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The Role of Engineering Education for Semantic Retrieval of Geographic Objects based on Ontological Descriptions and Conceptual Schemas*

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Geospatial information retrieval is not a trivial task. An integrated view must be able to describe various heterogeneous data sources and its interrelation to obtain shared conceptualizations. Ontology engineering is rapidly becoming a mature discipline, which has produced several tools and methodologies for building and managing ontologies for different purposes. In this paper, a methodology to semantically retrieve geospatial information based on ontological descriptions and conceptual schemas is proposed. It consists of providing semantic representations, which explicitly describe the properties and relationships of geographic objects represented by concepts, while the behavior describes the objects semantics. The work presents a methodology to integrate and share geospatial information. The approach is driven by application ontology, which has been designed using the GEONTO-MET methodology. The work is intended to establish the basis for the semantic processing oriented towards semantic information integration and retrieval. The semantic retrieval is an approach very useful in applications focused on semantic web and e-learning in order to process and infer knowledge with a wide range tools in Engineering Education.

Keywords: semantic information integration; application ontology; ontological description; conceptual schema

1. Introduction

Information retrieval provides the ability to handle data transparently across multiple data sources. It is relevant to a number of applications including enterprise information integration, medical information management, geographical information systems, e-commerce and e-learning applications. The *semantic geospatial information integration* is the process of using a conceptual representation of the data and of their relationships to eliminate possible heterogeneities. The most important issue of semantic data integration and retrieval is the concept of *ontology*, which is an explicit specification of a shared conceptualization [1].

Ontologies have been developed by the Artificial Intelligence community to facilitate knowledge sharing and reuse [2]. Carrying semantics for particular domains, ontologies are largely used for representing domain knowledge. A common use of ontologies is presented in data standardization and conceptualization, via a formal machine-readable ontology language.

Nowadays, geographic information is increasingly used by several entities around the world. Moreover, the need of sharing and retrieving information from different sources is an obvious consequence from such proliferation of systems. Unfortunately, integrating and retrieving geographic information are not trivial tasks. We must deal with several heterogeneity problems, which increase complexity of integration approaches [3].

According to the above, a fast search for geographic information on the Web will return several links, representing different parts of our world. But, what does happen when someone needs information that is divided into more than one system? For example, information about "rivers in Mexico" can be obtained by querying two or more different systems. Even distribution of information is one of the problems, there are some others: these systems have been developed by different entities with different points of view and vocabularies, and here is when we have to face heterogeneity issues. They are encountered in each communication between interoperating systems, in which interoperability refers to the interaction between information from different sources involving the task of information retrieval to combine data. Thus, if we have two systems, which share information and represent rivers, many problems related to the heterogeneity are presented. First, the heterogeneity in the conceptual model—one system represents a river as an object class and the other as a relationship; heterogeneity in the spatial model—rivers could be represented by polygons (or a segment of pixels) in one

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system, while they are represented by lines in the second system; schematic heterogeneity—both systems hold the name of a river, but one keeps information about the border; and semantic heterogeneity—one system may consider a river as a natural stream of water larger than a creek with border and the other defines a river as any natural stream of water reaching from the sea and lake into the land.

In this paper we have focused on developing an approach based on GEONTO-MET methodology [4] to semantically retrieve geospatial data, taking into account application ontology. In addition, we propose ontological descriptions and a conceptual schema in order to lead the semantic retrieval and integration. As a case study, a geographic application ontology (*Kaab*) based on the standards of the National Institute of Statistics, Geography and Informatics (INEGI) of Mexico is built using the GEONTO-MET methodology. A mechanism to retrieve geographic concepts based on the Jena framework in order to access the ontology, by means of SPARQL queries has been also implemented. The retrieved instances of concepts can be visualized in a web-mapping application.

The remainder of the paper is structured as follows. Section 2 presents the related work with respect to semantic integration and retrieval issues. Section 3 briefly describes the GEONTO–MET methodology, which is used to build the application ontology (*Kaab*). Section 4 presents the approach to semantically retrieve geospatial information. Some results of the work are outlined in Section 5. Conclusions and suggestions for future work are presented in Section 6.

2. Related work

In this section, several approaches focused on information retrieval for different data sources, as well as for solving the problem of semantic heterogeneity are described. Some of these works have exploited the metadata, designing descriptors of the information contained in the repositories. Other projects have proposed the use of ontologies to define intelligent searches, focused on retrieving objects or concepts from different sources. According to the above, the proposed approach is oriented towards improving the conceptualization as an important feature for the semantic retrieval. It gives an architecture for the integration and retrieving of the domains that have been explicitly conceptualized, describing the relationships between concepts and properties.

In [5] a theory of similarities focused on the context on language modeling Web Services is presented. The implementation is based on the framework for WMSL, which consists of the intersection of logical descriptors. In order to provide the similarity measure of a concept, the attributes or properties are extracted of its specification in the WMSL [6] to form a matrix, which is compared with other concepts and their respective matrix. So, the identical pairs are assigned to a weight, which is similar or different. In [7] a framework of semantic annotations is introduced. [8] proposes to integrate and retrieve information on distributed heterogeneous resources on the Web. Therefore, the semantic annotations is defined by the knowledge base [9]. They argumented that the knowledge discovery process and control over them depend directly on the concepts called entities that can be generally described and interconnected to define a process of discovery of pieces of knowledge within data with little or no human assistant.

Other examples from this context are described in [10] and [11], in which the design, the syntax and the implementation of the semantics and the integration within e-business is treated. This integration is performed by reconstructing the notion of object-relation with shared components. There was a high level language to describe knowledge and integrate it into the semantic web by techniques of positional, slotted and Artificial Intelligence, creating a language that defines the concepts and the semantic relationships between them in order to integrate accurate data between different data sources.

On the other hand, in [12] the work is focused on the discovery and retrieval of spatial data in distributed environments on Spatial Data Infrastructures (SDI). The discovery and recovery is performed by means of classes that are addressed by an algorithm, which consists of three steps. The first, the search terms are mapped to concepts in the domain ontology based on the hybrid ontology approach proposed by [13]. In the second step, the concepts are extended on the basis of the hierarchy of concepts in the domain ontology, and the third step consists of the expansion of the query, and the adequate descriptions of geographic information that are sought and returned to users. If the results are consistent, the search is over.

In [14] authors argue that information modeling requires to be controlled to allow successful sharing of information. Also, they suggest that any coherent information model need to be based on accepted ontological foundation to guarantee unambiguous interpretation. In addition, their work attempts to show that ontology based information modeling provides more cognitive foundation for information systems models and therefore it minimizes the problem of semantic heterogeneity.

In [15] a framework to link the formal representation of semantics (i.e., ontologies) to conceptual schemas describing information stored in databases is proposed. 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. At the formal level, highly abstract concepts express the schema and the ontologies. At the domain level, the schema is regarded as an instance of a generic data model. At the application level, a particular case of geographic applications is processed. Additionally, they discuss the influence of ontologies in both the traditional and the geographic systems methodologies, emphasizing on the conceptual design phase.

3. GEONTO-MET methodology

GEONTO-MET is a methodology focused on formalizing the geographic domain conceptualization. The main goal is to provide semantic descriptions, which represent the properties and relationships describing so the behavior of geographic objects and taking into account these features directly from the geographic domain ontology. In this paper, we only present a general vision of the methodology; it is deeply described in [4].

GEONTO-MET is composed of four stages: *Analysis* provides an abstraction model of the geographic objects involved in the domain. *Synthesis* makes the conceptualization of the geographic domain. A set of application ontologies (in tourist and topographic contexts) and domain ontology called *Kaab* are generated by the *Processing* stage. Finally, *Description* produces an alternative representation of geographic objects as well as the integration of them into a semantic description template. This approach is based on a set of axiomatic relations allowing directly translate the relations between concepts to the conceptualization. In this way, the *semantic resolution* is improved, that is, the definition of such relations can be iteratively refined. To achieve this, we use a couple of sets $A_1 = \{is, has, does\}$ and $A_2 = \{prepositions\}$. These sets are necessary and sufficient to define the rest of relations, involved in the conceptualization of geographic domain.

One could think that this reduction is a limitation for the richness of expressiveness that the conceptualization can implicitly contain. Nevertheless, the universe of possible relations is not *a priori* defined, due to the *"relation"* in a classic sense is not predefined. In fact, the reduction of axiomatic relations has two main advantages: first, it is possible to define as many *"typical relations"* as needed, because this type of relations is treated as concepts. In other words, *"typical relations"* are part of conceptualization, they are not considered as axioms, and these are defined as *concepts*. The second advantage is that relations have semantics associated to them, not only from an axiomatic definition but also from the conceptualization itself (the context of each relation).

4. The semantic retrieval approach

The approach consists of using the application ontology (*Kaab*) that has been implemented in Protégé, applying the GEONTO-MET approach [4] in order to carry out the retrieving of geospatial objects. We propose the Jena API [5] to implement the retrieval mechanism. This framework provides an integrated programming environment for RDF, RDFS, OWL and SPARQL as well as it includes an inference engine based on rules.

This API extracts instances of concepts from Kaab. This ontology has been implemented in OWL. Therefore, it is necessary to generate a persistent data model of this conceptualization to establish the link and map between the components. The instances are retrieved using SPARQL, which is the query language that offers an access protocol of metadata into the OWL structure.

In Fig. 1 the general framework to retrieve geospatial objects, by means of instances of concepts, which are mapped with geospatial objects stored into a geographic database is shown. The process starts with the transformation of geographic domain ontology into a persistent model in OWL. It consists of translating the abstract entity classes and concepts inherited from ontology to tabular form, in which SPARQL can access to the *Kaab* features.

Moreover, a set of predicates in order to map geographic concepts and instances stored in the OWL persistent model is used. In this case, a searching method by strings is implemented to retrieve the instances from the *Kaab*. The method is composed of *subject*, *predicate* and *objects.*

All the strings generated by Jena API are composed of a triplet of these features in order to

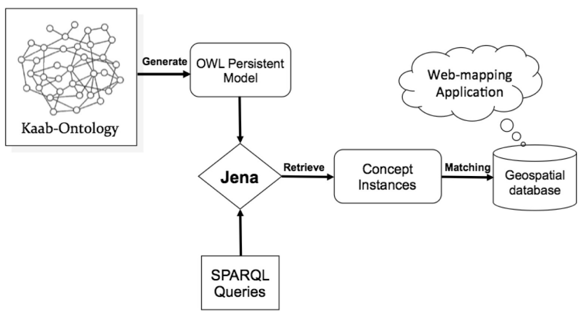

Fig. 1. Schema proposed to retrieve and match instances with geospatial objects.

semantically represent the state of the conceptualization of a geographic object in a certain context. The instances are retrieved by means of a set of queries built in SPARQL. The main purpose is to show the way for accessing the ontology and retrieving the instances of concepts that belong to certain class and accomplish with the semantic searching criteria. The advantage for this retrieval mechanism is that the query model is oriented to data, whereby a language represents the meaning of each defined feature in a vocabulary and it is possible to semantically extract instances of concepts related to the context of the ontology. When the instances of concepts are retrieved, they are stored in tables, in which each table has an identifier that is directly mapped to the *shapefiles*[1] in order to link the semantic result with spatial component (objects). The geographic data that accomplish with the criteria are visualized in a web-mapping application.

4.1 Template for semantic description

In the modeling approach, the modeler is required to capture a user's view of the real world in a formal conceptual model. Such an approach forces the modeler to mentally map concepts acquired from the real world to instances of abstractions available in his paradigm choice. On the other hand, the consolidation of concepts and knowledge represented by a conceptual schema can be useful in the initial steps of ontology building. To adequately represent the geographic world, we must have machine representations capable not only of capturing descriptive attributes about its concepts, but also of describing the relations and properties of these concepts.

A conceptual schema to describe the contents of the real world abstraction in order to specify the behavior of the geospatial entities is proposed. In this case, conceptual schemas certainly correspond to a level of knowledge formalization [15–19]. Conceptual schemas are built to abstract specific parts of the geospatial domain and to represent schematically which geographic entities should be collected and how they must be organized. We perceive that geographic data modeling requires models more specific and capable of capturing the semantics of geospatial data, offering higher abstraction mechanisms and implementation independence. The proposed conceptual schema is composed of two types of concepts (C): *terminal* (C_T) and *non-terminal* (C_N). The first ones are concepts that do not use other concepts to define their meaning (they are defined by "simple values"). The meaning of non-terminal concepts is conceived by other concepts, which can be terminal or non-terminal concepts (see Equation (1)).

$$C = C_N \bigcup C_T \tag{1}$$

Each concept has a set of *aspects*. They are defined as characteristics that describe the properties, relations and instances involved in geospatial objects. We shall use the term "relation" to denote unary relations/properties. From this point of view, all aspects of a terminal concept are simple, e.g. the type of all aspects that belong to the set of primitive types (punctual, linear and areal objects) is denoted by (T_P) in Equation (2).

$$\begin{aligned} &T_P = \{number, character, string, enumeration, struct\},\\ &A = \{a_i | type(a_i) \in T_P\}, \end{aligned} \tag{2}$$

Where T_P is the set of primitive types; A is the set of aspects. Thus, the set of *terminal concepts* is defined by Equation (3).

$$C_T = \{c(a_1, a_2, \ldots, a_n) \ni a_i \in A, i = 1, \ldots n\} \tag{3}$$

Moreover, the *non-terminal concepts* have at least one aspect that does not belong to T_P. It is denoted by Equation (4):

$$C_N = \{c(a_1, a_2, \ldots, a_n) \ni \exists\ a_i \notin A\}, \tag{4}$$

Where c is a concept. Finally, the set of relationships R is defined by the pairs associated to Γ and Φ, in which Γ and Φ are non-reflexive, non-symmetric, and transitive relations (see Equation (5)).

$$\begin{aligned} &R = R_\Gamma \cup R_\Phi = \{(a,b) | a\Gamma b, a \in C_N, b \in C\} \cup\\ &\{(a,b) | a\Phi b, a \in C_N, b \in C\} \end{aligned} \tag{5}$$

According to the previous definitions, it is necessary to express the semantics that can provide a conceptual schema by means of a description D. We consider the concepts C embedded into the conceptual schemas by means of geospatial objects, which are represented by primitive types as well as the set of relationships R involved among geospatial objects (see Equation (6)).

$$D = \langle C, R \rangle \tag{6}$$

In Fig. 2, a conceptual schema designed for the geospatial domain is depicted. Thus, this schema is adaptive for any context. In other words, it reflects the main features involved in the domain. For instance, if we have topographic, geologic, or tour-

[1] *Shapefile* is a popular geospatial vector data format for GIS software. It is developed by ESRI as a (mostly) open specification for data interoperability between ESRI and other software products. It spatially describes geometries: points, polylines, and polygons.

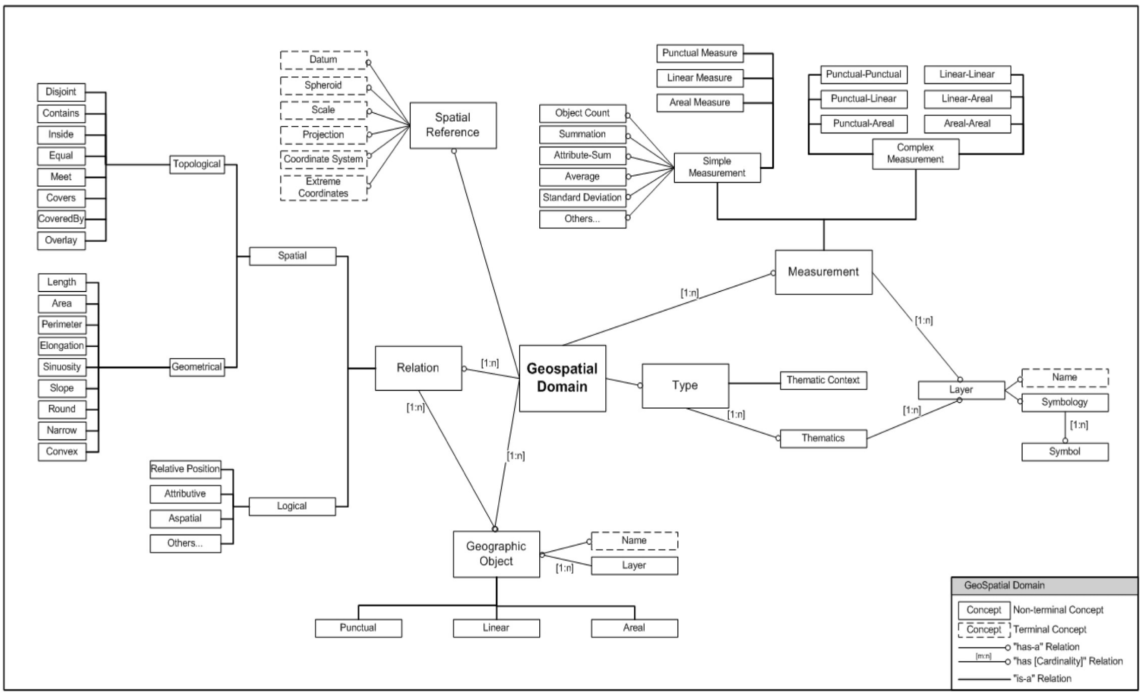

Fig. 2. Conceptual schema proposed to generate semantic descriptions.

ism contexts, it is possible to describe the entities, properties and relationships embedded between geographic objects, as an inheritance mechanism. This conceptualization provides us an explicit vocabulary that represents the ontological commitment of the cognitive and intuitive perception of the human beings.

As result, a symbolic description that represents a logical and structured organization of C_T and C_N is obtained. These concepts are used as a guide to generate the semantic description. In order to build the description, a set of tags is considered. The JTS (Java Topology Suite) API is used to populate the C_N and for exchanging the geometric information the WKT strings (Well Known Text) are defined. The template for the semantic description is composed of the following tokens that are defined in Table 1:

( ) It represents the object "name".
< > It establishes the relationship between objects.

Table 1. Template proposed to define the semantic description

{
[object thematic**]** **(**object**)** **<**relationship**>**
. . .
[thematic**]** **(**object**)** **<**relationship**>**
direction
};
. . .
{
Other object description
};

{ } It represents the complete description of each geospatial object.

Direction. It represents the relative orientation of an object.

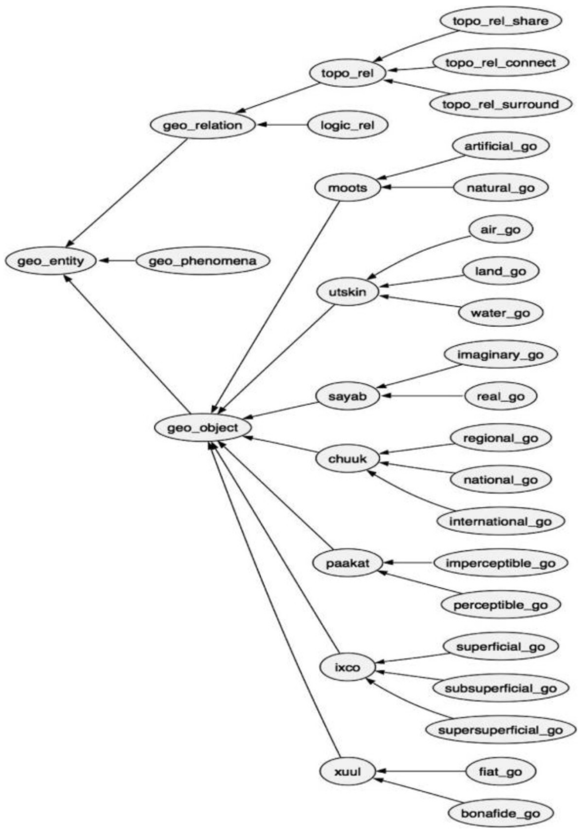

Fig. 3. Main hierarchy of *Kaab* ontology.

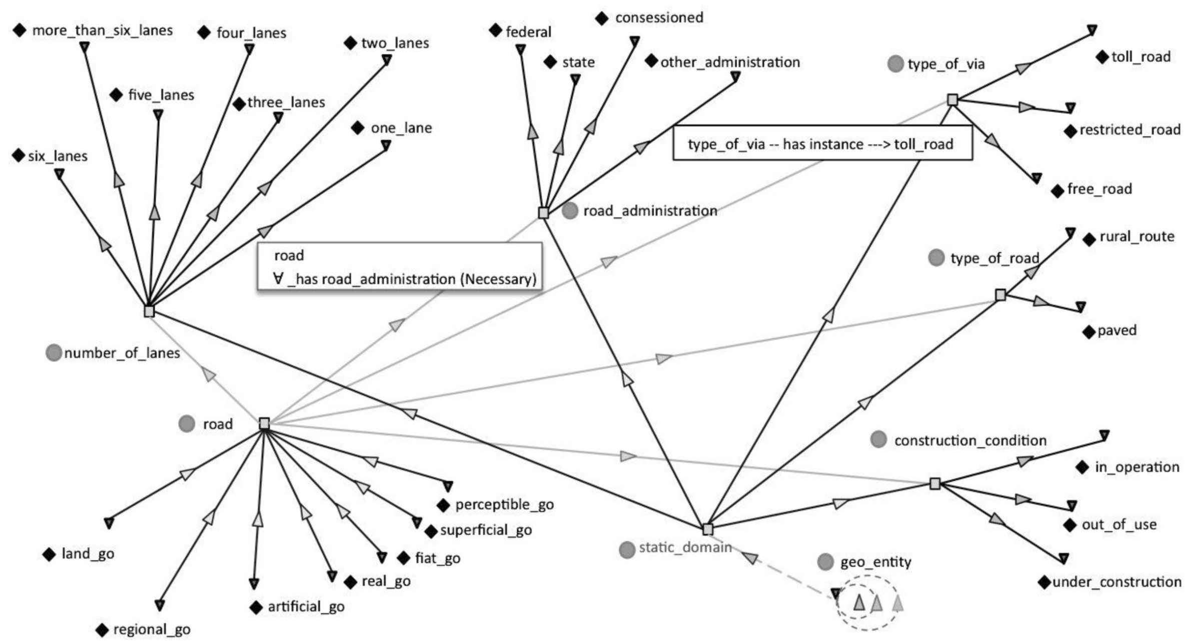

Fig. 4. Ontological description of the concept "road".

5. Results

In this section, we present some results related to the GEONTO-MET. The ontologies designed by applying this methodology were implemented in Protégé 4.3.1. Figure 3 depicts the main hierarchy of the *Kaab* ontology.

Thus, an ontological description of the concept *"road"* with the relations *"has"* and *"is"* is depicted in Fig. 4.

In Fig. 5, the ontological description that represents abilities of concept instances is shown. The ability of a concept is defined by the relation *"does"*.

On the other hand, a semantic description of geographic objects is depicted in Fig. 6. We appreciate that a XML document is generated in order to share and integrate geospatial information. A native template has been built to describe the semantics of geographic objects.

Finally, the instances of concepts retrieved by the SPARQL query are mapped to the geographic

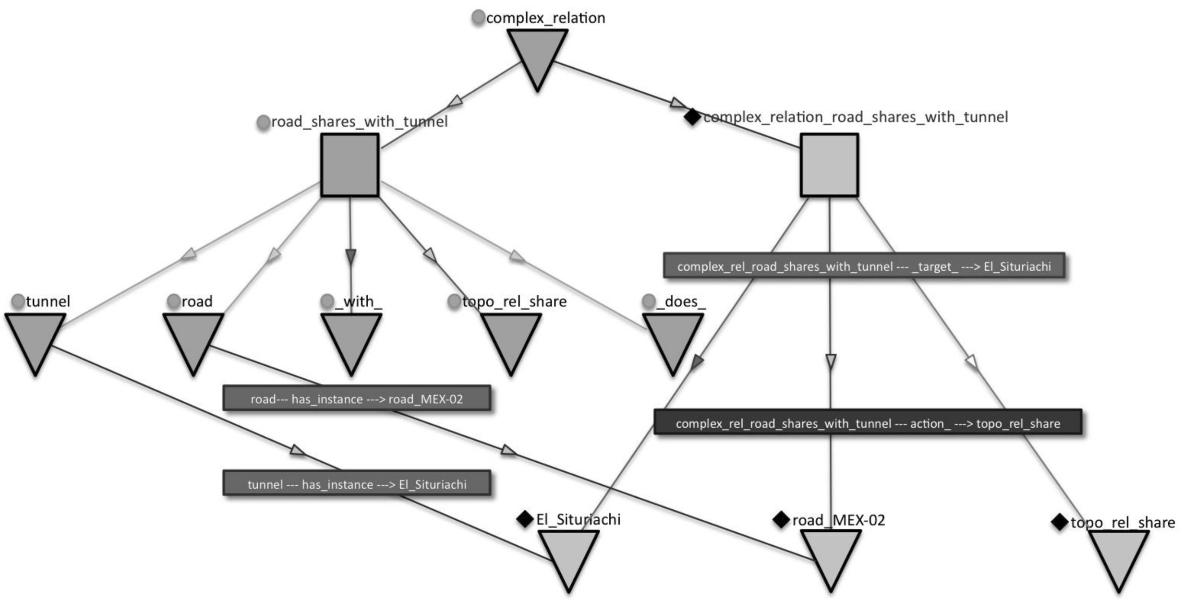

Fig. 5. Ontological description of "abilities" related to instances.

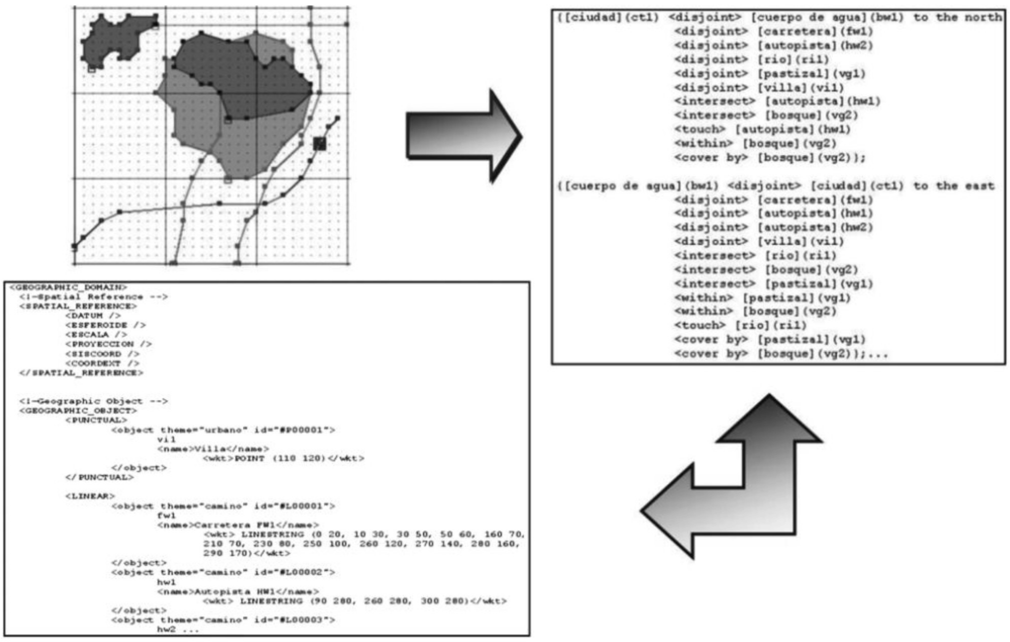

Fig. 6. Semantic description and XML document from geographic objects.

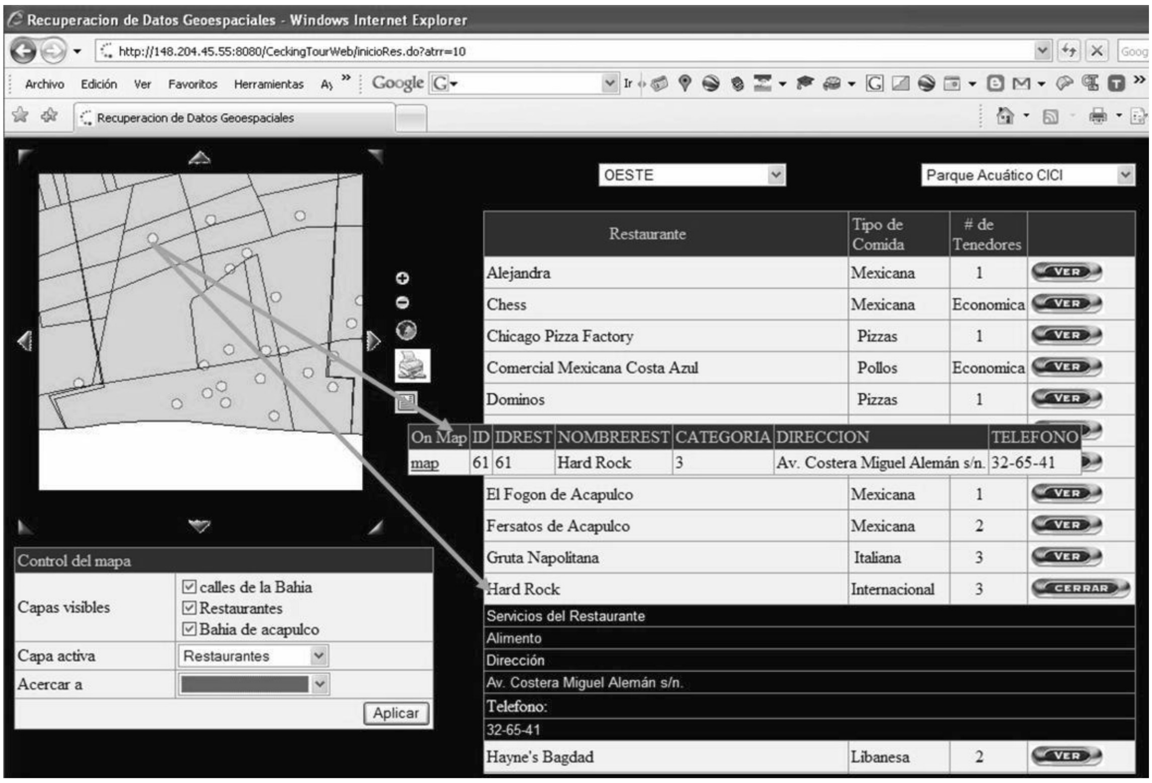

Fig. 7. Web-mapping application designed to apply the semantic geospatial retrieval approach.

objects stored in the *Shapefile*. The goal is to avoid ambiguities in the query process of geographic information systems (GIS). The result is presented as a case study in a web-mapping application shown in Fig. 7.

6. Conclusion and future work

In this work an approach to semantically retrieve geospatial information based on application ontology led to a conceptual schema has been described.

The main goal is to provide semantic descriptions, which represent the properties and relationships that describe the behavior of geographic objects. Thus, it is focused on producing an alternative representation of geospatial data.

On the other hand, we proposed conceptual schemas to describe the contents of the real world abstraction to specify the behavior of the geospatial entities, in which context plays an important role to guarantee shared and explicit conceptualizations. In addition, several scenarios can converge in the same *semantic description*, although any representation could be more reach than other. This fact essentially depends directly on the cognitive sense of each subject. As a case study, a mechanism to retrieve geographic concepts with Jena framework in order to access the ontologies, by means of SPARQL queries has been also implemented. The retrieved instances of concepts can be visualized in a web-mapping application.

Future works are mainly oriented towards proposing conceptual issues related to translate semantic descriptions into geospatial ontologies, as well as what would be required to establish these kinds of ontologies. Additionally, our work is led to formalize appropriate methods to represent ontologies of the geospatial domain and to measure semantic contents between geospatial ontologies.

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