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Geosemantic Proximity, a Component of Spatial Data Interoperability

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Abstract

Since the early 1990s, interoperability of spatial data has been a major concern in the spatial information community (standardization bodies, research community, developers and users). However, the recent increase in the number of data sources and their widespread availability on Internet have emphasized the interoperability difficulties. One major concern is to deal with the interoperability of spatial data in their global context, that is to take into consideration their intrinsic semantics in combination with the semantics of their spatial and temporal properties. Doing so requires a more global approach that we have named geosemantics*. In this paper, we present the concepts of* geosemantics *and* geosemantic proximity*. Hence, we begin with a conceptual framework for spatial data interoperability based on human communication, cognition, and ontology. The spatial characteristics involved in this framework are emphasized. Then* geosemantic proximity *is explained, especially the comparison of contextual properties which provide concepts and conceptual representations with real world semantics. Finally, we describe how it can be used to evaluate qualitatively the semantic similarity between spatial concepts and spatial conceptual representations in order to facilitate the work of the user who looks for the spatial data that best fit his needs.*

1. Introduction

Spatial data interoperability has been a major subject of interest for more than a decade for standardisation bodies (e.g. OGC, ISO/TC 211) and the research community. It is brought to decrease the long delays and high costs of acquiring new spatial data for every new need, i.e. as a solution that allows for the sharing and integration of spatial data. Thus, interoperability is much needed to solve the frequent semantic, spatial, and temporal heterogeneities between data sources (Bishr 1997; Charron 1995; Laurini 1998).

This heterogeneity problem comes from the existence of multiple sources of spatial data depicting the same territory with similar but yet slightly different objectives, or from data describing adjacent territories but appearing *mergeable* for a given study (Charron 1995). In such situations, users have difficulties to figure out which spatial data best fit their needs or interoperate the best with their spatial dataset. In Canada, for instance, one can find similar data in the National Topographic Data Base produced by the Department of Natural Resources Canada (Natural Resources Canada 1996), in the Street Network Files, the Digital Boundary Files, and the Digital Cartographic Files produced by Statistics Canada (Statistics Canada 1997), in the VMap libraries produced for military purposes (VMap 1995), in the National Atlas of Canada also produced by the Department of Natural Resources Canada (Natural Resources Canada 2001), and also in several provincial topographic data sources which usually are at scales slightly larger (B.C. Ministry of Environment 1992; Nouveau-Brunswick 2000; OBM 1996; Québec 2000). All of these sources have been set up to meet specific organisation's needs at a given time. And now, they are all accessible to the population and basically describe the same topographical reality from different perspectives. As such, in these data sources, the same topographic feature corresponding to a water saturated area is described as *Wetland*, *Marsh/swamp*, *Marsh*, *Swamp*, *Marsh/fen*, *Milieux humides* or *Marais*, which somehow all refer to the same kind of topographical features. Consequently, people are affected by problems in the use of these data sources, namely to locate sources that best fit their needs for the area of interest or to share and integrate multiple data sources. Automatic identification of similarities and differences between feature representations in heterogeneous spatial databases is essential to the concept of spatial interoperability. Such automatic identification that would detect the geometric and temporal similarities and differences in addition to the semantic similarities and differences still represents a major challenge. This paper presents an undergoing research which aims at defining a theoretical framework for spatial data interoperability and developing the notion of *geosemantic proximity*.

In the next section, we review the basic notions upon which the framework is developed. Then, in the third section, we present this theoretical framework for spatial data interoperability. In the fourth section, we introduce the notion of *geosemantic proximity*. Finally, we conclude and present future work.

2. Basic Notions

The theoretical framework and the notion of *geosemantic proximity* presented in this paper are derived from research performed in a number of areas such as: communication science, human perception, ontology, database modelling, artificial intelligence, geographic information science, context and semantic similarity. The human communication process (Darnell 1971; Schramm 1971) constitutes an improved representation of interoperability, which consists basically of an individual who wants to transmit something he has in mind about real world phenomena to someone else. It is composed of a human source, signals, a communication channel, a human destination, possible noise sources, and a feedback mechanism; and it involves a number of representations of the reality, namely the source and the destination cognitive models, and the physical signals that convey a message from the source to the destination (Bédard 1986). Source and destination cognitive models are built up from raw or transmitted physical signals that reach our sensory systems, instantiating *perceptual states* (Barsalou 1999) of which the selective attention retains and stores only the subset of interest to constitute *concepts* (also called *perceptual symbols* (Barsalou 1999)). A concept is composed of hidden data elements and a translation process that encapsulates the data elements and converts them into *conceptual representations* and vice versa. In other words, a concept is a kind of "simulator" (Barsalou 1999) in itself that produces *conceptual representations* that are simulations of the concept for specific intended uses. For example, *waterbodies*, *coastlines*, *lakes* and *rivers/streams* are conceptual representations that could simulate a concept equivalent to *water areas*. The concept's translation process works also to recognise a conceptual representation that corresponds to the concept and, as such, a simulation (i.e., a possible conceptual representation) of the concept shall match with the incoming conceptual representation.

Multiple representations of real world phenomena take place in communication. Their identifications and descriptions have been explored in philosophy, artificial intelligence (AI), and database areas through the notions of ontology and conceptual modelling of databases. Ontology, in philosophy, refers to the description of the world in itself (Peuquet et al. 1998); a model and an abstract theory of the world (Smith and Mark 1999); the science of being, of the type of entities, of properties, of categories, and relationships that are part of the reality (Peuquet et al. 1998; Smith and Mark 1999). In AI, it is defined as "an explicit specification of a conceptualisation" (Gruber 1993) and a "logical theory accounting for the intended meaning of a formal vocabulary" (Guarino 1998). Consequently, ontology is defined here as a formal representation of phenomena with an underlying vocabulary including definitions of the intended meaning to describe phenomena and their interrelationships.

Conceptual database models are simplified abstractions of parts of the reality derived from a data-centered analysis (Simsion 2001), they are used to communicate information about this reality. In conceptual models, spatial concepts are described in terms of general categories, classes, properties, relationships, generalisations, aggregations, roles, constraints, behaviours, geometric properties, temporal properties and so on using lexical or graphical formalisms (Brodeur et al. 2000). In database conceptual models, objects must be unique and, therefore, qualified by a single set of properties and relationships. However, the same part of the reality can be described by more than one conceptual model, giving rise to interoperability problems when linking these different models to build a more global dataset (in scope or spatial coverage). Consequently, ontology is here seen as an underlying layer providing the necessary linkage components between conceptual models to allow interoperability. More specifically, it provides "identity" to phenomena and their different representations by the way of intrinsic and extrinsic properties (see section 3 for more details) that enable the matching between classes and instances.

The way an individual perceives, abstracts, and represents real world phenomena is governed by the context, that is the situation providing a conceptual representation with specific intrinsic and extrinsic properties and its real world semantics (Kashyap and Sheth 1996; Wisse 2000). A major issue in semantic interoperability of spatial data is to develop reasoning capabilities that take the context into consideration. As such, semantic proximity is seen as a context-based reasoning methodology that aims at expressing the similarities between conceptual representations. It has been studied for instance in semantic networks and in context-based approaches. Semantic networks are node-arc-like structures (Cohen 1982; Frankhauser and Neuhold 1992; Lehmann 1992) where nodes depict conceptual representations and arcs represent relationships between conceptual representations. In semantic networks, semantic proximity corresponds essentially to the conceptual distance of the shortest path between two conceptual representations. In context-based approaches, semantic proximity is described in terms of qualitative relationships expressing the contextual relatedness of two conceptual representations (e.g. semantic resemblance, semantic relevance, semantic relation, semantic equivalence and semantic incompatibility) (Kashyap and Sheth 1996).

3. A Theoretical Framework for Spatial Data Interoperability

This section describes the theoretical framework for spatial data interoperability. The following situation in which interoperability occurs is assumed: a user agent (A_u) searching information about the hydrographic network in the Sherbrooke City area enters a query on a search engine with the keywords “Lake”, “River”, and “Sherbrooke City” for a given spatial database, that is the data provider agent (A_{dp}). Once A_{dp} has received and interpreted the request, it searches the required information, and replies to A_u with its own content, e.g. the main “Watercourses” and “Waterbodies” in the neighborhood of “Sherbrooke”, for instance “Nations Lake”, “Magog River”, and “Saint-François River” corresponding exactly to the A_u’s request. In this situation, interoperability corresponds to an interpersonal communication-like process between two agents that use their own vocabulary to represent abstractions of real world phenomenon. The two agents’ common background and common set of symbols allow them to end up understanding each other (Bédard 1986; Schramm 1971). Based on this situation, we developed a theoretical framework for spatial data interoperability, illustrated in Figure 1, in which five expressions of the reality appear. First, we have the topographic reality (***R***) at a given time and about which A_u wants information, especially about the hydrographic network. Second, there is A_u’s abstraction of reality (***R’***) consisting of properties grouped and structured in concepts that forms its cognitive model. Third, we have conceptual representations (***R’’***) generated by A_u consisting of physical signals translating only relevant properties of concepts within a specific situation, e.g. “Lake”, “River”, and “Sherbrooke City” being the data transmitted for interoperability. Then, this is packaged in a message and placed on the communication channel towards destination A_{dp}. When the message reaches destination, A_{dp} decodes the received conceptual representations in order to recognise them and assign them a signification. Received conceptual representations must infer concepts of similar meanings to A_u’s initial concepts. A_{dp}’s concepts constitute the fourth expression of reality (***R’’’***) and are shown in Figure 1 by “Waterbody”, “Watercourse”, and “Sherbrooke”. Once conceptual representations are recognised, the information retrieval process is started and the concepts satisfying A_u’s interests are sent to A_u into encoded conceptual representations being the fifth expression of reality (***R’’’’***). Figure 1 illustrates this with “Nations Lake”, “Magog River” and “Saint-François River”. Once these conceptual representations reach A_u, the decoding starts in order to recognize them as well as to verify if they infer the same concepts (***R’***) of interest. If so, we say that interoperability happenned in the interaction between the two agents.

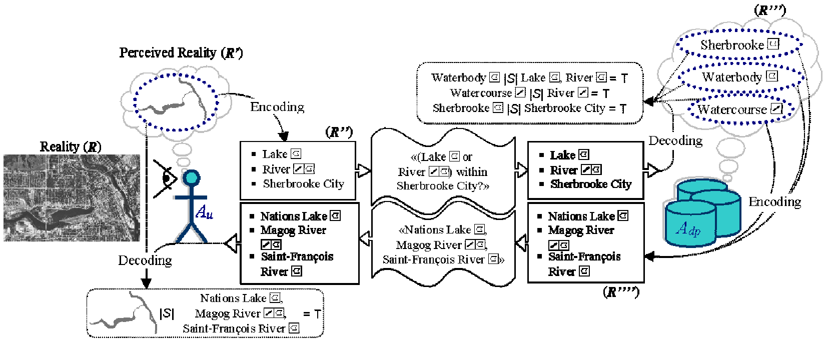


Figure 1: A theoretical framework for spatial data interoperability (adapted from the communication process of geographical information science in (Bédard 1986))

In this framework, each expression of the reality (***R***, ***R’***, ***R’’***, ***R’’’***, and ***R’’’’***) constitutes a separate ontology per se and, together, consist of what we call the *five ontological states of spatial data interoperability*. Each state must include properties providing identity to phenomena representations allowing agents to recognize them. Ontology is also frequently distinguished in three levels (Guarino 1998; Kashyap and Sheth 1996; Smith 1999), typically the global ontology (e.g. Wordnet, CYC), the domain ontology (e.g. *National Standards for the Exchange of Digital Topographic Data: Topographic Codes and Dictionary of Topographic Features* (Canadian Council on Surveying and Mapping 1984)), and the application ontology (e.g. National Topographic Data Base—Standards and Specifications (Natural Resources Canada 1996), VMap Specifications (VMap 1995), Base de données topographiques du Québec (BDTQ) à l’échelle 1/20 000- Normes de production (Québec 2000)). These ontologies are characterized by different levels of granularity and called here the *three levels of ontology*. Navigation between ontology levels is typically initiated at the application level and follows a bottom-up approach. As part of the framework, we introduce the ontology of interoperability as a two dimensional representation, one being the *five ontological states of spatial data interoperability* and the second, the *three levels of ontology*.

Encoding and decoding functions are fundamental translation processes in the framework. Translation processes are generally viewed as middleware components, but here they are tied to concepts found in ***R'*** and ***R'''***. These processes are responsible to generate and recognize conceptual representations that match concepts based on their respective context.

Context is omnipresent in real world phenomena descriptions and consists of elements that influence the use of a concept and that provide its real signification. The description of context is typically embedded into the phenomenon representation and consists of the union of intrinsic properties ($C°$) – i.e. components of literal meaning (e.g. identification, attributes, attribute values, geometries, temporalities, domain), and extrinsic properties (∂C) – i.e. components providing meaning through associations with other representations (e.g. semantic, spatial, and temporal relationships as well as behaviours) (Figure 2, Equation 1).

Let:

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

Then:

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

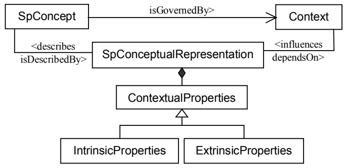


Figure 2: Contextual properties

4. *Geosemantic proximity*

Geosemantic proximity (*GsP*) is part of the spatial concept translation process that identifies the matching of the spatial concept with a spatial conceptual representation from their contextual properties (i.e. descriptive, spatial, and temporal properties), as well as reconciles their semantic, spatial, and temporal heterogeneities. Similarly to human reasoning, *GsP* determines qualitatively the *geosemantic* similarity of a spatial concept with a spatial conceptual representation. It is grounded on the intersection between the context of the concept and the passed conceptual representation (Figure 3, Equation 2).

Let:

C_K: Context of K
C_L: Context of L
GsP (K,L): *Geosemantic proximity* between K and L

Then:

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

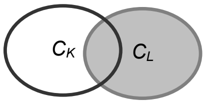
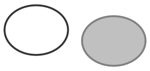


Figure 3: Intersection between context of K and context of L

However, as defined in Equation 1, context is made of two components. We have first the intrinsic properties that are here associated with the *interior* of C_K and C_L respectively. Second, there are the extrinsic properties that consist of the *boundary* of C_K and C_L respectively. Consequently, *GsP* (Equation 2) can be expanded as a four-intersection matrix involving intrinsic and extrinsic properties to evaluate semantic, spatial, and temporal commonalities between *K* and *L* (Equation 3), and from which *geosemantic* predicates can be derived: *disjoint*, *meet*, *overlap*, *covers*, *covered by*, *inside*, *contains*, and *equal*. *GsP* is thus homomorphic to the spatial and temporal topological models as used in geographical information science (Allen and Hayes 1985; Egenhofer 1993).

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

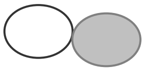
A concept *K* is *disjoint* from a conceptual representation *L* when there are no commonalities between intrinsic and extrinsic properties and, therefore, all four intersections are empty, e.g. a *road* and a *tree*.



disjoint (K,L) :=
$\{\forall p_i \in C_K°, \forall q_i \in \partial C_K \mid (p_i \notin C_L°) \wedge (p_i \notin \partial C_L) \wedge (q_i \notin C_L°) \wedge (q_i \notin \partial C_L)\}$

$$\begin{bmatrix} \Phi & \Phi \\ \Phi & \Phi \end{bmatrix}$$

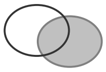
A concept *K touches* a conceptual representation *L* when both evoke similar things by having common extrinsic properties and, therefore, only the intersection of extrinsic properties is not empty, e.g. *waterbody* and *watercourse* (as defined in the National Topographic Data Base (Natural Resources Canada 1996)).



meet (K,L) :=
$\{\forall p_i \in C_K°, \forall q_i \in \partial C_K \mid (p_i \notin C_L°) \wedge (p_i \notin \partial C_L) \wedge (q_i \notin C_L°)\} \wedge \{\exists q_i \in \partial C_K \mid q_i \in \partial C_L\}$

$$\begin{bmatrix} \neg\Phi & \Phi \\ \Phi & \Phi \end{bmatrix}$$

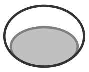
A concept *K overlaps* a conceptual representation *L* when they have common intrinsic and extrinsic properties and, therefore, none of the intersections is empty, e.g. *Bridge* and *Hazard to air navigation*.



overlap (K,L) :=

$$\{\exists p_i,p_j \in C_K^\circ, \exists q_i,q_j \in \partial C_K \mid (p_i \in C_L^\circ) \wedge (p_j \in \partial C_L) \wedge (q_i \in C_L^\circ) \wedge (q_j \in \partial C_L)\} \qquad \begin{bmatrix} \neg\Phi & \neg\Phi \\ \neg\Phi & \neg\Phi \end{bmatrix}$$

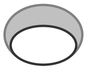
A concept *K covers* a conceptual representation *L* when the conceptual representation is more specific than the concept. Thus some concept intrinsic properties match some conceptual representation intrinsic properties, the remaining concept intrinsic properties match some conceptual representation extrinsic properties, and concept extrinsic properties match some conceptual representation extrinsic properties. Therefore, only the intersection between concept extrinsic properties and conceptual representation intrinsic properties is empty, e.g. *waterbody* and *lake*.



covers (K,L) :=

$$\{\forall p_i,p_j \in C_K^\circ, \forall q_i \in \partial C_K \mid (p_i \in C_L^\circ) \wedge (p_j \in \partial C_L) \wedge (q_i \in \partial C_L)\} \qquad \begin{bmatrix} \neg\Phi & \Phi \\ \neg\Phi & \neg\Phi \end{bmatrix}$$

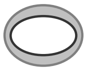
Conversely, a concept *K* is *covered by* a conceptual representation *L* when it is more specific than the conceptual representation. Thus some concept extrinsic properties match conceptual representation extrinsic properties, the remaining concept extrinsic properties match some conceptual representation intrinsic properties, and concept intrinsic properties match the remaining conceptual representation intrinsic properties. Therefore, only the intersection between concept intrinsic properties and conceptual representation extrinsic properties is empty, e.g. *lake* and *waterbody*.



covered by (K,L) :=

$$\{\exists p_i \in C_K^\circ, \exists q_i,q_j \in \partial C_K \mid (p_i \in C_L^\circ) \wedge (q_i \in C_L^\circ) \wedge (q_j \in \partial C_L) \wedge ((p_i \vee q_i) \in C_L^\circ)\} \qquad \begin{bmatrix} \neg\Phi & \neg\Phi \\ \Phi & \neg\Phi \end{bmatrix}$$

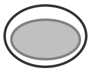
A concept *K* is *inside* a conceptual representation *L* when it is more specific than the conceptual representation. Thus some concept extrinsic properties match conceptual representation intrinsic properties and some concept intrinsic properties match the remaining conceptual representation intrinsic properties. Therefore, only the intersection between concept extrinsic properties and conceptual representation extrinsic properties as well as the intersection between concept intrinsic properties and conceptual representation extrinsic properties are empty, e.g. *street* and *road*.



inside (K,L) :=

$$\{\exists p_i \in C_K^\circ, \exists q_i \in \partial C_K \mid (p_i \in C_L^\circ) \wedge (q_i \in C_L^\circ) \wedge ((p_i \vee q_i) \in C_L^\circ)\} \qquad \begin{bmatrix} \Phi & \neg\Phi \\ \Phi & \neg\Phi \end{bmatrix}$$

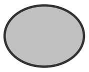
Conversely, a concept *K contains* a conceptual representation *L* when the conceptual representation is more specific than the concept. Thus some concept intrinsic properties match some conceptual representation extrinsic properties and the remaining concept intrinsic properties match some conceptual representation intrinsic properties. Therefore, only the intersection between concept extrinsic properties and conceptual representation extrinsic properties as well as concept extrinsic properties and conceptual representation intrinsic properties are empty, e.g. *road* and *street*.



contains (K,L) :=

$$\{\forall p_i,p_j \in C_K^\circ \mid (p_i \in C_L^\circ) \wedge (p_j \in \partial C_L)\} \qquad \begin{bmatrix} \Phi & \Phi \\ \neg\Phi & \neg\Phi \end{bmatrix}$$

A concept *K* is *equal* to a conceptual representation *L* when they exactly represent the same thing. Thus all concept extrinsic properties match all conceptual representation extrinsic properties, and all concept intrinsic properties match all conceptual representation intrinsic properties. Therefore, only the intersection between concept extrinsic properties and conceptual representation intrinsic properties as well as the intersection between concept intrinsic properties and conceptual representation extrinsic properties are empty, e.g. *marshes/swamps* (as defined in Vmap (VMap 1995)) and *wetlands* (as defined in the National Topographic Data Base (Natural Resources Canada 1996)).



equal (K,L) :=

$$\{\forall p_i \in C_K^\circ, \forall q_i \in \partial C_K \mid (p_i \in C_L^\circ) \wedge (q_i \in \partial C_L)\} \qquad \begin{bmatrix} \neg\Phi & \Phi \\ \Phi & \neg\Phi \end{bmatrix}$$

5. Conclusion and Future Work

In this paper, we have drawn a framework for spatial data interoperability laid on communication science, cognitive science, ontology, geographic information science, context, and semantic similarity. This framework consists basically of an interpersonal communication happening between a user agent and a data provider agent and is perfectly suited to describe interoperability of spatial data. Framework basic components are spatial concepts, spatial conceptual representations, ontology of spatial data interoperability, context, and *geosemantic proximity*.

Geosemantic proximity is essentially a context-based reasoning methodology that qualifies the similarity of a spatial concept with a spatial conceptual representation. It consists of a four-intersection matrix that analyses the commonalities between a spatial concept and a spatial conceptual representation using their respective intrinsic and extrinsic contextual properties (including geometric and temporal properties). This methodology fits exactly in the spatial information realm since it is homomorphic with existing spatial and temporal topological models (Allen and Hayes 1985; Egenhofer 1993).

Further developments are necessary to formalize context of spatial concept and spatial conceptual representations with detailed intrinsic and extrinsic properties. Then a prototype will be implemented to validate the *geosemantic proximity* methodology.

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