-temporal models proposed for modeling spatial and temporal features of GIS. The demonstration section will provide a detailed description of spatial and temporal features modeling approach. Finally, the conclusion will be given in section 5.

2 THE DYNAMIC ASPECTS OF SPATIAL INFORMATION

Geographical objects have geometric properties. The geometry of a spatial object can be changed over time (such as urban expansion, the boundary of a land parcel). Geographical objects include not only the geometric information of spatial entities, but also their positions over time (such as a vehicle movement) and their attributes' characteristics over time (such as the type of land cover, road traffic volume). GIS should describe the current state and the past dynamics of geographical spatial objects in a well-defined area. There are different aspects of time that can be considered here. The state of spatial object can be changed continuously over time (such as temperature) or can be changed discretely over time (such as cadastral applications). These changes require measures of valid time when those changes occur in the real world, transaction time when those changes are modeled in the database. These features require the extraction of current states, past states and predicted future states at specified instants and their durations over specified intervals. Instant is described at different granularities. Since the observation and capturing of some real world objects are not always precise, we need also to support the representation of uncertain information. Accordingly the geographical spatial object must be totally time-referenced. Powerful conceptual models must be available to describe and handle temporal aspects of objects in GIS.

3 BACKGROUND AND RELATED WORK

Before reporting upon the details of the meta-model proposed, we provide a very brief review of some spatial-temporal models proposed to modeling GIS applications.

GeoFrame-T model (DA ROCHA et al, 2001). Following this approach, Time is included in attributes, objects and relationships levels. In order to simplify the modeling process, a group of stereotypes has been specified to model these temporal aspects using UML modeling language.

The Feature Evolution Model (FEM) (LOHFINK et al. 2007) based on a 'state-event-state' approach represents both geographic entities and change as objects, using inheritance to distinguish between events and processes. It provides a suitable way of accessing states either directly, or by the occurrents that produced them.

Jugurta, and Cirano (2008) have proposed the Spatial-Temporal UML-GeoFrame model. This model provides a basic class diagram. The UML-GeoFrame model can specify two types of temporal occurrence: Interval and Instant, which it is done using stereotypes. Time granularity can be Date, Time and Timestamp.

4 DEMONSTRATIONS

In this section, we will present the temporal conceptual data model we propose for the representation of temporal aspects. Our proposed model follows the object-oriented programming standard.

This section includes three major parts: (a) modeling the spatial aspects, (b) modeling time and temporal aspects of objects and associations, (c) an example of modeling spatial-temporal aspects. We will show how to quickly create the application diagram using UML and represent different temporal aspects. In the demonstration, we will discuss the modeling process.

4.1 Modeling spatial aspects

The representation of spatial relationships and spatial properties of information is also a well researched topic. Spatial representation models, including both the vector (object-based) and the raster (field-based) approaches. The GIS vector approach considers that geographical spatial objects in the real word can be represented either as:

- Points: represent discrete point features such as trees, buildings and so on
- Lines: represent linear features such as roads, streams, rivers and so on
- Areas (polygons): represent bounded areas such as forest, cities, lakes and so on
- Complex objects: represent object which composed of the above objects such as country which can include cities, forest, roads, etc.

One of the strengths of the vector data model is that it can be used to render geographic features with great precision. Vector approach is good at representing discrete features.

Raster approach represents a surface as a regular (grid) of equally sized cells or irregular (partitions with varying sizes and shapes). Each cell includes an attribute value and location coordinates. Raster approach is good at representing continuous features such as: land use, temperature, elevation, air movement, chemical concentration.., Etc. Its main advantage is its simplicity

The model that we take for the spatial representation in this study is GeoProfile model. This model incorporates the spatial dimension by proposing a set of stereotypes. The three main stereotypes are *GeoObject, GeoField, and NetObject. GeoObject* can be a *Point*, a *Line*, a *Polygon* or *ComplexSpaObj*. *GeoField* type value can be selected from the following options: *AdjPolygons, Isolines, TIN, GridOfPoints, GridOfCells, IrregularPoints* or *ComplexField*. *NetObject* models network objects, which can be nodes (*Node*), unidirectional arcs (*UnidirectionalArc*) or bidirectional arcs (*BidirectionalArc*). Fig. 1 shows the stereotypes used for the modeling of spatial proprieties.

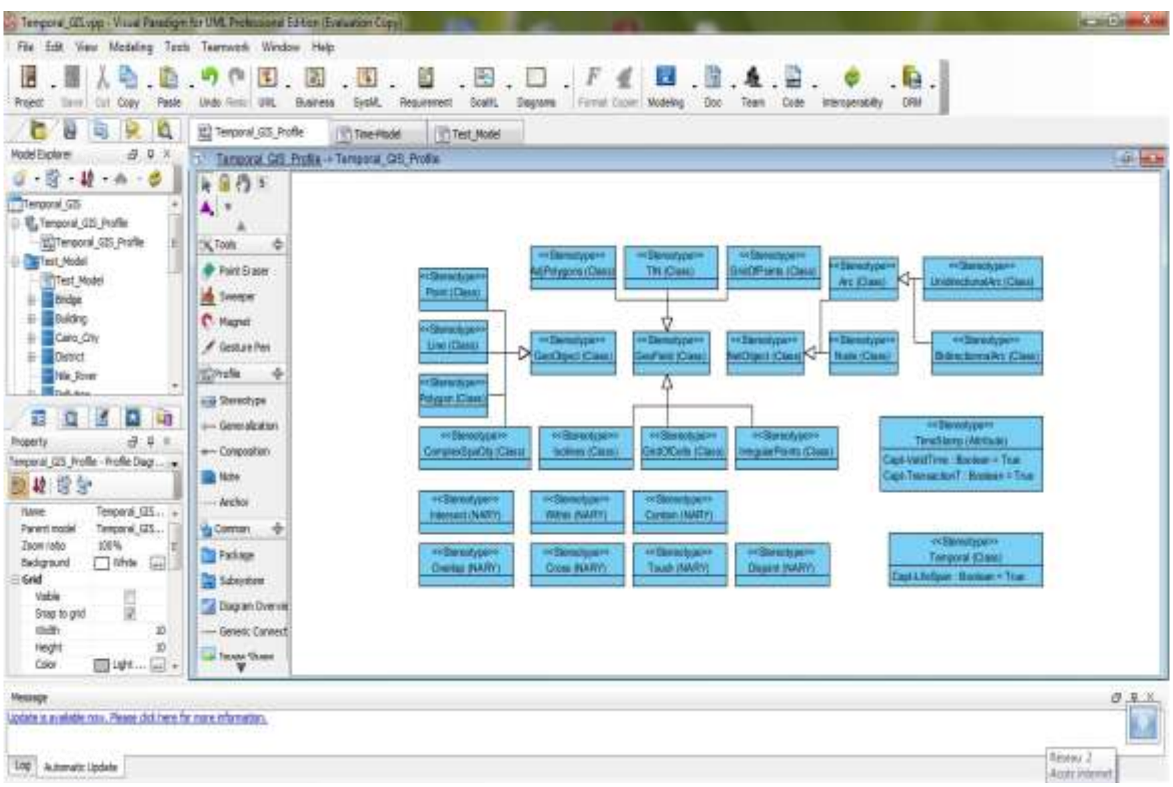

Fig.1. Modeling spatial aspects

Most classifications of spatial relations distinguish between topological relations and metrical relations. The specific relations we are interested in are those of topological relationships (*Touch, Disjoint, Cross, Within, Overlap, Contain, and Intersect)* described by (Chen et al, 2012). This article gives the definition of these predicates for better understanding of topological relationship.

4.2 Modeling time and temporal aspects

Geographical information systems models are still not able for a fully representation of temporal aspects of spatial data. For example, they do not usually support: the representation of data at multiple levels of granularity, the handling of data that may involve uncertainty or the record of the history of change. To resolve these problems, the first step is to model the time and after identify the temporal object and model it.

Modeling Time

The unified temporal conceptual model proposed in (Radjai and Rassoul, 2013) is based on pre-existing representation formalisms. The resulting formalism allows the access to the successive states of IS by the notion of time and assures a good representation of temporal aspects. Firstly, we need to introduce the model of time that includes multiple temporal dimensions. A class *Time* may be an instant (class *Instant*), *Interval* (class *Interval*), Set of Instants (class *Set-Of-Instants*), Set of intervals *(Set-Of-Intervals*) or period (class *Period*). An instant can be relative (class *Instant_R*) or absolute (class *Instant_A*). *Instant* and *Period* are expressed in a given calendar (Class *Calendar*). Class *Instant* is fully described by the five attributes *granularity*, *position*, *duration*, *uncertainty* and *isShifted*. These attributes are fully described in (Benzler and Clark, 2005). In Fig. 2, the model of time proposed by Chafiqa and Idir (2013) is shown:

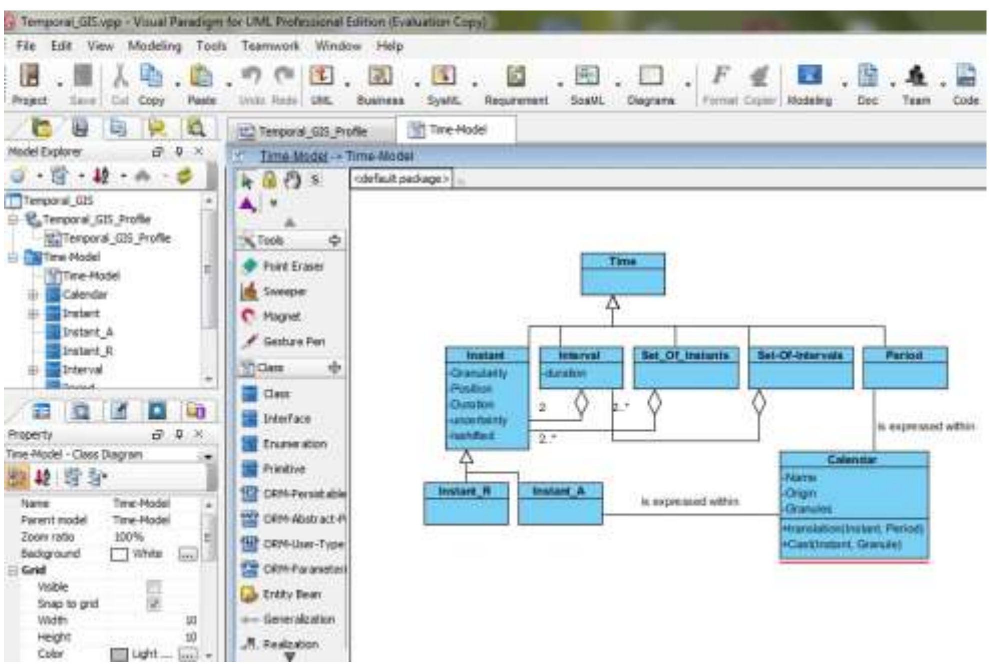

Fig. 2. Model of time, (Radjai and Rassoul, 2013)

Modeling temporal aspects of objects and associations

The stereotypes <<*Temporal*>> and <<*Timestamp*>> are proposed to deal with temporal aspects. The first contains the *Capt-LifeSpan* tag that has *Boolean* type. This is used to define the temporal states of objects and associations, which can be *Scheduled*, *Active*, *Suspended* or *Disabled*. The second stereotype contains two tags *Capt-TransactionT* and *Capt-ValidTime* that have Boolean types. This stereotype is used to indicate the temporal type of attributes and to store the history of objects and association states and attributes. It explicitly timestamp the object and association types and register all the time of their instances. Constraints are attached to the stereotype <<*Timestamp*>> that ensures for valid time. If the valid time is a set of intervals, these cannot overlap. If it is a set of instants, these must be distinct. Furthermore, there is no time future for transaction time. As we have seen, these temporal constraints are inherent to the definition of the temporal features of entity and relationship types. However, it must be explicitly defined. In fig. 1 (Radjai and Rassoul, 2013), the temporal stereotypes are described.

4.3 Application context

The case study application for the implementation of the model proposed is the representation of the GIS of Cairo city. Cairo is the capital of Egypt. It is a land divided by the River Nile. Many flying bridges cross the River Nile linking its three main districts: Old Cairo, Giza and Zamalek. There are a total of 11 districts, with a total population in excess of 16 million people; it’s among the world's most densely populated cities. It has high rise buildings and increased vehicular movement. All these activities contribute to air pollution. In order to make decisions for processing incorporating environmental policies and management, we need to observe and predict the state of temporal GIS model of air pollution. Knowing the states of temporal GIS can be useful in the decision making process.

4.4 Implementation

The conceptual model proposed is represented using UML and has the advantage of being implementable by any OO programming language and database development environment. The implementation of the temporal extension allows showing the validity of our approach and, at the same time, it provides the users with the ability to graphically specify temporal information in the UML. We have implemented it in the Visual paradigm for UML tool which is one of the tools that admits the definition of stereotypes and tagged values. Fig. 3 shows the modelling process of the model specified in this tool.

When we want to capture the evolution of a geographic object, we should join the <<*Temporal*>> stereotype to spatial stereotypes. To store the history of geographic object, we must register all the time of each instance of this object. This is done by including the <<*Timestamp*>> stereotype whose goal is to explicitly timestamp the object. To store the changes of an association, we proceed in a similar way as we did for object. Fig. 3 presents an example of the modelling process of spatial and temporal classes of geographic information system of Cairo city.

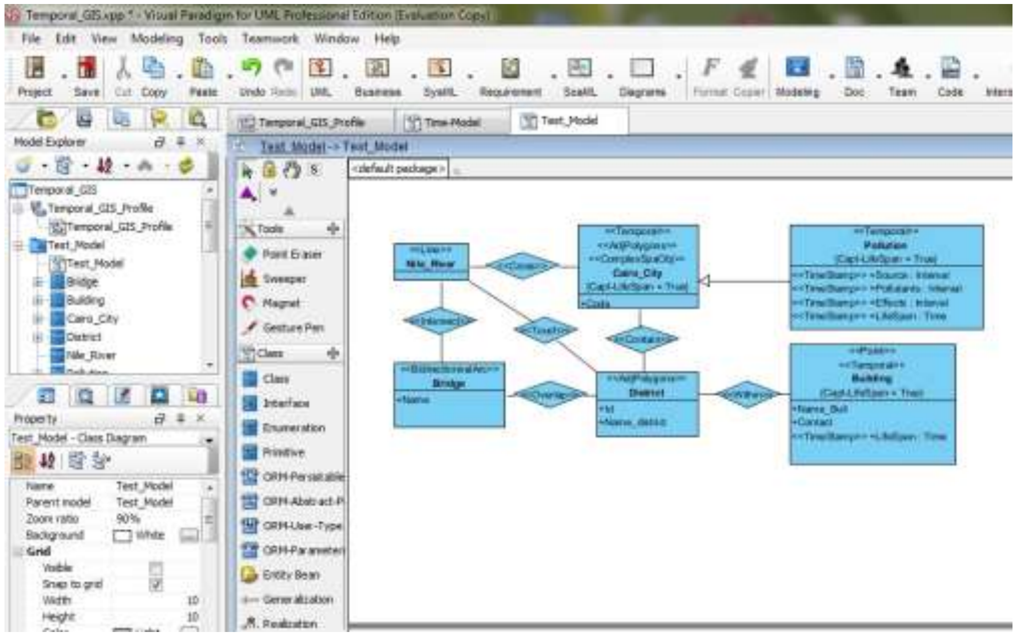

Fig. 3. Example of spatial temporal classes

5 CONCLUSION

This paper presents the first step towards a unified model for representing spatial and temporal aspects of geographic data. The aim of this paper is not to propose one more new conceptual model for GIS, but rather to combine a set of constructors, extracted from existing models towards a unified geographic model for modeling GIS domain.

The model GeoProfile proposed by (LISBOA-FILHO et al. 2010) is used for representing spatial aspects. This model combines Vector and Raster approaches to model spatial properties.

The temporal model which is presented in (Radjai and Rassoul, 2013) not only supports both certain and uncertain, relative and absolute time but supports several different temporal primitives: instant, interval, period and temporal sets. The model supports also temporal types: valid time, transaction time and bitemporal time.

The spatial and temporal models are based on the object paradigm; using UML formalism. The Object-oriented approach has great advantages in modeling complex geographical objects.

This study contributes in the continuing efforts toward handling the different temporal aspects in Geographic Information System. We have very favorable evaluation results, that our approach truly meets the desired requirements. This work is the first step toward the unification of modeling spatial and temporal aspects in GIS. Implementation phases are still to be done in future works.

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