Interoperability of Geographic Information: A Communication Process –Based Prototype

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ABSTRACT

Since 1990, municipal, state/provincial, and federal governments have developed numerous geographic databases over the years to fulfill organizations' specific needs. As such, same real world topographic phenomena have been abstracted differently, for instance *vegetation* [1], *trees*, *wooded area*, *wooded area*, *milieu boisé*, *zone boisée* (unknown geometry). Today, information about these geographic phenomena is accessible on the Internet from Web infrastructures specially developed to simplify their access. Early in the nineties, the development of interoperability of geographic information has been undertaken to solve syntactic, structural, and semantic heterogeneities as well as spatial and temporal heterogeneities to facilitate sharing and integration of such data. Recently, we have proposed a new conceptual framework for interoperability of geographic information based on the human communication process, cognitive science, and ontology, and introduced geosemantic proximity, a reasoning methodology to qualify dynamically the semantic similarity between geographic abstractions. This framework could be of interest to other disciplines. This paper presents the details of our framework for interoperability of geographic information as well as a prototype.

Keywords: Interoperability of geographic information, geographic repository, ontology, communication process, cognition.

1. INTRODUCTION

Since 1990, municipal, state/provincial, and federal governments have developed numerous geographic databases over the years throughout the world. These geographic databases were defined to fulfill organizations' specific needs. As such, same real world topographic phenomena have been abstracted independently and differently, for instance *vegetation*, *trees*, *wooded area*, *wooded area*, *milieu boisé*, *zone boisée* (unknown geometry) [2,18,19,20,23,30]. Today, information about these geographic phenomena is accessible on the Internet from Web infrastructures specially developed to simplify their access (e.g. NSDI in United States, CGDI in Canada, GDI-DE in Germany). In order to meet their specific requirements, users need to aggregate geographic information coming from multiple databases into coherent sets, which still causes many problems.

Early in the nineties, standardization bodies (e.g. OpenGIS Consortium Inc., ISO/TC 211), the research community, and the industry involve in geographic information undertook the development of interoperability of geographic information to solve problems of information sharing and integration. More specifically, they aimed at solving syntactic, structural, and semantic heterogeneities as well as spatial and temporal heterogeneities between geographic information [5,17,27]. Today, considerable progress has been made regarding syntactic and structural heterogeneities [8,22], (e.g. [15,21]). Nevertheless, the semantic issue must also be taken into consideration in the solution to claim complete interoperability of geographic information. A few models have been proposed to increase the interoperability of geographic information. However, we found necessary to develop a conceptual framework for interoperability of geographic information [6], which is based on the human communication process, cognitive science, and artificial intelligence (e.g. ontology [10]), to better understand where each contribution applies as well as to foster new ones. Furthermore, we developed a reasoning methodology called geosemantic proximity to evaluate the semantic similarity between geographic abstractions, which is consistent with common spatial analysis methodologies used in the geographic information realm.

This paper presents the details of our framework for interoperability of geographic information as well as an experimental prototype, called GsP Prototype, which makes use of software agents developed in Java™ communicating in XML. It will show the different types of abstractions involved in interoperability and where ontologies and geosemantic proximity specifically apply in the context of interoperability. Thus, the remaining parts of this paper are structured as follow. Section 2 reviews research work related to interoperability of geographic information. Section 3 describes our conceptual framework for interoperability of geographic information and the geosemantic proximity notion. Section 4 presents the GsP Prototype. Finally, we conclude in Section 5.

2. INTEROPERABILITY OF GEOGRAPHIC INFORMATION

The conceptual framework for interoperability of geographic information and the prototype presented in the next sections rely on a number of disciplines such as human communication,

[1] Spatial pictograms description: :0D; :1D; :2D; :multiple geometry; : alternate geometry (see Bédard, Y, et M-J Proulx 2002 Perceptory Web Site. WWW Document, http://sirs.scg.ulaval.ca/Perceptory)

cognition, computer science, and geographic information. Research work related to interoperability, ontology, context, and semantic proximity are prominent in our work.

In the context of the OpenGIS Consortium Inc., interoperability has been defined as a set of software components adhering to common interface definitions that are fit together and work like a unique system even if they are located in a distributed environment in a way that is transparent to users [28]. On the other hand, IEEE defined interoperability in a broader scope as the "ability of two or more components to exchange information and to use the information that has been exchanged" [12]. According to the IEEE definition, interoperability has to go beyond the interconnection of software components using common interfaces to include reasoning capabilities to enable the software components to work in co-operation without human interventions. Accordingly, Fonseca [9] has proposed the ontology-driven geographic information system. In artificial intelligence realm, ontology refers to "an explicit specification of a conceptualisation" [10] and "a logical theory accounting for the intended meaning of a formal vocabulary" [11]. As such, ontology-driven geographic information system aims at embedding ontologies in software components to provide them with a knowledge base for reasoning.

Considering that people usually end up understanding each other in their mutual communication, we consider that interoperability is like a human communication process. Extensively covered in the literature [25,26,31], the human communication process refers to the transmission of details about something that one human being has in mind to someone else. A typical communication process is composed of a human source, a human destination, physical signals, a communication channel, a source of noise and a feedback mechanism. It involves different abstractions of real world phenomena especially, the source and destination cognitive models and the different physical signals that form messages, which are transmitted by the source to the destination.

The source and destination cognitive models result from the direct observation of phenomena as well as the observation of interpreted signals received from others. The human sensory systems capture signals and produce *perceptual states* from which the human selective attention selects and stores permanently characteristics of interest as *perceptual symbols* or *concepts* [1]. A concept is made of cognitive elements, which are basically hidden data-like components, and a set of functions enabling the concept to recognize and produce physical signals (i.e. *conceptual representations*) used to convey total or partial representations of itself in a given context [1]. The human memory cumulates concepts in clusters intending a some kind of similarity between each other [16]. We refer to this cluster of concepts as the ontology of an individual.

In databases and geographic information systems, concepts, their description, and their interrelations with others are captured in conceptual models using a given formalism (e.g. UML). A conceptual model helps to think about, to document, to communicate, and to realize databases about parts of reality. It is a good practice to support a conceptual model with a data dictionary, which provides the intended meaning of each component. Abstraction of geographic phenomena is typically influenced by the situation and circumstances from which phenomena are perceived. This refers to the *context*.

Other approaches of interoperability of geographic information have been proposed recently to simplify the sharing and integration of geographic information. Bishr [5] introduced the *Semantic Formal Data Structure (SFDS)*, a mediation approach. It ties together an export schema, a federated schema, and a proxy context mediator. The export schema identifies local database concepts made available to users. The federated schema describes domain specific concepts such as for transportation, soils, etc. The proxy context mediator is a common ontology that makes the correspondence between export schema concepts and federated schema concepts.

Benslimane [4] developed the *Isis solution*, also a mediation approach, which is organized in two layers: data and mediation. The data layer consists of heterogeneous databases and their local schema. The mediation layer is a compound of the universe of discourse, a global ontology, a context of reference, and database specific co-operation contexts, in which operation contexts maps classes from heterogeneous databases.

Uitermark [29] worked on a geographic data integration approach that used on the one hand a domain ontology describing concepts of a given discipline (e.g. topographic mapping) and on the other hand application ontologies describing concepts stored in local geographic databases. This approach proposed static semantic mapping of application and domain ontology concepts in Prolog clauses to support integration of heterogeneous geographic data when queried based on the domain ontology.

Cruz et al. [7] also worked on the integration problem of heterogeneous geographic data in the context of semantic interoperability. They proposed a system consisting of an ontology as a common knowledge along with a static *agreement* document encoded in XML, which maps local concepts to *ontology*'s concepts, to interact with local heterogeneous geographic databases. When the system received a query, the query was translated according to the ontology and the local *agreement* documents into sub-queries to be executed on local databases.

The *Matching Distance (MD) model* [24] introduced the measure of a conceptual distance between two geographic concepts. The conceptual distance was a weighted sum of the semantic proximity of parts, functions, and attributes of two geographic concepts. The semantic proximity of these elements consisted in the ratio of common elements to the sum of their common and distinguishing elements.

3. A COMMUNICATION BASED FRAMEWORK FOR INTEROPERABILITY

This section presents our conceptual framework for interoperability of geographic information and the notion of geosemantic proximity. They both serve as the theoretical foundation of the GsP Prototype presented in the next section.

A Communication-Based Conceptual Framework

In the previous section, we mentioned that interoperability is consistent with the human communication process. Let us take a situation between a user agent (A_u) and a data provider agent (A_{dp}) to describe briefly what interoperability should be. A_u

wants information about the hydrologic network for flood analysis in the Sherbrooke area and sends a request to A_{dp} about lakes and rivers within Sherbrooke. As soon as A_{dp} receives the request, he/she/it starts its interpretation, which consists in the identification of concepts he/she/it knows that correspond to the conceptual representations (e.g. watercourse, waterbody, in the proximity of Sherbrooke) of the request. When A_{dp} has identified concepts matching A_u request's conceptual representations, he/she/it brings together the data satisfying it (e.g. Lac des Nations, Magog River, and Saint-François River) and sends them to A_u. In turn, A_u starts the interpretation of the answer based on his/her/its own set of concepts. Here, A_u and A_{dp} use their own sets of concepts and vocabulary in their communication between each other and end up understanding each other because of their common background and common symbols they use.

Using this situation, we recognize five different expressions of the reality ***R***, ***R'***, ***R''***, ***R'''***, and ***R''''***, which serve in developing our conceptual framework for interoperability (Figure 1). ***R*** refers to the geographic reality centric to A_u and A_{dp}, which is beyond description. ***R'*** corresponds to A_u's set of abstractions consisting of the selected set of properties about ***R*** arranged into concepts that Au maintains. It constitutes A_u's cognitive model. ***R''*** represents the set of conceptual representations that A_u produces to communicate with A_{dp}. These conceptual representations convey germane properties of ***R'*** concepts expressing A_u's explicit needs (e.g. lakes and rivers within Sherbrooke). Parallel to ***R'***, ***R'''*** consists of the set of A_{dp}'s concepts, which are kept in his/her/its memory. These concepts are used to assign a meaning to ***R''*** conceptual representations (e.g. watercourse, waterbody, and Sherbrooke) as well as to retrieve and encode data that answer Au's request. Finally, ***R''''*** represents the data that is encoded by A_{dp}, and transmitted into a message to A_u through the communication channel. Once A_u has received the message, interpreted its content (i.e. the data) with his/her/its own set of concepts, and validated that it answers his/her/its request, we can assert that interoperability happened. Consequently, interoperability agrees to a bi-directional communication process including a feedback mechanism in both directions to control the good reception and understanding of messages.

The Geosemantic Proximity Notion

Following Barsalou's theory [1], concepts are able to produce and interpret conceptual representations in order to raise interoperability automation and, as such, concept's reasoning capability becomes a basic agent's component in the conceptual framework. Recently, we proposed the notion of *geosemantic proximity* (*GsP*) [6] for the similarity assessment between the respective contexts of a geographic concept and a geographic conceptual representation. Context is a fictitious and imaginary notion that leads the abstraction process, which makes some properties more important than others. Hence, the context (C) consists of the set of properties of a geographic concept or a geographic conceptual representation, which we separate into intrinsic ($C°$) and extrinsic (∂C) properties. Intrinsic properties refer to the literal meaning of the geographic concept or the geographic conceptual representation whereas extrinsic properties provide meaning by the influence that other geographic concepts or geographic conceptual representations have on it (e.g. behaviours and relationships). Thus, the context of a geographic concept K consists in the union of its intrinsic and extrinsic properties, Eq. (1), and is illustrated with a *segment metaphor* where the interior corresponds to the intrinsic properties and the limit to the extrinsic properties (Figure 2).

$$C_K = C_K{}^{\circ} \cup \partial C_K \qquad (1)$$

where:

- C_K: Context K
- $C_K°$: Intrinsic properties of CK
- ∂C_K: Extrinsic properties of CK

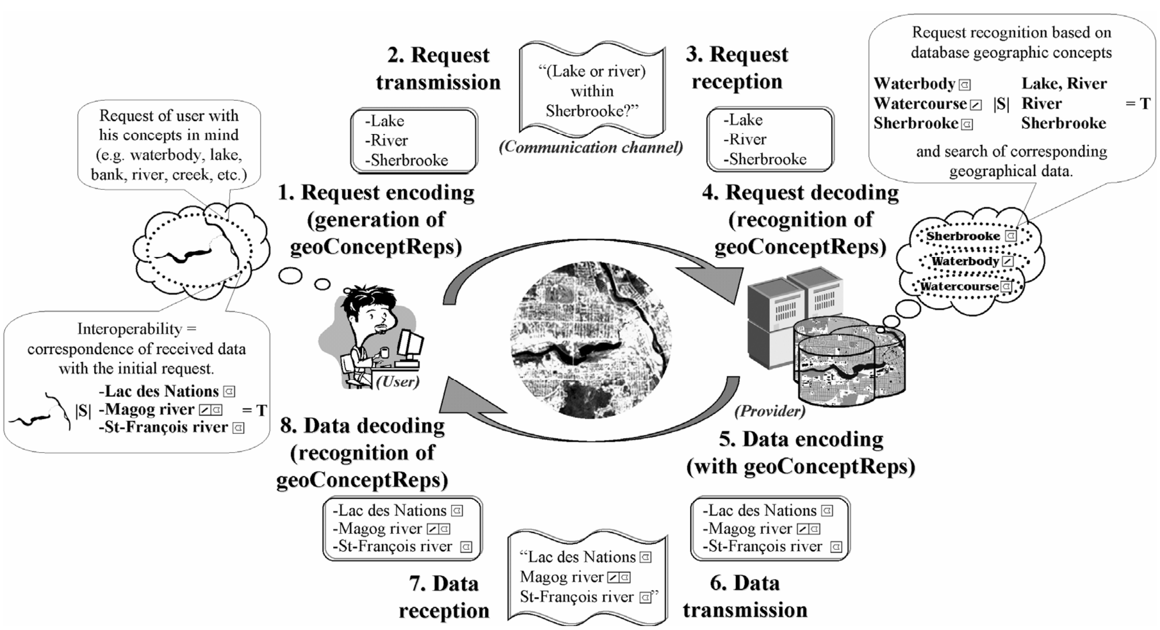

Figure 1: Interoperability Conceptual Framework

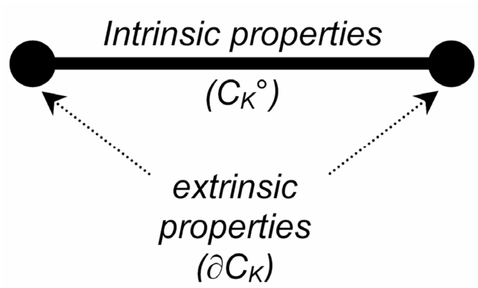

Figure 2: Segment Metaphor

GsP is a reasoning method that qualifies the similarity between a geographic concept (K) and a geographic conceptual representation (L) by comparing their respective context as shown in Eq. (2) and Figure 3, i.e. to analyse their common and distinctive properties.

$$GsP\ (K,L) = C_K \cap C_L \qquad (2)$$

where:

- C_K: Context of the geographic concept K
- C_L: Context of geographic conceptual representation L
- *GsP* (K,L): Geosemantic proximity between K and L

Figure 3: K and L Context Intersection

Integrating intrinsic and extrinsic properties of K and L –i.e. Eq. (1), into Eq. (2) expands the GsP assessment into a four-intersection matrix, as in Eq. (3). Each matrix component is

$$GsP\ (K,L) = \begin{pmatrix} \partial C_K \cap \partial C_L & \partial C_K \cap C_L° \\ C_K° \cap \partial C_L & C_K° \cap C_L° \end{pmatrix} \qquad (3)$$

evaluated empty or not (denoted by $\varnothing/\neg\varnothing$ or *f* / *t* respectively) and, hence, sixteen geosemantic proximity predicates are derived: *GsP_ffff* (disjoint), *GsP_ffft*, *GsP_fftt* (contains), *GsP_tfft* (equal), *GsP_ftft* (inside), *GsP_tftt* (covers), *GsP_ttft* (coveredBy), *GsP_fttt* (overlap), *GsP_tttt*, *GsP_tfff* (meet), *GsP_tftf*, *GsP_tttf*, *GsP_ttff*, *GsP_fttf*, *GsP_fftf*, *GsP_ftff* (see [6] for more details).

4. *GSP PROTOTYPE*

The *GsP Prototype* has been developed to validate the computing feasibility of our interoperability conceptual framework and the *geosemantic proximity* notion. It has been developed using software agents developed in Java™, which interact using XML encoded messages.

The Prototype's Architecture

The prototype architecture (Figure 4) depicts how two software agents (A and B) communicate together and exchange information through a communication channel. This architecture can be expanded to consider more than two agents interacting in pairs.

All agents are identical and operate in the same manner. Messages exchanged between agents are made of geographic conceptual representations (called GEOCONCEPTREPS) encoded in XML. When an agent receives a message, it extracts the GEOCONCEPTREPS and stores them in an internal object structure, which can be compared to a human being perceptual state. Each GEOCONCEPTREP is passed to a *Proxy* to be interpreted. The *Proxy* first looks into a limited size cache memory, the *geoConMem*, which holds the most recent geographic concepts (called GEOCONCEPTS) used by the agent, to identify a GEOCONCEPT equal (or *GsP_tfft*) to the GEOCONCEPTREP. This cache memory resembles to a human being short-term memory. If nothing is found, then the *Proxy* looks into a geographic repository, the *geoRep*, which constitutes the agent's ontology, to identify GEOCONCEPTS that are similar to the GEOCONCEPTREP. *GeoRep* compares to a human being long-term memory. If any, found GEOCONCEPTS are then sorted by their respective *GsP* and the one having the most important *GsP* is used to answer the other agents.

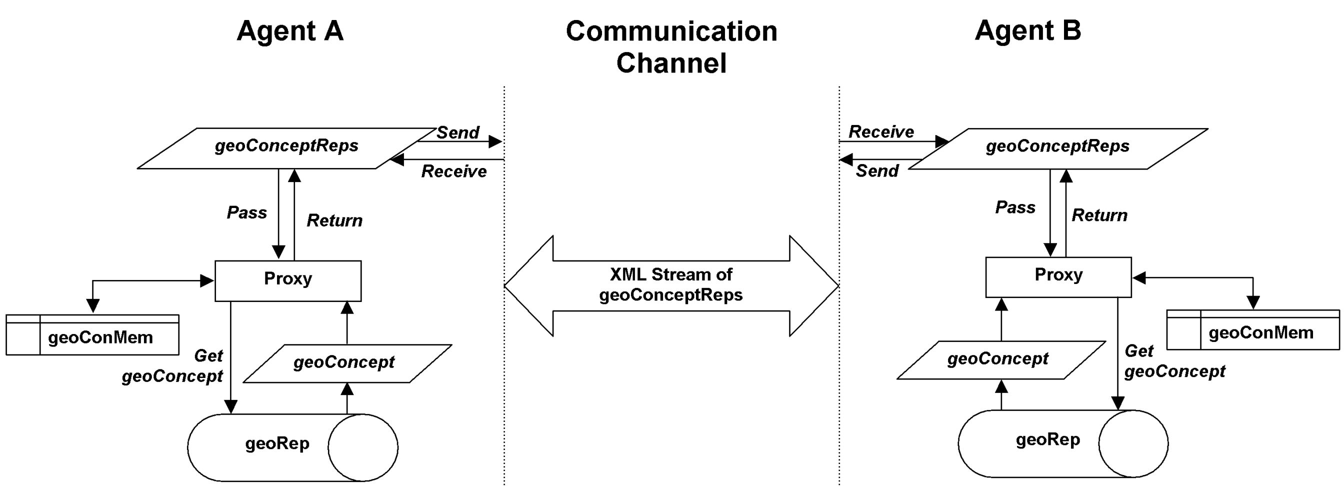

Figure 4: Prototype's Architecture

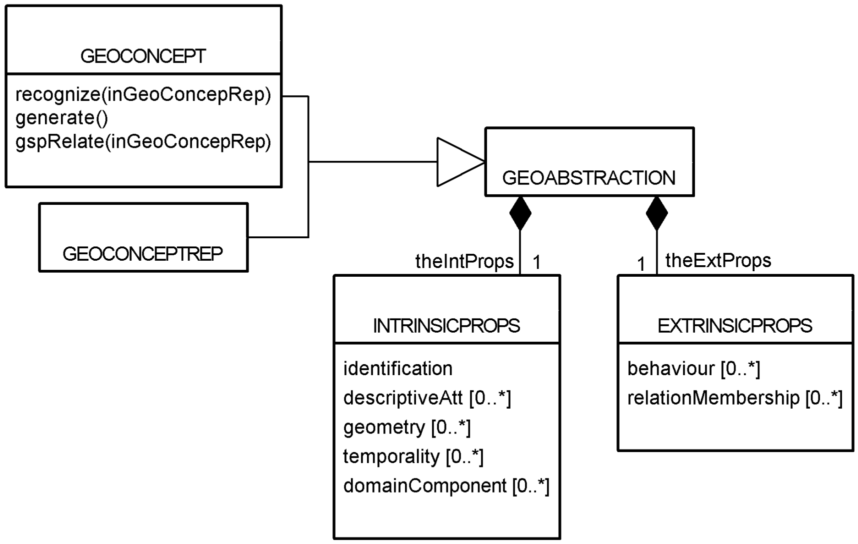

Figure 5: GEOCONCEPT and GEOCONCEPTREPS UML Class Diagram

In this architecture, a GEOCONCEPTREP serves as a data carrier, which conveys data from one agent to another. The GEOCONCEPTREP object structure is described in Figure 5. On the other hand, GEOCONCEPTS either from *geoConMem* or *geoRep* consist of hidden data, i.e. not directly accessible by other agents, as it is the case for the set of concepts a human being has in memory. This data is encapsulated by functions (Figure 5), which serves to recognize or interpret GEOCONCEPTREPS, to generate GEOCONCEPTREPS in messages, and to compute the *geosemantic proximity* (i.e. gspRelate) of the GEOCONCEPT with a GEOCONCEPTREP.

The prototype implementation

From this architecture, we developed the *GsP Prototype*. The *GsP Prototype* is operated from two user interfaces. The first interface is the agent's user interface (Figure 6). It consists of a window from which one can send a query through this agent to another agent and monitor the agent's communication operation. The window title bar identifies the agent and its ontology (e.g. agent1 (NTDB_RN)). The agent's console is composed of a drop-down menu showing GEOCONCEPTS the agent has knowledge about. It is also composed of a **SEND QUERY** button that initiates a query toward an external agent about the selected GEOCONCEPT when clicked. The last console component is a text field in which the agent displays user messages. The communication monitor has four fields from which one can follow the agent's communication activities. At the right hand side of the user interface, the **EXTERNAL AGENT** field identifies the agent's name with which this agent interacts. When processing a received message, the agent displays in the **PROCESSING GEOCONCEPTREP (R''/R'''')** field the GEOCONCEPTREP being processed (one at a time according to the architecture above). The **GEOCONCEPT (R'/R''')** field displays either the selected GEOCONCEPT from the console drop-down menu when a query is initiated or the GEOCONCEPT found similar in the recognition of a message's GEOCONCEPTREP. When a message –i.e. a request or a reply, is transmitted to the external agent, the **TRANSMITTING GEOCONCEPTREP (R''/R'''')** field displays the GEOCONCEPTREP produced out of the GEOCONCEPT shown in the **GEOCONCEPT (R'/R''')** field.

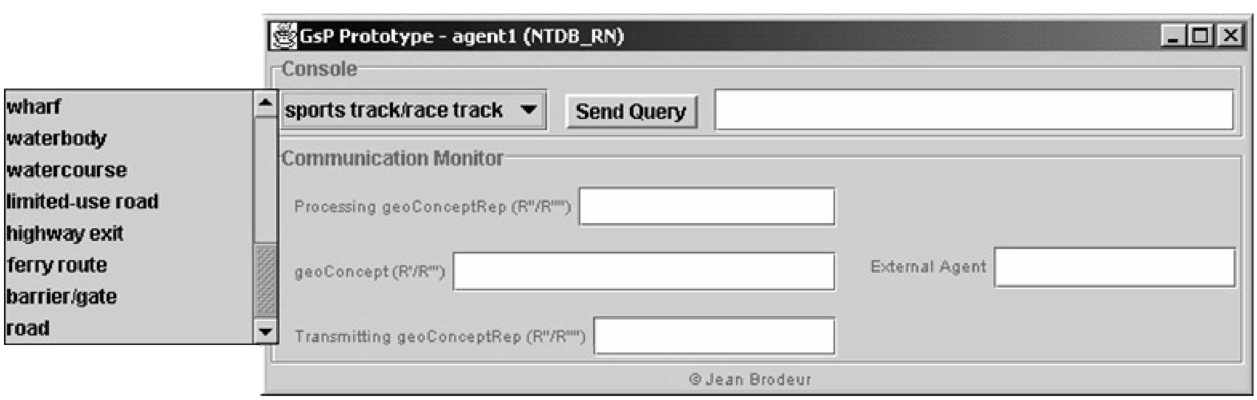

Figure 6: Agent's User Interface

Figure 7: Agent Manager User Interface

The Agent Manager is the second user interface (Figure 7) used in the prototype. It serves to instantiate and manage software agents. To instantiate an agent, the user must identify it with a name and assign it an ontology (i.e. its knowledge base). The name must be unique among all instantiated agents. The ontology refers to an ODBC data source name, which refers to a geographic repository containing the set of GEOCONCEPTS and their interrelationships. The four buttons at the bottom of the user interface serve to create (**New**), to activate (**Start**), to disable (**Stop**), and to delete (**Kill**) agents. The right hand side of the window displays the state of an agent. An agent is **Null** if it doesn't exist or has been killed, is **Operating** if it has been started, and is **Sleeping** if it has been stopped.

In the *GsP Prototype*, ontologies have been developed using *Perceptory* [3], a tool specially designed to develop geographic repositories consistent with international standards in geomatics [13,14]. *Perceptory* geographic repositories consist of a Unified Modeling Language (UML) class diagram supported by a set of metadata –i.e. the data dictionary, providing the semantics of each component of the class diagram. It handles (1) name and definition of object classes, (2) attribute name, definition, and domain of values, (3) description of attribute values and their data types, (4) operations, (5) geometry, (6) temporality, (7) relationships, (8) constraints, (9) lineage information, and so on. Figures 8 and 9 illustrate a UML class diagram of the National Topographic Data Base (NTDB) Road Network and the data dictionary description of the road class, respectively.

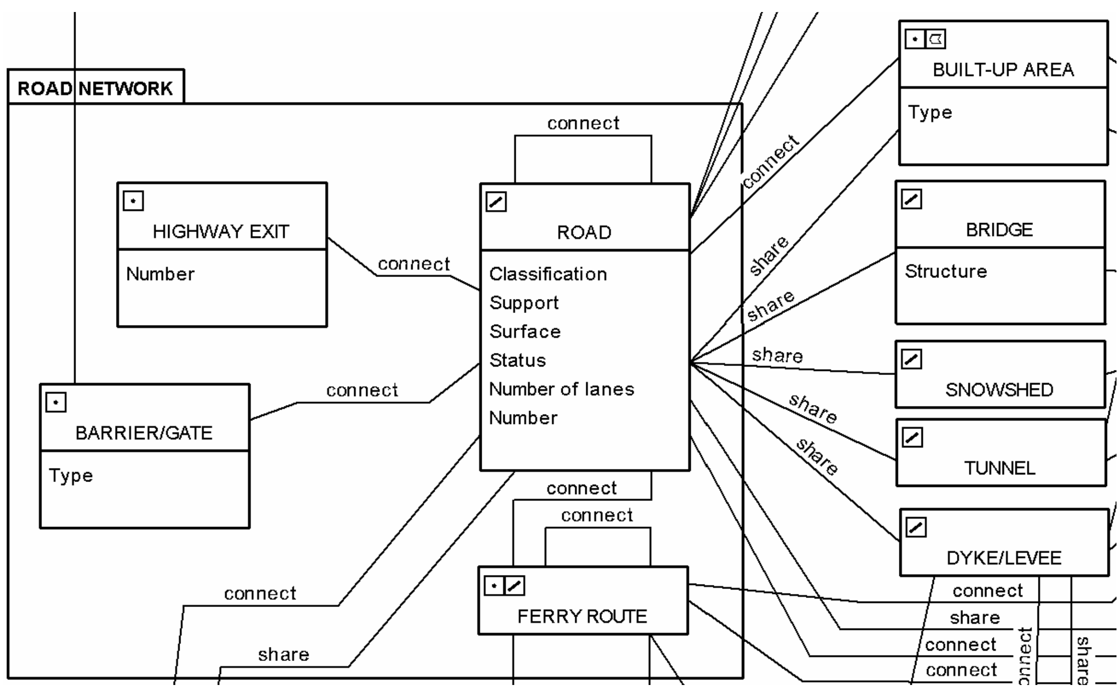

Figure 8: NTDB Road Network UML Class Diagram

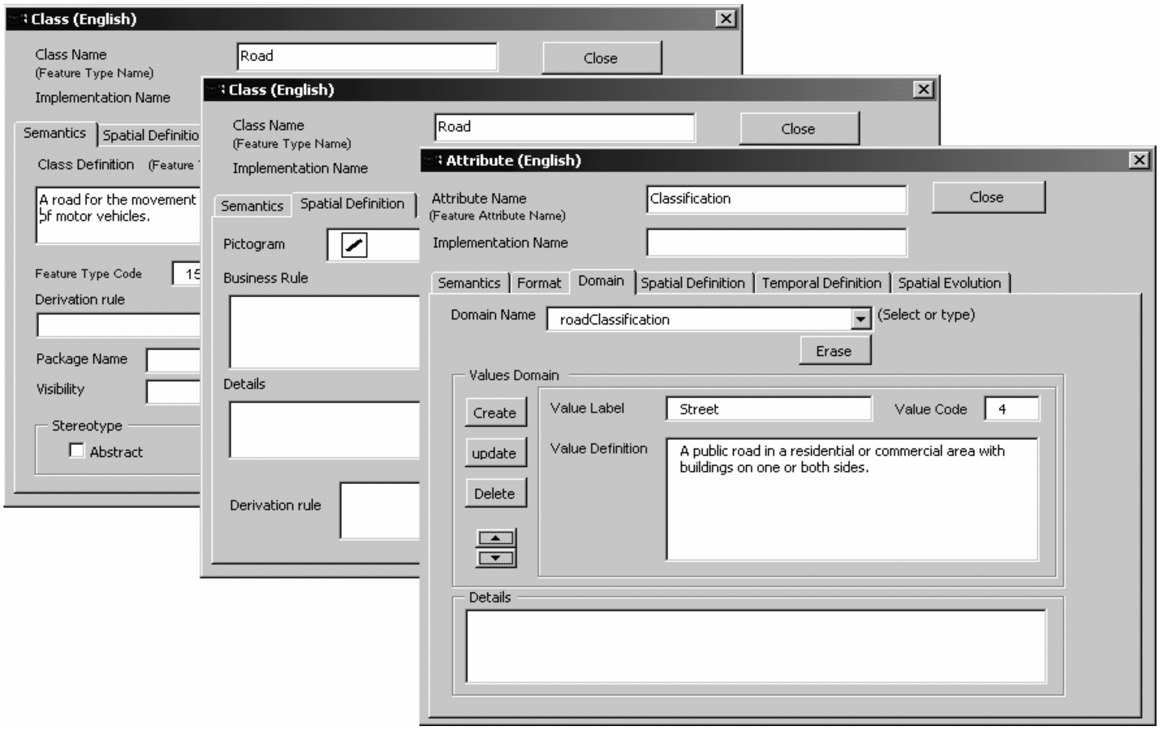

Figure 9: The *Road* Example of the *Perceptory* Data Dictionary

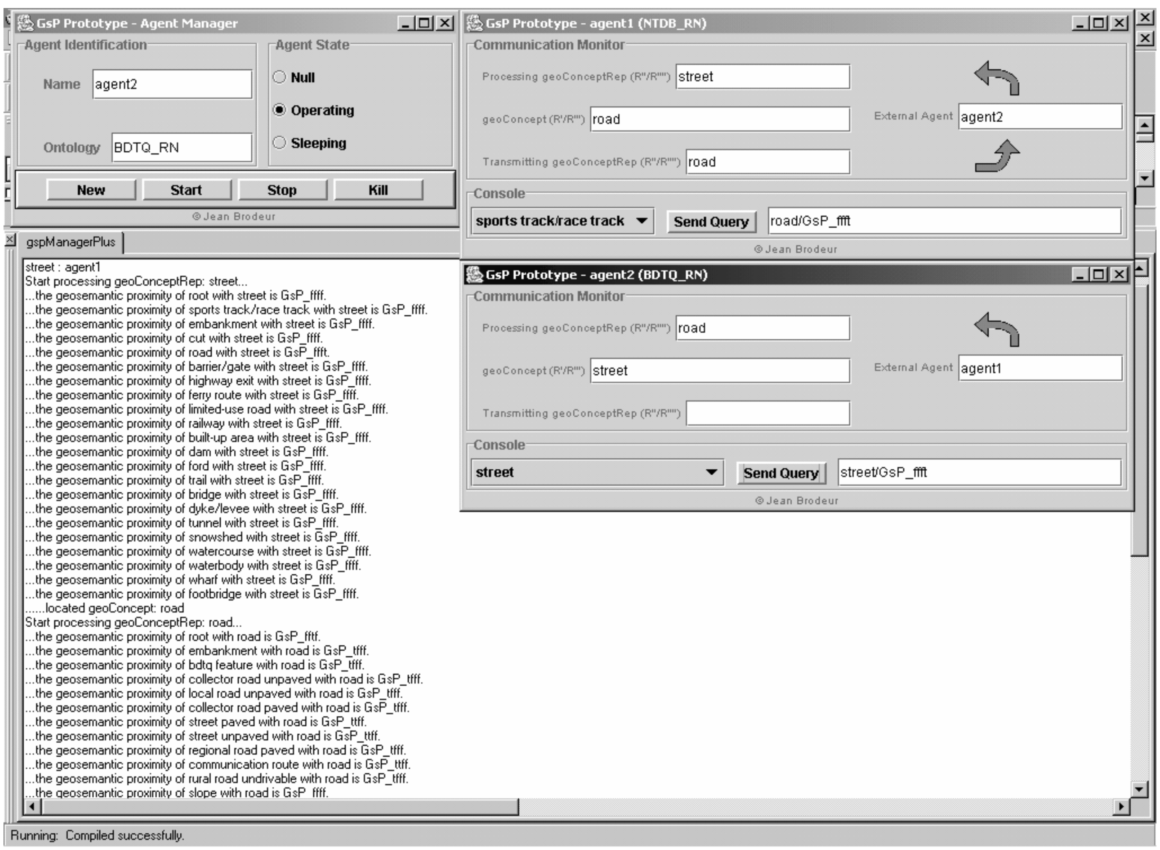

Figure 10: Prototype Operation

Figure 10 demonstrates the way the *GsP Prototype* operates. Two agents are instantiated and activated: *agent1* with the NTDB_RN ontology and *agent2* with the BDTQ_RN ontology (both ontologies refer to a different abstraction of the road network). In this example, *agent2* sends a request for information about street to *agent1*. As such, the street geoConcept produces a geoConceptRep which *agent2* includes in an XML message (Figure 11) and sends it toward *agent1*. Once *agent1* receives the XML message, it extracts the geoConceptReps, displays them in the **Processing GeoConceptRep (R''/R''')** field and processes them one by one for recognition as described earlier. In our case, the request contains only one geoConceptRep: *street*. Therefore, we can observe in the message log window (at the bottom of the agent manager) *agent1* computing dynamically the *GsP* of its geoConcepts with the geoConceptRep *street* and finding that *road* has the highest *geosemantic proximity* with *street*. Consequently, *agent1* uses the geoConcept *road* to respond to *agent2* –i.e. to produce a geoConceptRep, to include it in an XML message, and to send the message toward *agent2*. Similarly to *agent1*, *agent2* decodes and interprets the message, and finds that the geoConceptRep road answers its initial request about street, which completes the interoperability paradigm.

```
<?xml version="1.0" encoding="UTF-8"?>
<GsPmessage type="query">
  <conceptualRepresentation>
    <intrinsicProperties>
      <identification>
        <name>street</name>
        <definition>rue : voie de communication
        généralement bordée de bâtiments dans une
        agglomération.</definition>
      </identification>
      <geometry>1</geometry>
    </intrinsicProperties>
    <extrinsicProperties>
      <relationMembership>
        <relation>
          <name>Inheritance</name>
          <firstMember>street</firstMember>
          <secondMember>communication
          route</secondMember>
        </relation>
      <role>subtype</role>
      </relationMembership>
    </extrinsicProperties>
  </conceptualRepresentation>
</GsPmessage>
```

Figure 11: Example of XML Message

5. CONCLUSION

In this paper, we have presented a framework for interoperability of geographic information based on a human communication-like process and identified where semantic similarity applies in support to interoperability. We have also introduced the notion of *geosemantic proximity*, a context-based approach to qualify and compute dynamically the semantic similarity between a geographic concept and a geographic conceptual representation. This notion consists in a four-intersection matrix between intrinsic and extrinsic properties of a geographic concept and a geographic conceptual representation. The conceptual interoperability framework as well as the notion of geosemantic proximity has been demonstrated with the *GsP Prototype*. Ontologies are here used as agents' knowledge bases in support to semantic interoperability. It is our understanding that this approach could be used in a broader and more general scope to support interoperability in general.

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