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Geosemantic Proximity to Improve Geospatial Information Discovery in a Wireless Environment

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Today, more and more geospatial data sources, which have been created for specific purposes using different ontologies may be searched using Pocket PC or Palm PDA with wireless connection to the Internet as well as WAP-based Web browsers on cell phones. In this paper we propose a solution to increase the efficiency of search engines when looking for geospatial data. More specifically, we describe a framework for geospatial data interoperability and the notion of geosemantic proximity to interact with geospatial databases that could be used in a wireless environment. Examples illustrate the suitability of this notion to support efficient searching for geospatial data over the Web, especially in a wireless environment. Finally, we briefly address preliminary results obtained with our prototype.

Davantage de sources de données géospatiales élaborées pour des besoins particuliers selon différentes ontologies peuvent maintenant être accédées à l'aide d'ordinateurs de poche ou d'assistants numériques personnels (PDA) branchés sur Internet à l'aide de connexions sans fils et de fureteurs Web sur des téléphones cellulaires qui utilisent le protocole WAP. Dans cet article, nous proposons une solution pour accroître l'efficience des engins de recherche de données géospatiales. Plus spécifiquement, nous élaborons un cadre conceptuel d'interopérabilité des données géospatiales et la notion de proximité géosémantique pour interagir avec des bases de données qui peuvent être utilisées dans un environnement sans fils. Des exemples illustrent la pertinence de cette notion qui appuie la recherche efficiente de données géospatiales sur le Web, spécialement dans un environnement sans fils. Finalement, nous abordons succinctement des résultats obtenus à l'aide de notre prototype.

1. Introduction

It is well known that topographic elements are depicted differently in various geospatial data sources. For instance, the National Topographic Data Base (NTDB) provided by Natural Resources Canada, the Street Network Files by Statistics Canada, and the VMap libraries for military purposes depict Canada differently. There are also several other topographic data sources produced by provincial departments that depict parts of Canadian topographic elements, e.g. BC Digital Base Line Mapping (Geographic Data BC) and the *Base de données topographiques du Québec* (BDTQ). Typically, these data sources provide different abstractions of the topographic reality, resulting in data sharing and integration problems when users try to merge data from two or more sources. For example, a water area is represented as a *waterbody* in the NTDB, a *lake/pond* in VMap libraries, a *lake* in BC Digital Base Line Mapping, and a "*lac*" in *Base de données topographiques du Québec* (N.B. = point, = line, and = surface pictograms symbolize the kind of geometry used to describe the phenomenon geographically [Bédard 1999]). Increasingly such geospatial data sources are becoming readily available on the Web. Selecting the most appropriate data source for someone using either a Pocket PC or Palm *Personal Digital Assistant* (PDA) with wireless connection to the Internet as well as WAP-based Web browsers on cell phones requires tedious keying of several queries before getting the best answer and results in unnecessary and costly data transfer. Wireless technologies require highly efficient search engines that can identify very precisely the desired geospatial data sources in order to minimize both the data keying on these type-unfriendly devices and the cost of data transfer. These facts lead us to develop new approaches to better interoperate with geospatial data sources on the Web.

Interoperability of geospatial data is considered a solution for various problems, such as for sharing and integrating geospatial data on the fly. It provides the means to solve syntactic, structural, semantic, geometric, and temporal heterogeneities [Bishr 1997; Charron 1995]. Standardization organizations, such as the Open GIS Consortium Inc. (OGC) and ISO/TC 211-Geographic information/Geomatics, as well as the research community have built solid foundations of geospatial data interoperability regarding syntactic and structural heterogeneities (e.g. [ISO/TC 211 2001a; ISO/TC 211 2001b; Open GIS Consortium Inc. 1999; Open GIS Consortium Inc. 2001] that give content, structure, and syntactical descriptions of geospatial data). However, as structural heterogeneities can only be solved for semantically similar representations of phenomena [Bishr 1997], assessing the semantic proximity of geospatial data becomes an important issue for geospatial data interoperability.

However, accessing available geospatial data sources on the World Wide Web in an interoperable mode is still an unresolved issue that becomes especially important with technologies such as PDA and wireless applications. When interacting with geospatial data sources, people using PDA or WAP-enabled cell phones are usually not aware of the data specifications of these sources, their data dictionaries, or their technical thesaurus to get exactly the information they need. Also considering the actual Internet bandwidth for such technologies, searching geospatial information on the Web using different keywords could result in fastidious and expensive operations.

In this paper, we present a framework for geospatial data interoperability and, more particularly, the new approach of *geosemantic proximity*, which takes simultaneously into consideration geometric and semantic characteristics of an object and plays an important role in the framework. *Geosemantic proximity* is seen here as an approach that facilitates the search for geospatial information on the Web, based on the user's vocabulary, which results in both time and cost savings.

The remainder of this paper is structured as follows. The next section reviews basic elements upon which our framework and the notion of *geosemantic proximity* have been delineated. The third section presents our framework of geospatial data interoperability. Section 4 describes the approach of *geosemantic proximity*. In section 5, we mention a prototype developed recently and preliminary results. We conclude and present future works in section 6.

2. Background

The framework of geospatial data interoperability and the approach of *geosemantic proximity* presented in the following sections are based on studies on human communication, cognition, database modeling, artificial intelligence (AI), and geographical information; especially those related to ontology, context, semantic proximity, topology, mapping specifications, and semantic interoperability. We consider the human communication process [Schramm 1971; Weiner 1950] to be a powerful representation of interoperability. Human communication corresponds to the process involving an individual who transmits to someone else something that he has in mind and that describes phenomena of a given reality. It is essentially composed of a human source, signals, a communication channel, a human destination, possible noise, and a feedback component. Cognitive models of the source and the destination refer to signals (raw and transmitted) that reach their sensory systems and generate *perceptual states* [Barsalou 1999], also called percepts. The human attention selects and records only properties that appear pertinent and structures them into concepts, or *perceptual symbols* [Barsalou 1999]. Concepts are composed of both hidden data-like elements and a translation process that (1) converts data elements into conceptual representations and (2) recognizes conceptual representations. Conceptual representations are the physical symbols used to convey the concept in specific situations.

When communicating, humans deal with multiple representations of real-world phenomena. The description of real-world phenomena has been studied by people working in AI (*ontology* [Gruber 1993]) and database modeling. Conceptual database modeling consists of abstraction of parts of reality from a data-centered perspective [Simsion 2001], used to convey information about it. Multiple conceptual models could describe the same portion of reality differently according to the needs of different systems or users, leading to interoperability problems when integrating the data. In such cases, an ontology could provide means to facilitate the integration of such data since it provides linkage elements such as identity (described later in this section), which allow interoperability.

The context influences the abstraction of real-world phenomena. Context is here defined as the situation or the circumstances in which phenomena are observed, which drive the selection of distinctive intrinsic and extrinsic properties, and provide the intended semantics [Kashyap and Sheth 1996; Ouksel and Sheth 1999; Wisse 2000]. When dealing with geospatial data interoperability, it becomes essential to take the context into account. Semantic proximity in a context-based perspective is an approach well defined in the litterature [Kashyap and Sheth 1996; Ouksel and Sheth 1999; Sheth and Kashyap 1992] that supports reasoning functionalities and expresses the semantic relationships between conceptual representations using qualitative predicates such as semantic resemblance, semantic relevance, semantic relation, semantic equivalence, and semantic incompatibility.

As mentioned above, conceptual representations are physical symbols used to convey details about concepts. However, concepts and conceptual representations have to refer to the same set of phenomena to be interoperable. Therefore, they are not as important as the phenomena to which they refer. As such, the notion of identity of phenomena appears to be significantly related to geospatial data interoperability in the sense that concepts and conceptual representations involved in a communication process should refer to the same phenomena. In other words, the identity of phenomena must be recognized from source and destination concepts as well as from the conceptual representation. Identity is then defined as a meta-property that allows us to distinguish and individualize geographic phenomena [Guarino and Welty 2000] as well as to recognize representations that refer to the same phenomenon.

We can envision that a concept and a conceptual representation are made of intrinsic properties providing literal meaning and bounded by extrinsic properties restricting the scope of the concept or the conceptual representation. A concept and a conceptual representation can be associated to a segment on a semantic axis. The interior of the segment corresponds to the set of intrinsic properties of the concept or the conceptual representation whereas the boundary of the segment corresponds to the set of extrinsic properties. In this regard, the notion of topology as studied in geospatial information by authors such as [Clementini and Di Felice 1994; Egenhofer 1993; Egenhofer and Franzosa 1991; Egenhofer et al. 1994] is here extended for the purpose of semantic interoperability within the approach of *geosemantic proximity*.

Let's take the example of *road* to clarify the above notions of intrinsic and extrinsic properties of a concept and a conceptual representation and the associated notions of interior and exterior. On the one hand, a *road* can be described by its *classification type* (e.g. highway, main, secondary, and so on), its *surface type* (e.g. paved or unpaved), its *road number* or *road name*, and its geometric representation (e.g. a line). These represent intrinsic properties and, as such, the interior of the *road* concept. On the other hand, a *road* can have relationships with other features such as *built-up areas*, *railways*, *bridges*, *ferry routes*, and other *roads*. The memberships of a *road* in these relationships represent extrinsic properties and, as such, are boundaries of the *road* concept.

3. Geospatial Data Interoperability on the Web

In Figure 1, we illustrate geospatial data interoperability as an interpersonal communication-like process. For example, this process corresponds to a user agent (A_u), which could be an individual using a pocket PC with a wireless link to the Internet, who wants information about the road network within the area of Sherbrooke and queries a geospatial data source, i.e. a data provider agent (A_{dp}), which could be a geospatial database on a server also connected to the Internet, about *streets* within the *Sherbrooke* area. As soon as A_{dp} gets the request and interprets it using its personal knowledge (e.g. *road* and *Sherbrooke*), it first locates the information corresponding to A_u's request, then translates it into a form that is understandable by A_u (e.g. *King Street* ◪, *Portland Blvd* ◪, and so on), and sends it to A_u. A_u evaluates the answer he has received and determines if it corresponds exactly to his request. The two agents can understand each other because they share a common background and a set of symbols that they use. Hence, in order to develop our framework for geospatial data interoperability, we use five expressions of the topographic reality, $\boldsymbol{R}$, $\boldsymbol{R}'$, $\boldsymbol{R}''$, $\boldsymbol{R}'''$, and $\boldsymbol{R}''''$, each representing a separate ontology, which is related to the others thanks to the communication process. Together, they form what we call the *five ontological phases of geospatial data interoperability*. $\boldsymbol{R}$ corresponds to the topographic reality as it appears to A_u at a given instant and for which A_u wants information. $\boldsymbol{R}$ cannot be directly described. $\boldsymbol{R}'$ refers to A_u's abstraction of $\boldsymbol{R}$, which consists of a set of selected properties structured in concepts in order to form A_u's cognitive model. $\boldsymbol{R}'$ is called A_u's *affordances* of $\boldsymbol{R}$ [Gibson 1979]. $\boldsymbol{R}''$ joins together the conceptual representations that A_u generates to translate the significant properties of A_u's concepts in a given situation. These conceptual representations are physical signals that use a vocabulary to depict the concepts partly or wholly and to specify the intended meaning. These signals transit through the communication channel to reach A_{dp}. $\boldsymbol{R}'''$ consists of the set of A_{dp}'s concepts. These concepts are used to decode and recognize the $\boldsymbol{R}''$'s conceptual representations and grant them a specific semantics. In an ideal situation, A_{dp}'s concepts have a meaning closely similar to A_u's initial concepts. $\boldsymbol{R}''''$ designates the conceptual representations sent back to A_u. They are retrieved from A_{dp}'s knowledge base and encoded before being transmitted.

Since the encoding and decoding translation processes are typically viewed as middleware components, they are tied into our framework to concepts that appear in $\boldsymbol{R}'$ and $\boldsymbol{R}'''$. These processes generate and recognize the conceptual representations that match the concepts. They also take into account the respective contexts of the concept and the conceptual representation.

As illustrated in this framework, geospatial data interoperability is a bi-directional process that also includes feedback in both directions in order to ensure that messages have reached the destination and are understood properly. We think that this is an important issue when considering semantic interoperability of geospatial data.

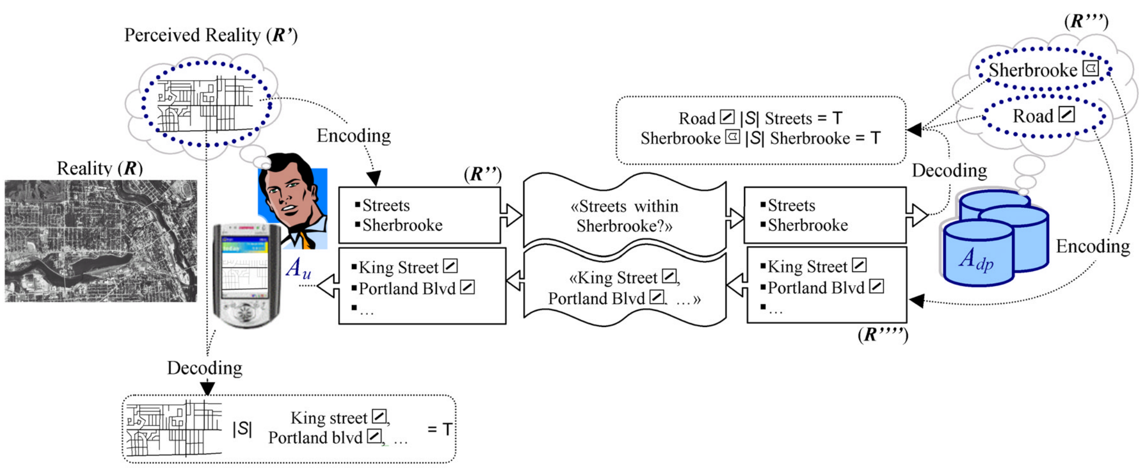

Figure 1: A Framework for Geospatial Data Interoperability

This communication process is typical on the Web. People surf the Web to find geospatial information using their respective knowledge and vocabulary. They also use their knowledge and vocabulary to recognize answers they get and to evaluate them against their queries. However, as geospatial data sources are not able to recognize messages encoded in other vocabularies than theirs, people have to know in advance the exact vocabulary or must have access to the metadata repositories describing the geospatial data (i.e. to have access to data sources' ontologies) to query the geospatial data sources. This makes the interaction with geospatial data sources arduous on the Web. As a result, semantic interoperability with geospatial data sources available on the Web is still a problem and automatic solutions are more and more needed. Hence, we propose the notion of *geosemantic proximity* to resolve this issue.

4. Geosemantic Proximity and the Web

As illustrated in Figure 1, agents exchange personal knowledge by communicating conceptual representations. On the Web, user agents' concepts and data provider agents' concepts (as illustrated in Figure 1) must be able to recognize conceptual representations in the incoming signals and to generate conceptual representations translating part of their own knowledge. When considering spatial information, an important aspect is the assessment of *geosemantic proximity* between a concept and a conceptual representation. This section presents this new notion of *geosemantic proximity*, which takes the context into consideration.

The context is thought of as a meta-concept omnipresent when abstracting phenomena. It governs the way phenomena are perceived and is typically described by intrinsic properties (i.e. properties of literal meaning, such as identification, attributes, attribute values, geometries, temporalities, domain) and extrinsic properties (i.e. properties providing meaning because of their association with other abstractions, such as semantic, spatial, and temporal relationships as well as behaviours). Figure 2 illustrates the relationships that exist between phenomenon, context, abstraction, concept, conceptual representation, property, intrinsic property, and extrinsic property in a UML class diagram.

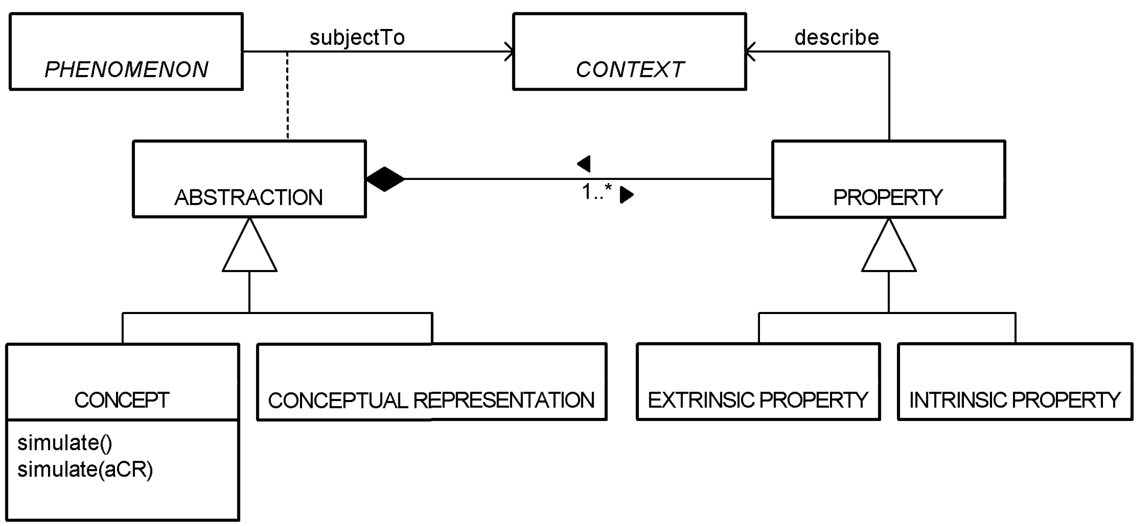

Figure 2: UML Class Diagram Describing Phenomenon, Abstraction, Context, Properties, and their Relationships

We view the context of a concept K (C_K) (just as for the context of a conceptual representation) as consisting of the union of the intrinsic properties ($C_K°$) and the extrinsic properties (∂C_K) of C_K (Equation 1).

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

Where:

C_K = Context of *concept K*
C_K° = Intrinsic properties of C_K
∂C_K = Extrinsic properties of C_K

We present the intrinsic properties as the interior of a segment on a semantic axis and the extrinsic properties as the boundaries of that segment. We use this representation in order to exploit the topological relationships between the context of a concept and the context of a conceptual representation.

Geosemantic proximity (*GsP*) is a context-based approach, which compares intrinsic and extrinsic properties of a spatial concept to those of a spatial conceptual representation in order to express their similarity qualitatively. It is used by the translation process tied to the concept and determines how a given conceptual representation matches this concept. It consists of the intersection of the concept *K*'s context and the conceptual representation *L*'s context (Equation 2 and Figure 3).

$$GsP\,(K,L) = C_K \cap C_L \qquad \text{(Equation 2)}$$

Where:

C_K = Context of *concept K*
C_L = Context of *conceptual representation L*
GsP (K,L) = *Geosemantic proximity* between *K* and *L*

Figure 3: Intersection between context of K and context of L

We expand *GsP* into a four-intersection matrix (as used for spatial topological relationships [Egenhofer 1993]), which develops the four distinct intersections between the respective intrinsic and extrinsic properties of the concept *K*'s context and the conceptual representation *L*'s context (Equation 3). Each member of the matrix can be evaluated empty, denoted Φ or *f* (false), or non-empty, denoted ¬Φ or *t* (true).

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

(N.B. the notation used in equation 3 is the same as the one used by Egenhofer for spatial relationships [Egenhofer 1993])

Hence sixteen (2^4) different predicates are derived. According to the four-intersection matrix, they are presented by the intersection values listed row by row. As shown in Figure 4, the predicates are gathered into four groups:

- the upper subdivision shows the predicates characterized by common intrinsic and extrinsic properties (*GsP_tfft/equal*, *GsP_ttft/coveredBy*, *GsP_tftt/covers*, and *GsP_tttt*);

- the right subdivision shows predicates characterized by common intrinsic properties and no common extrinsic properties (*GsP_ffft*, *GsP_fftt/contains*, *GsP_ftft/inside*, and *GsP_fttt/overlap*);
- the bottom subdivision shows the predicates characterized by no common intrinsic properties and no common extrinsic properties (*GsP_fttf*, *GsP_ftff*, *GsP_fftf*, and *GsP_ffff/disjoint*); and
- the left subdivision shows the predicates characterized by common extrinsic properties and no common intrinsic properties (*GsP_tttf*, *GsP_tftf*, *GsP_ttff*, and *GsP_tfff/ meet*).

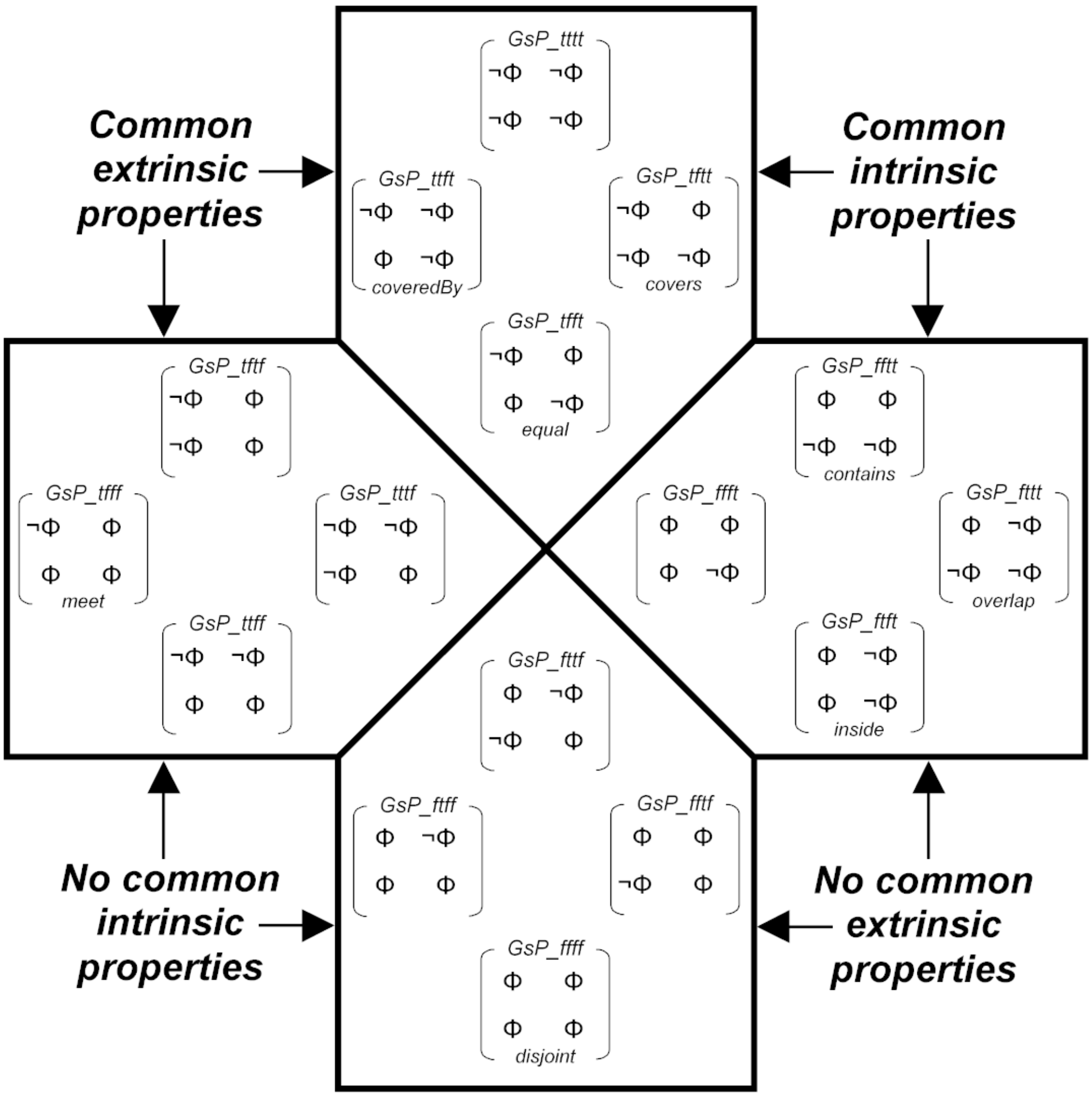

Figure 4: The Sixteen Predicates of *Geosemantic Proximity* Relationships

4.1 Examples

Let us look at some examples to illustrate how the *GsP* predicates can be used. In these examples, we assume an agent is associated with a predefined ontology, which describes a set of concepts using explicit intrinsic and extrinsic properties. This agent compares concepts of its associated ontology with conceptual representations it receives as part of a message from another agent in order to recognize these conceptual representations. These conceptual representations were typically encoded using the ontology of the agent transmitting the message. So, when the agent's concept *road* as described in [BC Ministry of Environment Lands and Parks (Geographic Data BC) 1992] is compared to the conceptual representation *vegetation* as described in [Natural Resources Canada 1996], *road* shows no explicit common intrinsic properties nor explicit common extrinsic properties with *vegetation*. Thus the *geosemantic proximity* of *road* with *vegetation* is *GsP_ffff* (or *disjoint*). (N.B. such assessment makes no assumption with regard to the spatial relationships that exist between road and vegetation instances.) However, the comparison of the agent's concept *road* defined in [Natural Resources Canada 1996] with the conceptual representation *street* (from the French *rue* as defined in [Québec 2000]) reveals that *road* has an attribute *street* and also both have the same type of geometric representation. As a result they have common intrinsic properties. Also as part of its description, the conceptual representation *street* has relationships with other kinds of roads that are included in the concept *road*, consequently *street* extrinsic properties are related to *road* intrinsic properties. Therefore, we can say that the *geosemantic proximity* of *road* with *street* is *GsP_fftt* (or *contains)*. Inversely, if we consider *street* as the concept and *road* as the conceptual representation, the *geosemantic proximity* of *street* with *road* is *GsP_ftft* (or *inside*). As another example, when comparing the agent's concept *hazard to air navigation* with the conceptual representation *bridge*, both described in [Natural Resources Canada 1996], on the one hand one can see that *hazard to air navigation* has a specific attribute that includes high bridges. On the other hand, they have one common geometric representation (line in this case). As such, *hazard to air navigation* has common intrinsic properties with *bridge*. Also, *hazard to air navigation* and *bridge* both have relationships with each other, as such intrinsic properties of one are related to extrinsic properties of the other. Accordingly, we can say that the *geosemantic proximity* of *hazard to air navigation* with *bridge* are *GsP_fttt* (or *overlap).*

5. Experiments

An experimental prototype was developed recently to validate the *GsP* approach within the proposed framework. It was developed in Java and XML, and makes use of geospatial repositories elaborated with *Perceptory* [Bédard 1999; Bédard and Proulx 2002], a UML-based case tool that supports geographic information standards of the ISO 19100 series. The prototype computes automatically the *geosemantic proximity* of a geoConcept when this geoConcept is compared to a geoConceptRep. As a result, it simplifies and reduces the time-consuming task of mapping geoConcepts with geoConceptReps, while minimizing subjective interpretations and possible mapping errors. Experiments are currently being conducted using ontologies on road networks and hydrographic networks using product specifications such as (1) Standards and Specifications for the National Topographic Data Base (NTDB) of Canada, (2) Specifications for the Digital Baseline Mapping at 1:20000 of Province of British Columbia (DBMBC), (3) Specifications for the Ontario Digital Topographic Database (ODTDB), (4) Specifications for the "Base de données topographiques du Québec" (BDTQ), and (5) Specifications for Digital and Hardcopy Property and Basemap Products of Province of Prince Edward Island (PEIBP). Preliminary results of the experiment are promising. For example, using geospatial data repositories that developed with the above product specification, the prototype maps automatically the geoConcept *road* from NTDB with the geoConceptRep *street* from BDTQ with a *geosemantic proximity* of *GsP_ffft* and the geoConcept *water disturbance* from NTDB with the geoConceptRep rapids from PEIBP with a *geosemantic proximity* of *GsP_ffft*. Description of the prototype, however, is beyond the scope of this paper and will be addressed in detail in the PhD thesis of the first author.

6. Conclusion

In this paper, we recognized that it is essential to take the semantics of geospatial data into consideration to facilitate and improve the search for geospatial data on the Web, especially in PDA and WAP-based wireless environments where keying queries is tedious and data transfer is costly. As such, we have presented a conceptual framework for the semantic interoperability of geospatial data, as a solution, resulting from a bi-directional communication process (Figure 1) involving a user agent and a data provider agent. In this framework, *geosemantic proximity* plays a major role for geospatial data interoperability. It expresses, qualitatively, the semantic similarity of a geospatial concept with a geospatial conceptual representation based on comparison of their intrinsic and extrinsic properties, which is developed using a four-intersection matrix. Examples have been presented to demonstrate the suitability of such an approach. A prototype was developed recently and experiments are presently being carried out to assess the strengths and the weaknesses of the approach.

Although our framework for geospatial data interoperability, the notion of *geosemantic proximity*, and the preliminary results of our prototype appear promising to access geospatial data sources in an interoperable manner, experiments that are presently conducted need to be finalized, documented, and discussed. Other issues need to be investigated further, notably the development of ontologies in the context of semantic interoperability of geospatial databases and the analysis of natural language definitions in order to extract more intrinsic and extrinsic properties of geospatial concepts and geospatial conceptual representations.

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