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Qualitative spatial reasoning methodology to determine the particular domain of a set of geographic objects

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ABSTRACT

Nowadays, there are many geospatial information from different sources such as satellite images, aerial photographs, maps, databases and others. They provide a comprehensive description of geographic objects. However, the task to identify the geographic domain is not an easy task, because it involves a semantic processing related to inference approaches that are based on the conceptualization of a domain. These approaches allow us to understand in a similar way that human beings recognize the geographic entities and help us to avoid vagueness and uncertainty. In this paper, a methodology to perform a qualitative spatial reasoning in geospatial representations is proposed. It is based on *a priori* knowledge, which is explicitly formalized by means of an application ontology. The knowledge described in the ontology is assessed according to a set of labels, belonging to any geographical domain for semantic analysis and mapping those labels to matching concepts defined in the ontology. As result, a set of geographic domains ordered by their relevance is obtained, providing a general concept directly related to the input labels, simulating the way that we perceive cognitively any geographic domain in the real world.

1. Introduction

Reasoning about spatial data is a key task in many applications, including geographic information systems (GIS), meteorological and fluid-flow analysis, computer-aided design, and protein structure databases (Guesgen, Ligozat, Renz, & Rodríguez, 2008). Such applications often require the identification and manipulation of qualitative spatial representations, for example, to detect whether one object will soon occlude another in a digital image or determine efficiently relationships between a proposed road and wetland regions in a geographic data set. Qualitative spatial reasoning (QSR) provides representational primitives (spatial "vocabulary") and inference mechanisms for these tasks (Bailey-Kellogg & Zhao, 2003). QSR has two primary goals: providing a symbolic model for human common-sense level of reasoning and providing efficient means for reasoning (Wolter & Lee, 2010).

The ability to perceive spatial objects and to reason about their relationships seems effortless for humans but it has proved that these actions are so difficult for computers. They have already attained the capabilities of a five-year-old child. Part of the computational problem lies in the difficulty of identifying and manipulating qualitative spatial representations. For example, although the pixels in a digital image define the locations of spatial objects implicitly, the task at hand might require a more qualitative characterization of the configuration of these objects, whether one object will soon occlude another (Bailey-Kellogg & Zhao, 1999).

Up-to-date GIS are becoming increasingly popular methods for representing and reasoning with geographical data (Elmes et al., 2005; Goodchild, 2009). These applications require methods of logical reasoning about geographical features and the relationships that hold between them, including spatially (Hobbs, Blythe, Chalupsky, & Russ, 2006; Lei, Kao, Lin, & Sun, 2009). The reasoning algorithms are widely used in the Artificial Intelligence field, whose the most relevant tasks are the capability of verifying the consistency of data sets, updating the shared knowledge, deriving new knowledge and finding a minimal representation

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(Donnelly, Bittner, & Rosse, 2006; Hernandez, 1994).

However, before performing any reasoning task, it is necessary to take into account a formal representation that allows us to conceptualize the domain knowledge of our interest (Renz, 2002; Buder & Schwind, 2012). In this case, ontologies are powerful tools to conceptualize any context, describing its concepts and expressing its relationships (Zhou, Ding, & Finin, 2011). Ontologies have also been cited as a method to carry out this reasoning (Mark, 2003; Egenhofer & Mark, 1995), but there are methodologies that do not handle the inherent vagueness adequately (Sharma, 1996). In fact, features are often dependent on the context in which they are made, with local knowledge affecting the definitions (Smith, 1996).

Geographic entities are not often a clearly demarcated entity, because they are part of another object (Liu & Daneshmend, 2004). Therefore, the individualization of entities is more important with respect to the geographic domains that they can belong or represent.

According to Bennett (2002), vagueness is inherent to the geographical domain, with many features being context dependent, as well as lacking precise definitions and boundaries. Vagueness is not a defect of our communication language but rather a useful and integral part. As a consequence, GIS cannot handle multiple possible interpretations in a correct manner, whereby the lack of this feature implies the creation of new techniques that allow the handling of various meanings, one of these is the inference based on reasoning.

Even though GISs are now a commonplace, the major problem is that of interaction. With gigabytes of information stored either in vector or raster format, present-day GISs do not sufficiently support intuitive or common-sense oriented human–computer interaction. Users may wish to abstract away from the mass of numerical data and specify a query in a way, which is essentially or at least largely, qualitative (Cohn & Renz, 2008). Arguably, the next generation GIS will be built on concepts arising from *Naïve Geography* (Egenhofer & Mark, 1995). Much of naïve geography should employ qualitative reasoning techniques, perhaps combined with the provision of "spatial query by sketch" (Egenhofer, 1997).

Qualitative reasoning is (QR) concerned not only with capturing the everyday common-sense knowledge of the physical world, but also the myriad equations used by engineers and scientists to explain complex physical phenomenon, while creating quantitative models (Weld & Kleer, 1989). The main goal of qualitative reasoning is to make this knowledge explicit, so that given appropriate reasoning techniques, a machine could make predictions, diagnostics and explanations of the behavior of physical systems in a qualitative manner, without recourse to an often intractable or perhaps unavailable quantitative model. According to that, note that although one use for qualitative reasoning is that it allows inferences to be made in absence of complete knowledge. It makes this not by probabilistic or fuzzy techniques, which may rely on arbitrarily assigned probabilities or membership values, but also by refusing to differentiate between quantities unless there is sufficient evidence to do so (Cohn & Hazarika, 2001).

The essence of QR is to find ways to represent continuous properties of the world by discrete systems of symbols. One can always quantize something continuously, but not all quantizations are equally useful. One-way to state the idea is the relevance principle: the distinctions made by a quantization must be relevant to the kind of reasoning performed (Forbus, 1984). The resulting set of qualitative values is termed a quantity space, in which indistinguishable values have been identified into an equivalence class. There is normally a natural ordering (either partial or total) associated with a quantity space, and one form of simple but effective inference is to exploit the transitivity of the ordering relationship. Another is to devise qualitative arithmetic algebras (Wolter & Zakharyaschev, 2000), typically these may produce ambiguous answers. Much research in the qualitative reasoning literature is devoted to overcoming the detrimental effects on the search space resulting from this ambiguity.

On the other hand, spatial reasoning in our everyday interaction with the physical world, in most cases is driven by qualitative abstractions rather than complete *a priori* quantitative knowledge. Therefore, QR holds promise for developing theories for reasoning about space. This justifies the increasing interest in the study of spatial concepts from a cognitive point of view, which provoked the birth of qualitative spatial reasoning within Artificial Intelligence and also GIS (Cohn, Bennett, Gooday, & Gotts, 1997).

Research in QSR is motivated by a wide variety of possible applications areas including GIS, robotic navigation, high level vision, spatial propositional semantics of natural languages, engineering design, common-sense reasoning about physical systems and specifying visual language syntax and semantics. There are other application areas including qualitative document-structure recognition (El-Geresy & Abdelmoty, 2006), applications in biology (Schlieder, 1996) and domains where space is used as a metaphor (Bennett, 1996; Knauff, Strube, Jola, Rauh, & Schlieder, 2004).

The goal of answering qualitative queries addresses an important aspect of common-sense reasoning by human beings and it can be found in many practical applications such as computer-aided tutoring or diagram understanding. Because of the lack of detailed numeric information, representations used by the approaches to data-poor problems are often carefully designed by hand with respect to an automatic task (Rauh et al., 2005).

In this work, we propose a methodology to perform a qualitative spatial reasoning, over a set of geospatial objects that are represented as input labels and belongs to a certain geographic domain. Three algorithms that perform the spatial reasoning and the inference tasks are proposed. They use the knowledge explicitly defined into application ontology and conceptual frameworks. The reasoning process is fundamentally based on the compute of topological relationships, which are used to describe the behavior of a geospatial object and their interaction with others.

The paper is organized as follows: Section 2 presents the state of the art related to the work in this field. Section 3 describes the proposed methodology to perform the qualitative spatial reasoning. Section 4 depicts the experimental results, applying the reasoning algorithms. The conclusion and future works are outlined in Section 5.

2. Related work

Spatial reasoning is an important issue in many application domains and it has been presented since the theory of points and lines geometry, which is considered one of the oldest branched of spatial reasoning (Renz, 2002). Other works on qualitative spatial reasoning are preceded by proposals oriented to spatial representations, in which the goal is that they can be read and understood by a machine (Sharma, 1996). In (Freksa, 1992) the importance of a correct representation of the reality to perform an efficient spatial reasoning process is described. In this case, machines are used to represent knowledge in a formal approach. However, the captured information must contain descriptions as close to how the human beings perceive their environment (Egenhofer & Mark, 1995). Thus, one of the main objectives of qualitative spatial reasoning is to find appropriate methods to represent continuous properties in the world, using a discrete symbols-based system (Cohn et al., 1997; Cohn & Hazarika, 2001).

According to the basis of QSR, in (Mark & Frank, 1991) some cognitive aspects of perception and knowledge representations as