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GeoSpatial Semantics

First International Conference, GeoS 2005
Mexico City, Mexico, November 29-30, 2005 Proceedings

Springer
Preface

GeoS 2005 was the 1st International Conference on Geospatial Semantics. It was held in Mexico City, November 29 and 30, 2005.

Within the domain of geographic information science (GIS), semantics has become one of the most prominent research themes over the last few years. Such concepts as ontology-driven geographic information systems and the geospatial Semantic Web have fuelled a plethora of research in such areas as geo-ontologies and semantic similarity. These topics complement the traditional focus in GIS research, which has dealt primarily with geometric entities, their spatial relations, and efficient data structures. Geospatial semantics are expected to play an increasingly important role for next-generation spatial databases and geographic information systems, as well as for specialized geospatial Web services.

GeoS 2005 was organized in order to provide a forum for the exchange of state-of-the-art research results in the areas of modeling and processing of geospatial semantics. Of particular interest were contributions that addressed theories for geospatial semantic information; formal representations for geospatial data; models and languages for geo-ontologies; alignment and integration of geo-ontologies; integration of semantics into spatial query processing; similarity comparisons of spatial datasets; ontology-based spatial information retrieval; ontology-driven GIS; geospatial Semantic Web; and multicultural aspects of spatial knowledge.

This volume contains 19 papers, which were selected from among 42 submissions received in response to the Call for Papers. Each submission was reviewed by three or four Program Committee members and 15 long and 4 short papers were chosen for presentation. Authors of papers included in this volume come from 11 different countries, highlighting the breadth of the international research community that focuses its attention on geospatial semantics. The program was rounded off with an invited keynote by Jerry Hobbs, and poster presentations.

We are indebted to many people who made this event happen. The members of the Program Committee offered their help with reviewing submissions. Our thanks go also to Miguel Torres, Marco Moreno, Rolando Quintero, and Giovanni Guzmán, who formed the Local Organising Committee and took care of all the logistics. The Centro de Investigación en Computación, Mexico City, Mexico, was the local host and co-sponsored GeoS 2005. Finally, we would like to thank all the authors who submitted papers to GeoS 2005.

November 2005

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Ontology-Driven Description of Spatial Data for Their Semantic Processing

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Abstract. We use ontologies in this paper to search for alternative representations of geographic objects thus providing a description of these objects in cartographic vector maps. We define ontologies based on two types of concepts ("terminal" and "non-terminal") and two kinds of relations ("has" and "is-a"). These are the basic elements used to describe a map. We also present a case study in which an ontology for topographic maps is created. Our approach is oriented towards solving heterogeneity and interoperability issues in GIS.

\section{Introduction}

Recently, the notion and concept of ontology has gained increased attention among researchers in geographic information science \cite{smith2005} to address the many problems of geographic data dealing with spatial data exchange and representation. According to Smith \textit{et al.} \cite{smith2005}, ontologies are essential to the creation and use of data exchange standards, and to the design of human-computer interfaces. Ontologies are also important in the solution of problems of heterogeneity and interoperability of geographic data.

Moreover, there are other problems regarding geographic objects representation. For instance, spatial analysis often requires very precise description of objects to provide good solutions. For instance, in Mexico City the population outgrows the official boundaries of the city, thus invading ecological and protected areas, and creating zones without services. Mexico City is thereby a dynamic entity, in which the actual boundaries cannot be defined exactly (just with inconsistencies). In this case, the boundary of Mexico City is an imprecise geographic object, and its analysis will be imprecise as well.

There are other sources of imprecision, for example, data in different scales, different resolution levels, or attributes that are implicit in the composition of the geographic objects. Although the consequences are diverse, the data that are used in GIS-applications are often imprecise; thereby it is important to consider alternative object representations, which are independent of the imprecise nature of the data.

In this paper, the features related to representation of spatial data are described in the proposed ontology. The objective is to generate descriptions of the spatial data. Furthermore, we present an example to show how such ontology can be built.

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At the same time, we define the concepts that compose the ontology. They are related to the properties of the set of spatial data, which are represented in the ontology. In our approach, the descriptions are generated using tuples of concepts related among them. In order to build the description, we use the relations "has" ($f$) and "is-a" ($\Phi$) which are defined in the ontology. In addition, the set of relations is defined by the pairs, which are associated to $f$ and $\Phi$ ($f$ and $\Phi$ are non-reflexive, non-symmetric and transitive).

The rest of the paper is organized as follows. Section 2 describes related work. In section 3, we present an ontology for geographic data and an approach to generate descriptions. Section 4 shows a case study of creating a description of the topographic data by means of the ontology. Our conclusions and future work are outlined in section 5.

2 Related Works

Guarino [2] coined the term "ontology-driven information systems" and provided a broad discussion on their place in the computer and information sciences. Gruber [4] defines ontology as a formal explicit specification of a shared conceptualization.

Fosseca et al. [3] propose a way to link the formal representation of semantics (i.e., ontologies) to conceptual schemas describing information stored in databases. The main result is a formal framework that explains the mapping between a spatial ontology and a geographic conceptual schema. The mapping of ontologies to conceptual schemas is made using three different levels of abstraction: formal, domain and application levels.

According to Worboys [10], geographic data models explicitly represent a set of basic objects, their geometry and their properties. But much of the semantics appears in the relations linking objects. Nevertheless, although some relations are represented in data models others are not. Usually, these non-represented relations appear implicitly when one is looking at a display of a geographic database [7]. In addition, the use of descriptions allows us to explicitly represent the relations that link objects, whereby we can say that descriptions contain a high semantic content [10] and these can be used as an alternative representation method for spatial data. Furthermore, the main purpose of the obtained descriptions is to partially solve problems of heterogeneity and interoperability of the spatial data.

In Mark et al. [6], the authors assume that cognitive categories in the geographic realm manifest certain special features as contrasted with categories for objects at surveyable scales. They argue that these features reflect specific ontological characteristics of geographic objects.

3 Ontologies for Spatial Data Description

We use ontology that describes spatial data according to a context. Our approach is oriented to describe cartographic vector maps. We define a map as a spatial partition $\Omega$ inside of a universe of geographic objects $\mathfrak{a}$, which consists of a set of representation primitives [9] (Equation 1).
\[ \Omega = \alpha_1 \cup \{ R_{p_1}, R_{p_2}, R_{p_3} \} \quad i = 1, \ldots, n, \]

where \( R_{p_i} \) is the primitive of representation "linear"; \( R_{p_i} \) is the primitive of representation "punctual"; \( R_{p_i} \) is the primitive of representation "areal"; \( \alpha \) represents the thematic number that involves the spatial partition.

We define two types of concepts (C) in the ontology: terminal (\( C_T \)) and non-terminal (\( C_n \)). Terminal concepts do not use other concepts for defining their meaning (they are defined by "simple values"). Non-terminal concepts use other concepts (terminal or non-terminal) in their definitions (Equation 2).

\[ C = C_n \cup C_T \]

(2)

Each concept has a set of aspects, because geographic objects have aspects. Aspects are properties and relations between geographic entities. In the following, we shall use the term "relation" to denote unary relations/properties as used in Berendt et al. [1]. From this point of view, all aspects of a terminal concept are simple, e.g. the type of all aspects that belongs to the set of primitive types (\( T_P \)), as shown in Equation 3.

\[ T_P = \{ \text{number, character, string, enumeration, struct} \}, \]

(3)

\[ A = \{ \alpha_i \, \text{type}(\alpha_i) \in T_P \} \]

where \( T_P \) is the set of primitive types; \( A \) is the set of aspects.

Then, the set of terminal concepts is defined by Equation 4.

\[ C_T = \{ c(\alpha_i, \alpha_{i+1}, \ldots, \alpha_n) \mid \alpha_i \in A, \, i = 1, \ldots, n \} \]

(4)

In the same way, the non-terminal concepts have at least one aspect that does not belong to \( T_P \). It is denoted by Equation 5.

\[ C_n = \{ c(\alpha_i, \alpha_{i+1}, \ldots, \alpha_n) \mid \exists \alpha_i \in A \} \]

(5)

where \( c \) is a concept.

Finally, the set of relations \( R \) is defined by the pairs that are associated to \( I \) and \( \Phi \), where \( I \) and \( \Phi \) are non-reflexive, non-symmetric, and transitive relations (Equation 6).

\[ R = R_I \cup R_\Phi = \{ (a, b) \mid a \in C, \, b \in C \} \cup \{ (a, b) \mid a \in \Phi, \, a \in C, \, b \in C \} \]

(6)

This description maps spatial data into the ontology. Once the concepts are defined in the ontology, we can start defining the non-terminal concepts (this means to select the aspect to be described). This process continues until we find a terminal concept. Once, the terminal concept is found, it is necessary to select a pair of geographic objects, verifying whether a relation between them exists, otherwise a part of the description needs to be generated. The terminal concepts are defined by the type of relation between two objects. Fig. 1 shows an ontology fragment for hydrological maps of the linear type: all objects that compose the hydrological network are represented by lines (drainage and rivers). The ontology consists of two types of concepts (non-terminal and terminal) and a set of relations. The relations are the following: "has" and "is-a"; there are three relations in this ontology.
The concepts in Fig. 1 are represented by “boxes with three points”. For instance, looking at “punctual” concepts (town and village), we note that many others can exist, such as archaeological sites, monuments, wells, or buildings. The proposed ontology defines all concepts required for the spatial data description, according to the standards of INEGI (the National Institute of Statistics, Geography and Informatics, who produces the official cartographic maps in Mexico). On the other hand, it is important to note that different ontologies may exist (one for each thematic layer) and they need
to be joined in a "general" ontology. For example, a topographic map is composed of rivers, contours, highways, and cities, and it can be merged in one ontology. Fig. 2 depicts a part of this general ontology for a topographic map. One can see that hydrological maps are a subset of the ontology shown in Fig. 1.

4 Case Study

In this section we present a case study using the proposed ontology to describe the aspects of spatial data in cartographic vector maps.

The map of Fig. 3 depicts different thematic layers. Each layer contains geographic objects represented by spatial primitives. This map contains Populations (POP), Hydrological Network (HYN), Roads (ROD) and Soils (SOL). In addition, each thematic layer is denoted in the map legend, and is described by specific symbols. The map is composed of 3 punctual objects, 6 linear objects, and 5 areal objects.

Fig. 3. Thematic map used in the case study

Thenceforth, we use the ontology to describe this map. Fig. 4 depicts the description. The description starts at the non-terminal concept called "Map". The non-terminal concepts are denoted by means of rectangles and the values of the terminal concepts are represented by ellipses.

According to the aspect of each non-terminal node, we establish a relation, which defines another non-terminal or terminal concept (depending on the objective). This leads to the complete description of the geographic objects that compose the partition (Fig. 4).

On the other hand, the properties (aspects) that belong to each terminal node contain quantitative values. Moreover, the ontology includes the topological and logical relations, symbol sets, and measurements of the map content.

In our approach, it is important to characterize beforehand the topological relations in order not to consider all of them in the semantic process because of their excessive number in some cases. Additionally, the description depends directly on the context; therefore it is not possible to count on a general context, since some semantic ambiguities may occur.
The method is focused on describing the *semantic content of a cartographic vector map*. However, this description depends on a number of spatial relations, properties and cartographic *measurements*¹ that needs to be considered. Wherewith, it is possible to increase the semantic resolution in the description².

The description is made using *tuples* of non-terminal and terminal concepts related among themselves (they are denoted by *Concept relation Concept*).

For instance, Fig. 3 is composed of several spatial objects. The objects in the layer reflect the relation “is-a” (i.e., *HWY is-a Linear Object*). Moreover, the topological relation “*Intersects*” is related *HW2 and FW3*, which are both linear objects. According to the *ontology* (Fig. 4), we see that the “*Intersects*” relation is a *topological relation* and at the same time, it is a *spatial relation*, whereby this relation is congruent with the description *FW3 Intersects HW2*. In Table 1 all spatial relations are depicted according to the description of Fig. 4.

¹ A measure is a procedure for computing values, which are the basis to evaluate characteristics of cartographic phenomena and assess the need for and the success of a map description.

² This assumption is only considered for the case study, because the map description contains all the relations of the map.
Table 1. Spatial relations between geographic objects

<table>
<thead>
<tr>
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<th>Y1</th>
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<th>C1</th>
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* = Intersect, + = Connect, v = Adjacency, = = Containment, = = North, ↓ = South

5 Conclusions and Future Work

We used ontologies to describe spatial data as an alternative representation. This representation allows us to handle imprecise data, since we translate them into a conceptual schema. We also showed how to generate the ontological (semantic) map description based on the two types of concepts: “terminal” and “non-terminal” as well as two kinds of relations: “has” and “is-a”. By using these elements, we described a cartographic map. As a result, maps with the same theme could be described using the same ontology (thematic ontology). As an example, we presented a fragment of the ontology and the result of its use in the description of a map. On the other hand, it is not possible to describe data that are not considered in the ontology. For instance, we cannot describe the freeways of a region, if the ontology is about hydrology. From this point of view, the ontology implicitly defines the context of the map theme. A great challenge is to define formally what the context is, but at first approximation, we believe that the context could be described by means of a “context” ontology. Our ontologies are intended to be used in map production. Semantic descriptions would allow us to explicitly represent the relations that link objects. Whereby we argued that descriptions will contain a higher semantic content if we use ontologies for their construction. They can be also seen as an alternative representation for spatial data.

From this point of view, we have implicitly obtained the semantics of the spatial data by means of an ontology. That is, the description based on the ontology O of the spatial dataset D, provided the semantics S of D related to the context C, which is also defined by O. As a future research, we will attempt to provide measures of the ambiguities and inconsistencies, which can be involved into the content. We will also search for mechanisms to minimize the degree of imprecision in the content.

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