Representation of Geographic Phenomena

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INTRODUCTION

Geographic Information Systems (GIS) provide methods of capturing, storing, manipulating, analysing, and presenting different types of geographically referenced information. In conjunction with other areas of study, such as cartography and remote sensing, GIS have evolved into a discipline with its own research base known as *Geographical Information Science (GIScience)*. Researchers in GIScience have increasingly recognised the need to consider time as an intrinsic element of models of geographic space, allowing the representation of dynamic elements in GIS. In GIScience, different approaches have been developed to dealing with elements which are subject to change over time, and an assorted terminology has been applied (e.g. *geo-phenomena, dynamic GIS, spatio-temporal GIS*).

Knowledge Representation (KR) is a sub-area of *Artificial Intelligence (AI)* which aims to represent elements and facts within a domain of knowledge through formal logic apparatus, in order to achieve intelligent behavior by providing methods of reasoning and drawing conclusions. The GIScience community has recently realised the role that *Knowledge Representation (KR)* approaches play in the development of modern GIS. Thus this article gives a discussion on KR approaches to modelling *geographic phenomena*, with particular attention to those based on the modeling of the concepts of *events* and *processes*.

This is a broad topic of research, with many inter-related areas, and is still under rapid development. Thus inevitably we shall not be able to cover all relevant work or even everything to the same level of detail. Rather, this article intends to give an overview on the main controversies, issues and challenges encountered in the field and present some of the approaches to overcome them. Relevant works in the area are left as additional readings. The next section presents background information on the topic. Then the following section gives an overview on existing approaches to representing and reasoning about events and processes and the concepts they are related to. Then the following sections, respectively, concludes the article and points to future direction in the field.

BACKGROUND

This section begins by introducing the field of KR, its related task of ontology development, and the problem of ontology grounding. Then an overview is given on qualitative spatial and temporal reasoning as important instruments for providing a KR of events and processes. Finally, this section gives an overall description of two phenomena which may affect the representation of events and processes: vagueness and information granularity.

Knowledge Representation

Knowledge Representation (KR) is one of the central areas in AI, and aims to provide appropriate representations of elements and facts within a domain of knowledge (Ringland & Deuce, 1988). These elements are represented as a set of symbols and logic is applied to provide formal apparatus to facilitate inferencing among these knowledge elements, resulting in new elements of knowledge. The fundamental goal of KR is to achieve intelligent behavior by providing methods of reasoning and drawing conclusions.

In the field of KR, substantial amounts of work focus on the development of *ontologies*. Ontology is defined by Gruber et al. (1993) as "an explicit specification of a conceptualisation" (p. 01). A conceptualisation, in turn,

DOI: 10.4018/978-1-4666-5888-2.ch311

is defined as "an abstract, simplified view of the world that we wish to represent for some purpose" (Gruber et al., 1993, p. 01). It comprises "the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them" (Gruber et al., 1993). Therefore, ontology deals with questions concerning what can be said to exist, and how such entities can related to each other. Ontologies can be specified in a wide variety of languages and notations (e.g., first-order logic, prolog, LISP). The ontology of geospatial phenomena is a critical emerging research theme in GIScience (Egenhofer, 2004). According to Kuhn (2005), geospatial ontologies can be seen as 'GIS at the type level'. That is, they should provide reasoning capabilities (spatial and non-spatial) about conceptual geospatial elements, similar to the reasoning provided by GIS about their instances.

The Ontology Grounding Problem

Grounding an ontology means establishing an explicit link between ontology and data. A characteristic of ontologies of geographic domain is that they are likely to contain concepts which can be effectively grounded upon data. For example, the abstract concept of "depth" in the geographic sub-domain of "water networks" could be defined in terms of water level measurements provided by a gauge. Then other concepts such as "shallow" and "deep" might be defined in terms of "depth." These terms, in turn, might be used in the definition of rivers, lakes, amongst others. Furthermore, as noted by Jakulin (2005), ontology grounding "is especially suitable for problem domains where extensive data is available, and where it would be time consuming to manually convert unstructured data into structured metadata" (p. 01), which is therefore applicable to the geographic domain.

Nevertheless, as pointed out by Mallenby et al. (2007), "the process of grounding an ontology upon data requires work at multiple levels, both in consideration of what predicates need to be grounded and how the data can be represented" (p. 06). This process requires determining the appropriate set of primitive symbols to be grounded so that higher level concepts can be defined in terms of these primitive ones, that is, without concerns about the data structure. Thus, if a representation model of geographic events and process is intended to work with real-world data, issues relating to the problem of grounding spatio-temporal geographic ontologies have to be addressed.

Qualitative Spatial and Temporal Reasoning

It is generally accepted that events and processes involve conceptual entities which exist in space and time. Thus an appropriate integration of these dimensions is essential for a comprehensive representational model of events and processes. *Qualitative spatial and temporal reasoning* are fields of study in computer science, whose goal is to provide ways of reasoning about elements of space and time (respectively), without the need for precise quantitative information. Combined approaches may also be developed, which characterise the field known as *qualitative spatio-temporal reasoning*.

Qualitative spatial reasoning allows inferences to be made about relations that hold between spatial objects. Perhaps the most popular approaches to QSR are the *Region Connection Calculus (RCC)* (Randell et al., 1992), and *Egenhofer and Franzosa's 9-Intersection Calculus* (Egenhofer & Franzosa, 1991). Whilst RCC has its essence in logic, the latter has a mathematical basis. Thus the former is of particular interest here. The RCC was introduced by Randell et al. (1992). This theory introduces a set of mereotopological relations which may hold between two given spatial regions. A primitive relation $C(x,y)$ (meaning x is is connected to y) is defined, which is the base to derive the others relations. Two spatial regions are regarded as connected when their topological closures share a common point. The RCC-8 consists of the following relations: DC (disconnected), EQ (equals), PO (partially overlaps), EC (externally connected), TPP (tangencial proper part), NTPP (non-tangencial proper part), TPPi and NTPPi, where the last two relations are the inverses of TPP and NTPP, respectively.

Qualitative temporal reasoning provides ways of drawing inferences about the relations that hold between temporal elements (i.e. instants and intervals). The most popular approach is the *Allen's Interval Algebra*, introduced by Allen (1983). The Algebra consists of the following 13 relations that hold between pairs of time intervals: < (before), > (after), M (meets), MI (met-by), O (overlaps), OI (overlapped-by), S (starts), SI (started-by), F (finish), FI (finished-by), D (is during), DI (contains) and = (equal).

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