

Ontology-based Geographic Data Access in a Peer Data Management System

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Abstract. *Ontology-Based Data Access (OBDA) is the problem of accessing one or more data sources by means of a conceptual representation expressed in terms of an ontology. We apply the principles underlying an ODBA in the light of a Peer Data Management System, using geographic databases as data sources. When dealing with geospatial data, specific problems regarding query answering and data visualization occur. To help matters, in this work, we present an approach and a tool, named easeGO, which provides access to a geographic database using an ontology as a middle layer between the user interface and the data. It also allows users to formulate queries using visual elements and spatial operators. We present the principles underlying our approach and examples illustrating how it works.*

1. Introduction

In distributed data environments, particularly those involving data integration, ontologies have been formally used to describe the semantics of the data sources. The goal is both to facilitate the standardization using a common representation model, and the discovery of the sources that provide the desired information [Lopes *et al.* 2012; Calvanese *et al.* 2009]. The use of ontologies as a layer between the user and the data source (in this work, a geographic database) adds a conceptual level over the data. It allows the user to query the system using semantic concepts without taking care about specific information from the database. Generally, this type of access has been called *Ontology-based Data Access* (OBDA) [Calvanese *et al.* 2009] and its principles can be applied to any setting where query answering is accomplished using the ontologies that describe the sources. Typical scenarios for OBDA instantiation are Peer Data Management Systems (PDMS) [Souza *et al.* 2011; King *et al.* 2010], Data Spaces [Hedeler *et al.* 2009] and the Semantic Web [Makris *et al.* 2010; Calvanese *et al.* 2009].

We apply the OBDA principles in a PDMS named SPEED - Semantic PEER Data Management System [Pires 2009]. The SPEED system is composed by data sources (called *peers*) and adopts an ontology-based approach to assist relevant issues in data management such as query answering. Query answering in SPEED means to provide capabilities of answering a query considering that such query is submitted over one of the peers and there is a set of mappings between the peer and their neighbors. Particularly, in this work, we are using geographic databases as data sources. In order to uniformly deal with geospatial data without worrying about their specific heterogeneity restrictions (syntactic or semantic), we use ontologies as uniform conceptual representation of peer schemas. When a peer asks to enter the system, its schema is exported to a *peer ontology*. During the ontology building process, a set of

correspondences (mappings) between the generated peer ontology components and the original database schema is also generated. We use the produced peer ontology and the set of correspondences to reformulate ontological queries into the database query language and retrieve corresponding instances from the geographic database.

One important issue in our work regards the use of geospatial data. A higher level of complexity is observed in geospatial data manipulation because of their special characteristics (e.g., spatial location). Thus, there is also a need for special visualization tools and exploration mechanisms to make provision for the spatial presentation and querying of these data. Considering these presented aspects, our approach has been specified and developed. Named as *Easy Geographical Ontological access (easeGO)*, it is concerned with two main issues: (i) an *interface* which allows working both with the peer ontology and a cartographic representation of the data (e.g., a map) to visualize the metadata and formulate queries and (ii) a *query manager*, which reformulates the query formulated in the interface (using the ontology or the map) into queries which may be executed by the DBMS (e.g., in SQL). After executing the query, the query manager receives the results and represents their output according to the user preferences on data visualization. The *easeGO* interface has been designed following the principles of visual query languages (VQS) [Catarci *et al.* 1997]. In this light, it is based on using the peer ontology and on direct manipulation interaction mechanisms. It may be used by any user, including the ones who are not familiar with the syntax of query languages such as SQL or are not interested in learning a query language. The *easeGO* tool has been implemented in the light of the SPEED system, although its approach can be applied to any OBDA environment which deals with geographic databases.

This paper is organized as follows: Section 2 introduces the SPEED system; Section 3 presents the *easeGO* approach; Section 4 describes the developed *easeGO* tool with some accomplished experiments. Related works are discussed in Section 5. Finally, Section 6 draws our conclusions and points out some future work.

2. The SPEED System as an OBDA

Peer Data Management Systems (PDMS) are characterized by an architecture constituted by various autonomous and heterogeneous data sources (e.g., files, databases), here referred as *peers*. The SPEED (Semantic **PEE**r Data Management System) system [Souza *et al.* 2011; Pires 2009] is a PDMS that adopts an ontology-based approach to assist relevant issues in peer data management. Its architecture is based on clustering semantically similar peers in order to facilitate the establishment of semantic correspondences (mappings) between neighbor peers and, consequently, improve query answering. Peers are grouped according to their knowledge domain (e.g., Education, Tourism), forming semantic communities. Inside a community, peers are organized in a finer grouping level, named semantic clusters, where peers share similar ontologies (schemas). Particularly, in SPEED, *peer ontologies* are employed to represent the schema of the sources stored in peers. A peer has a module to translate an exported schema described in its original data model to an ontology representation.

The paradigm of *ontology-based data access* (OBDA) has emerged as an alternative for assisting issues in data management (e.g., data sources heterogeneity), usually in distributed environments. The underlying idea is to facilitate access to data by separating the user from the data sources using an ontology [Kontchakov *et al.* 2011].

This ontology provides a user-oriented view of the data and makes it accessible via queries formulated only in the ontology language without any knowledge of the data source schema [Calvanese 2009]. OBDA settings have some common characteristics, such as [Lopes *et al.* 2012; Calvanese 2009]: (i) the data sources usually exist independently of the ontologies which describe them, (ii) ontologies and data sources show diverse levels of abstraction and may be represented using different models; (iii) the ontology is the unique access point for the interaction between the users and the system; and (iv) queries submitted on the ontology must be answered using a set of existing mappings between the ontology elements and the data source schema.

Comparing PDMS features with OBDA's, we can verify some common characteristics. A PDMS is a P2P system that provides users with an interface where queries are formulated transparently on heterogeneous and autonomous data sources [King *et al.* 2010]. The main service provided by a PDMS thus concerns query answering. Meanwhile, the main reason to build an OBDA system is to provide high-level interfaces (through ontologies) to the users of the system. In both settings, users should express their queries in terms of a data source view (i.e., an ontology), and the system should reformulate these submitted queries using existing mappings that help to translate them into suitable ones to be posed to the data sources.

Regarding these characteristics, and, since data sources schemas in SPEED are described using ontologies (named hereafter *peer ontologies*), we may consider the SPEED system as an OBDA setting. In SPEED, a query posed at a peer is routed to other peers to find answers to the query. An important step of this task is reformulating a query issued at a peer into a new query expressed in terms of a target peer, considering the correspondences between them. To accomplish this task, a query reformulation module has been developed [Souza *et al.* 2011]. However, such reformulation module has taken into account only conventional data (i.e., no geospatial ones).

Recently, the SPEED system has been instantiated with geographic databases. A tool named *GeoMap* was developed for automatically building a geospatial peer ontology [Almeida *et al.* 2011]. This peer ontology represents a semantic view of data stored in a geographic database. During the ontology building process, a set of correspondences between the generated peer ontology components and the original database schema is also automatically generated. Query reformulation in SPEED can now be accomplished in two ways, as depicted in Figure 1: (i) *vertically* (highlighted in a dashed line), between a query submitted in a peer using its local ontology and the data source schema and (ii) *horizontally* (highlighted in a solid line), between a source and a target peer ontology (i.e., between two neighbor peers). The former is the focus of this work. Particularly, we are interested in the way we can use peer ontologies to formulate queries and execute them, retrieving real data from geographic databases.

3. The *easeGO* Approach

One of the most representative realms of diversity of data representation is the geospatial domain. Geospatial data, besides hierarchical and descriptive components (relationships and attributes), are featured by other ones such as geometry, geospatial location and capability of holding spatial relationships (e.g., topological) [Hess 2008]. Furthermore, geospatial data are often described according to multiple perceptions, different terms and with different levels of detail. In our work, geospatial data are

represented by means of the vector model. As a result, they are expressed as objects and are stored as points, lines or polygons, depending on the scale of their capture. In this sense, the syntactic, semantic and spatial data heterogeneity should be considered when dealing with geospatial data in a PDMS and in query answering processes.

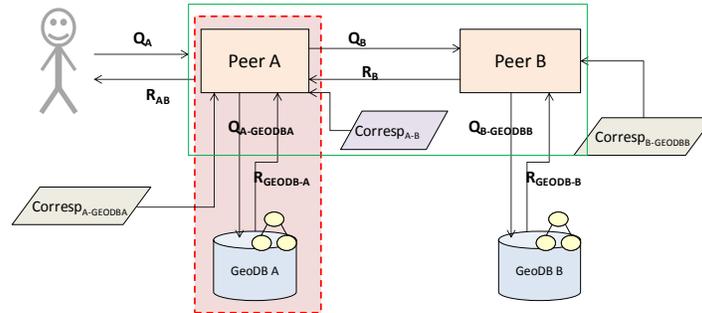


Figure 1: Query Reformulation in SPEED

On the other hand, an usual ontology is composed by concepts, properties, axioms and, optionally, instances. In order to deal with query reformulation, considering the *vertical access* shown in Figure 1, we have to deal with the correspondences between the peer ontology elements and their corresponding in the geographic database schema. The *easeGO* approach has been specified and developed to take into account the set of correspondences between the peer ontology and the geographic database schema elements, thus enabling query reformulation. Besides, the *easeGO* approach has put together two issues related to facilitate query formulation by users who are unfamiliar with geospatial query languages: (i) *visual query languages (VQS)* concepts and (ii) *OBDA principles*. The former provides the user with visual elements that abstract the underlying query language syntax, helping to guide editing querying actions so as to minimize the risk of errors [Catarci *et al.* 2004]. As already mentioned, the latter provides a unique data access by means of an ontology (i.e., a peer ontology).

Considering that, the proposed *easeGO* approach supports query formulation in the context of the SPEED system mediated by a peer ontology and using geospatial visual elements. An overview of the *easeGO* architecture is depicted in Figure 2. In the following, we present its components which are divided into two main modules: (i) the *interface*, composed by data view and querying options and (ii) the *query manager*, responsible for reformulating the submitted queries and executing them.

3.1 The *easeGO* Interface: User Perspective

It is known that the initial impression causes a very strong feeling, not just from person to person, but also between people and objects. This is also the case for computational system interfaces, especially those regarding the use of geospatial data. A geospatial data query interface design should deal with the characteristics and difficulties faced in the elaboration of a DBMS interface and provide the specific geographic application requirements, such as multiple representations for objects and spatial query formulation.

In this work, the interface design has the following goals: (i) users can be novices or experts, but our main purpose is to design an easy-to-use interface for the less experienced users, (ii) the interface should be capable of providing geospatial data exploration as well as making use of the peer ontology concepts to facilitate query formulation. Since we aim to provide geospatial query formulation, we have also to

accommodate in the interface a way of manipulating spatial relationships (e.g., adjacency, cross) between entities that are geometrically defined and located in the geographic space. This process is accomplished by using visual elements to compose the query expression. Indeed, we try to apply the principles underlying the so-called Visual Query Systems – VQS [Catarci *et al.* 1997]. VQS are characterized by features such as the use of icons and visual metaphors, instead of text, and the availability of interactive mechanisms to support query formulation.

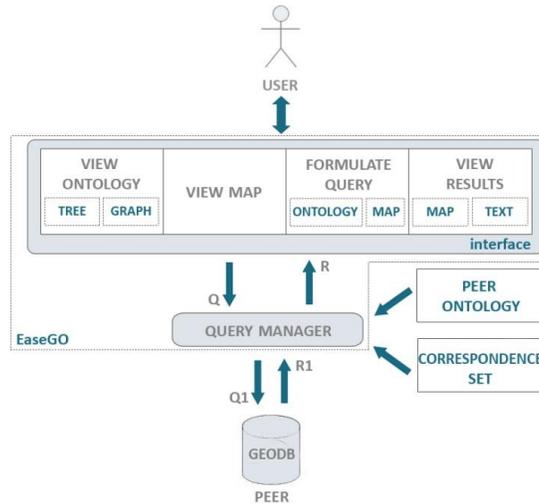


Figure 2. The *easeGO* Architecture

The scenario in which we consider the deployment of our approach consists of a geographic database which provides its own query language (i.e., object-relational geographic databases). As shown in Figure 2, the *easeGO* interface adopts a hybrid strategy for formulating queries and is composed by the following options:

- *View Ontology*: the peer ontology, which describes a given geographic database, defines a vocabulary which is meant to be closer to the user's vocabulary. The user can exploit the ontology concepts to formulate a query using search and navigational options. The ontology is depicted using tree or graph views.
- *View Map*: the geospatial data may be presented in a cartographic view using, for example, a map. This option gives the user a closer view of spatial reality where s/he is able to work with.
- *Formulate Query*: users may formulate queries using nodes and edges (which represent classes and properties) from the peer ontology. Each node/edge of the tree/graph corresponds to elements from the database schema. Once selected, a node becomes the focus for querying. Users may also formulate queries using visual elements provided by the map option. This option supports a predefined set of spatial operators that improves the *easeGO* query capability.
- *View Results*: users may define their preferences regarding the way they will see query results. The results may be shown using a table option (text data) or using the map, where resulting objects are highlighted in a different color.

When using the *peer ontology* to formulate a query, the user can select a node and request instances of this node. S/he may also, from this node, set the query in a visual way by using a form which is dynamically built. This form provides the existing properties of the chosen node. Using this form, the user chooses the properties s/he wants to view (as a project operation from the relational model) and determines the conditions (as a select operation from the relational model) that the query should verify.

When formulating a query by using the *map option*, users may choose a geographic object to be a query operand and drag it to a query area. Once the user has selected the first query operand and it has been dragged to the query area, s/he selects the spatial operator to be applied. If it is a unary operation, the query may be validated. However, if it is a binary operation, another geographic object will be selected.

From both query formulation options, a query Q (Figure 2) is generated. This query will be sent to the query manager, as explained in the following.

3.2 The *easeGO* Query Manager: Reformulating Queries

We define the query manager approach as follows: given a user query Q expressed in terms of the concepts of the peer ontology, a target geographic database schema GeoDB schema, and a set of correspondences between the peer ontology elements and the database schema ones, our goal is to find a reformulated query of Q expressed in terms of the concepts of the GeoDB schema in such a way that it may be executed by the DBMS. The reformulated query is named Q_1 which is executed in the DBMS and the query results R_1 are returned to the query manager. The query manager considers the user preferences regarding the data visualization and sets the resulting data R which is sent to the interface. R may be depicted using a table or highlighted on the map.

4. The *easeGO* Tool: Implementation and Results

The *easeGO* tool has been implemented in Java, using the OWLPrefuse [OWLPrefuse 2012] and GeoTools [GeoTools 2012] APIs. It provides access to geographic databases coded in Oracle Spatial [Oracle 2012] and PostGIS [PostGIS 2012].

The query formulation and reformulation process implemented in the *easeGO* tool is based on the aspects described in the previous sections. When the user starts working, a peer ontology is depicted through a graph or tree representation. The peer ontology is related to a particular geographic database which refers to a single geographic region. Following this, the user can navigate at the peer ontology level, browse geospatial data using layers over a map, or formulate queries. From the functional point of view, the *easeGO* tool current release provides the following:

- a) *Peer Ontology Navigation*: the user is able to navigate over the ontology concepts and choose one for querying. This querying process may be accomplished in a two-fold way: (i) by retrieving all the instances of a given concept or, (ii) starting from a general concept, the user can choose the properties s/he wants to see and define constraints to be applied over the data.
- b) *Form-based query formulation*: after choosing a concept using the peer ontology, the tool provides the user with a form which presents the concept's properties and enables query constraints definition. Thus, s/he is able to fill in the form, by choosing the desired properties and establishing constraints, to create a query expression in a high-level way.

- c) *Exploration of Geospatial Objects*: the exploration of geospatial objects means that objects are shown in the visualization area and can be selected for getting information about their descriptive attributes, for visualization operations (zoom, pan) or for spatial queries. It is also possible to enable or disable object layers.
- d) *Spatial Query Formulation*: using the cartographic view, the process of building a query involves the following steps: (i) the geographic objects of interest are selected and dragged to a query building area (ii) spatial operators are selected and (iii) the query is validated and then executed.
- e) *Query Results Presentation*: after executing a submitted query, the tool may depict the query results in a two-fold way: (i) using a table with the answers or (ii) highlighting the resulting geospatial objects on the cartographic view.
- f) *Hints and help messages* during the execution of each user task.

We provide some examples of these functionalities in the following.

4.1 easeGO in Practice

In the following examples, we use two geographic databases: (i) a database which stores attributes and geometries about *laboratories* in IFPB (stored in Oracle Spatial) and (ii) a database with data about *inhabitance control* in Paraíba state (stored in PostGIS). In both cases, their schemes were previously mapped to a peer ontology representation.

Figure 3 shows a screenshot of one of the tool's window that is split into four parts: (i) *peer ontology area* which shows the peer ontology (in a tree representation), describing, in this case, the laboratories database schema, (ii) *legend area*, where the kinds of ontology nodes are indicated, (iii) *search area*, where the user may choose one concept for querying, (iv) *query results area*, where answers belonging to a query are shown using a table. Using the tree representing the ontology nodes and properties, a user can select one node (i.e., a concept) and ask for its instances. In this example, the concept polygon has been chosen (option I), thus indicating that all the objects belonging to this concept are retrieved from the database. As a result, a table called "Laboratorios" (which is from type Polygon) is depicted in the query results area.

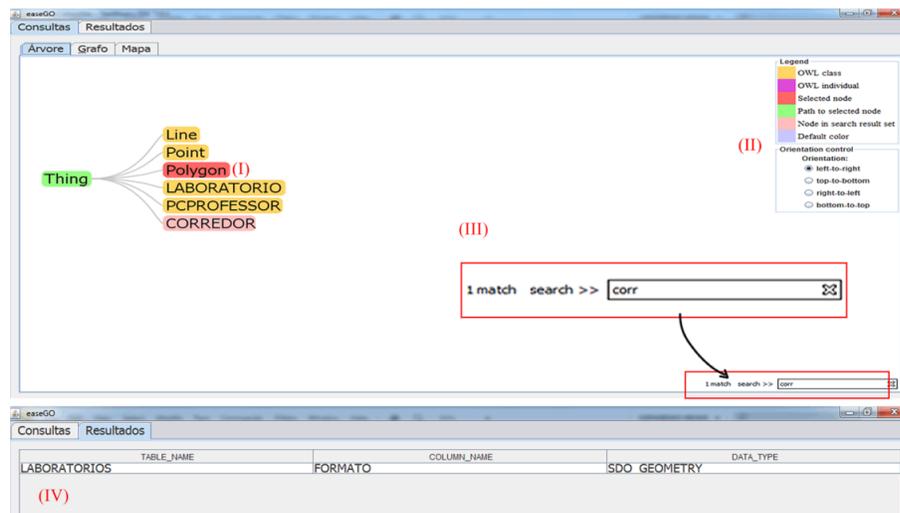


Figure 3. Peer Ontology Represented as a Tree and a Query Example

Using now the other geographic database (regarding inhabitation control data), Figure 4 (option I) depicts the peer ontology by means of a graph structure. In this example, the user has selected the concept “usuario” (which is highlighted) and a form-based query formulation option is presented to him/her (option II). This form is dynamically generated according to the underlying properties of the chosen ontology concept. The form shows the existing properties of the node and enables their setting for query answers presentation. Besides, the form lets the user to define constraints using the existing properties and commonly used operators (e.g., equality and logical operators). The user, then, fills in the form with his/her preferences and definitions. The tool generates a query which will be reformulated and executed. In this example, the user has chosen the concept “usuario”, together with the properties of “usuario_login”, “usuario_nome” and “usuario_email”. In addition, s/he has defined a condition over the user name (“usuario_nome = ‘Gustavo Brasileiro’”). A fragment of the query results is also shown in Figure 4 (option III).

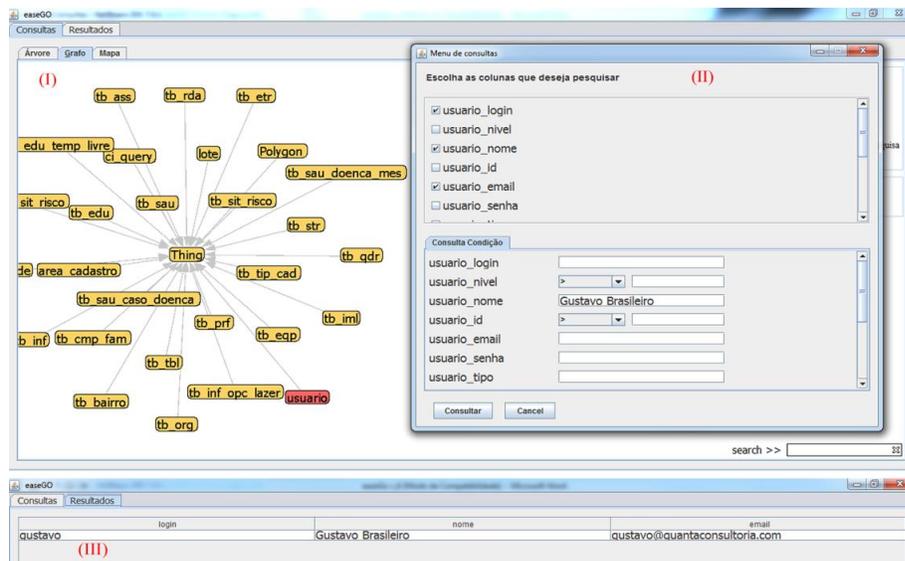


Figure 4. Peer Ontology represented as a Graph and a Query on the “Usuario” Concept

To allow geospatial objects exploration, the *easeGO* tool also provides another visualization/manipulation option (Figure 5). This cartographic view is composed by three main areas, as follows: (i) *geospatial objects area*, (ii) *spatial operators area* (which depict the set of available spatial operators using icons - this set is based on the standard operators provided by the PostGIS) and (iii) a *query formulation area*, where a visual query may be built. In this case, when a geographic object of an active layer is selected, it is represented as an icon and may be dragged to the query area as a query operand. In Figure 5, objects belonging to the “area-cadastro” layer are shown in the geospatial objects area. In this example, we show a visual query formulation where the user has selected a geographic object from the geospatial objects area (it is highlighted – option I), together with the disjoint spatial operator (option II). The visual query is built in the query area (option III) and its results are highlighted on the map (option IV).

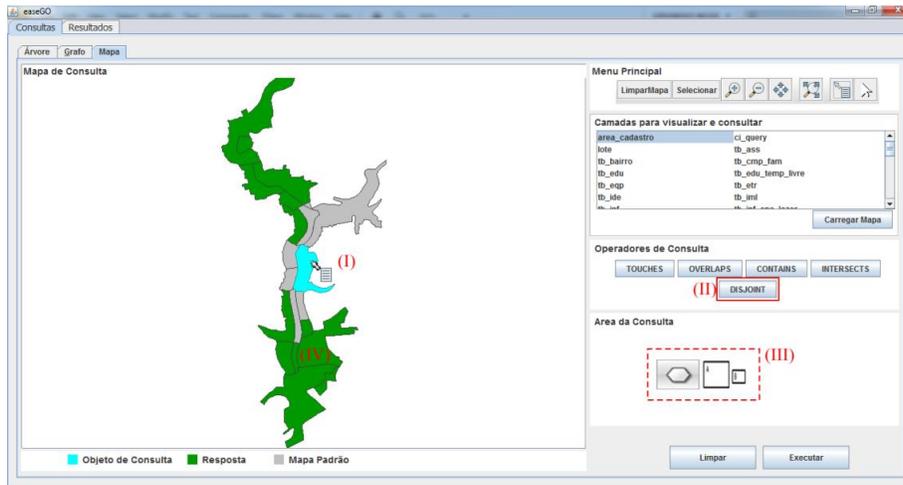


Figure 5. Cartographic View of Data and a Visual Spatial Query Example

In addition to formulating queries, users are able to explore geospatial data and execute some Geographic Information Systems (GIS) basic functions, such as: zoom in, zoom out, info, select, and pan. The *easeGO* tool allows users to enable or disable the data layers and to obtain any information about the descriptive attributes of a geographic object. While users are interacting with the system, tips and help messages are shown. These messages aim to report possible problems, to prevent errors from happening or to guide users in each step of a possible solution.

4.2 Experiments

We have conducted some experiments to verify the effectiveness of our approach. The goal of our experiments is two-fold: (i) to check whether the user is able to formulate queries easily using the peer ontology and the geospatial visual elements and (ii) to verify how the query manager accomplishes the query reformulation process. We have invited some users (undergraduate students in Computer Science and Geotechnologies as well as professionals used with GIS functionalities) to evaluate our tool. At first, we explained the goal of the evaluation together with the main objectives of the *easeGO* tool. We let them interact with the tool for a few moments. Then they received a questionnaire to be filled out. The evaluation was performed, as follows:

1. They were asked to navigate at the peer ontology and to formulate queries using the graph and tree views. They could use the search option, retrieve all instances from a given ontology concept or use the form-based query formulation option. Then, they should analyze the way they received query results.
2. They were also asked to follow the same process using the cartographic view of the data. They used the geospatial objects area and spatial operators to compose visual queries. Then, they could visualize query results on the map.

After testing the tool's options, they filled out a questionnaire stating their opinions on the interface design, the use of peer ontologies and the map view, and the way query results were presented. Five measures were required: *learning facility* (in which degree the tool is easy to learn to use), *query formulation facility* (in which degree the user considers as an easy process to formulate a query), *design issues* (in which degree the interface layout contributes to query formulation and data

visualization), *results clarity* (in which degree the answers were free of ambiguity), and *results satisfaction* (in which degree the answers fulfilled the required query). They were also asked to provide comments pointing out their other perceptions.

Figure 6 presents a summary of the evaluation regarding the *peer ontology* access option. In terms of learning facility, query formulation, results clarity and satisfaction, the users provided a good or even great impression. Only some of them considered the interface layout hard to understand and suggested some improvements such as: a better way of presenting the query results, functions provided on the map option should be also available in the peer ontology view and the interface design could be better. Figure 6 also presents the users perceptions on the map access option. Since most of users were not used to deal with geospatial data and queries (i.e., only a few of them are GIS users), they had more difficulty to learn about how to use the map and to formulate queries. The main problem regarding query formulation was indeed the fact that they did not know the semantics underlying the spatial operators. Nevertheless, after learning the overall principles, they could then accomplish the task properly. Thus, after this initial impression, they were comfortable to formulate queries and clearly visualize the produced results. In this sense, the outcome of the experiments indicated that the tool can be used also by less-experienced users to query a domain (in this case, a geographic one) in which they have no initial expertise.

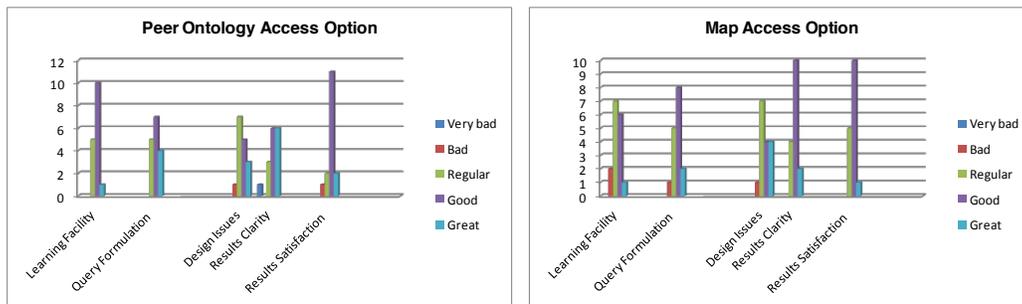


Figure 6. Experimental Results Summarization

The comments collected in our experiment can be summarized as follows: “the *easeGO* tool is very friendly, presenting a good initial impression and layout, with a reduced learning time. The peer ontology really abstracts the underlying geographic database, and some other improvements around the ontology view could be accomplished (e.g., providing results in the map area). Messages are very useful. The geospatial objects area (e.g., map) is interesting for formulating spatial queries, with a very simple visual query mechanism. Its layout could be improved in order to allow better understanding of the visual elements, especially the spatial operators.”

5. Related Work

Currently there are many tools and approaches that make use of query interfaces using ontologies. As an example, the Sewasie system [Catarci *et al.* 2004] provides access to heterogeneous data sources using an integrated ontology. Another example regards the Quelo system [Franconi *et al.* 2010] which also allows access to heterogeneous data sources through a visual interface and its reasoning processes are driven by an ontology.

Particularly, in the geospatial realm, Vilar [2009] provides a query expansion mechanism that pre-processes a user query aggregating additional information from

ontologies. Zhao *et al.* [2008] provide an integrated access to distributed geospatial data using RDF ontology and query rewriting. Zhifeng *et al.* [2009] use SPARQL to perform semantic query and retrieval of geospatial information which has been converted to a geospatial ontology. Baglioni *et al.* [2008] create an intermediate semantic layer between the user and the geodatabase in order to facilitate the user's queries. They also enrich the generated ontology with semantics from a domain ontology by finding correspondences between the classes and properties of the two ontologies. Also, Viegas and Gonçalves [2006] present the GeOntoQuery approach which allows different queries formulated over the same geographic database using an ontology.

Comparing these works with ours, we go one step further as we put together both OBDA principles and VQL ones using a peer ontology and visual elements to allow access over the geospatial data in the light of a PDMS setting. Another difference is the use of the correspondences set for allowing query reformulation.

6. Conclusions and Future Work

This work is an attempt to put in an easy-to-use way the task of accessing geospatial data using an ontology as a middle layer together with visual elements. To achieve this, aspects related to geographic databases, query interface design and ontology navigation have been considered. The *easeGO* tool provides an intuitive and transparent setting where the user is able to work with a peer ontology or with a cartographic view of the geospatial data. A query formulated in the interface is reformulated by the query manager using a set of existing correspondences between the peer ontology and the database schema. Query results can be visualized both in a table form or using the map.

Experiments accomplished with real users showed that the *easeGO* tool has some advantages: (i) it does not require that users have previous knowledge about the underlying database schema or query language; (ii) it gives the user a closer view of spatial reality where he is able to work with; (iii) it supports a predefined set of spatial operators that improves query capability and (iv) it allows users to pose queries by a visual, form or ontological paradigm, helped by message tips that cover all tasks.

The *easeGO* tool has been implemented in the light of the SPEED system, although its approach can be applied to any OBDA environment which deals with geographic databases. As future work, this tool will be extended to provide query reformulation between two neighbor peers, taking into account the semantic correspondences between them.

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