Knowledge Discovery using Geosensor Networks

Michael F. Worboys
National Center for Geographic Information and Analysis
University of Maine
5711 Boardman Hall, Orono, ME 04469-5711
worboys@spatial.maine.edu

Abstract

Geosensor technology is radically changing our ability to collect data in a wide range of domains. While sensor hardware and low-level system technology is advancing rapidly, higher level modeling needs to be advanced in parallel, so that users can effectively utilize the potential. This paper proposes an approach to modeling interaction with geosensor networks based on dynamic primitives. Much of the current spatiotemporal information system technology is based on the snapshot metaphor, where the dynamic world is imagined as a temporal sequence of snapshots. This imposes limitations on the representations and reasoning capabilities of such systems. In particular, it is not possible using temporal snapshots to explicitly model events, processes, and actions. This paper summarizes some of the work done on extensions to current models to provide fuller event modeling capabilities, and gives examples of applications to the geosensor and geographic domain. The work will have impact in understanding physical aspects of the global security environment, because event-based models are needed for effective and high-level handling of geospatial intelligence information.

1. Introduction

Sensor technology is radically changing the strategies for collection, management, and analysis of geospatial information. Such sensors have the potential to collect and provide continuous streams of geo-referenced information, in a wide range of contexts. Using nanotechnology, there now exist low-cost, low-power devices that are general-purpose computing platforms with multi-purpose on-board sensing and wireless communications capabilities. Today, research efforts are in progress to develop the appropriate infrastructure for systems consisting of large numbers of small unattended, possibly mobile, and collaborative sensors nodes that have non-renewable power supply and communicate among themselves. Such sensors may also act collaboratively within broader network configurations, ranging in scale from a few cameras monitoring traffic to thousands of nodes monitoring an ecosystem, city or defense scenario. The challenge of sensor networks is to aggregate sensor nodes into computational infrastructures that are able to produce globally meaningful information from raw local data obtained by individual sensor nodes. This will then impact aspects of the global security environment, because event-based models are needed for effective extraction, filtering, synthesis and communication of geospatial intelligence information.

This paper addresses the issue of the provision of high-level models of such geosensor-based infrastructures that facilitate human interaction with them through query languages. Figure 1 shows the overall architecture of such systems. The sensors are arranged in a hierarchy, where a higher-level sensor may communicate with its direct descendants, located within range by means of wireless communication. Messages are passed up and down the hierarchy and the root is linked to a base station that acts as a mediator between the network and users. The whole structure is dynamic and may reconfigure to take account of the changing scenario.

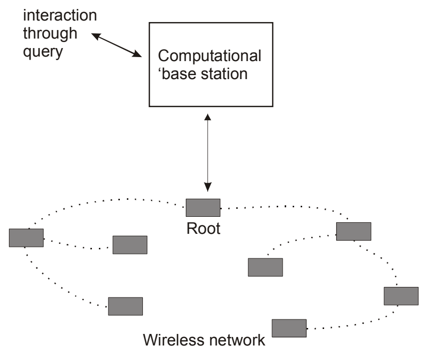

Figure 1: Top-level architecture of a geosensor system

2. Motivating example: A geosensor network for traffic management

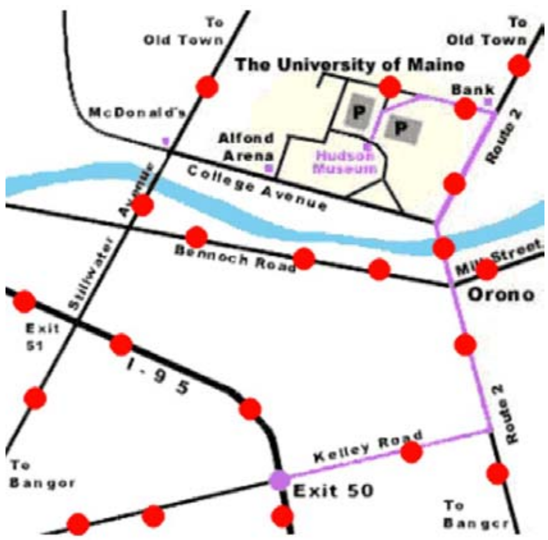

Figure 2: Geosensor network for traffic around the University of Maine

Consider the following queries to an imaginary geosensor network, depicted in figure 2, showing deployment of sensors on the road network around the University of Maine

- Is there a vehicle at Exit 51?
- Is the vehicle on Stillwater moving onto Bennoch Road?
- Is the traffic slowing down on Bennoch Road?
- Will the wide vehicle coming off the I-95 cause problems on Stillwater?
- Are there any unusual events currently in the system?
- Have there been any unusual events in the system in the last 12 hours?

The query sequence begins with a simple closed query and progresses to complex event mining interactions. We note that many of the more interesting queries concern occurrences rather than objects, and we believe this will be the case for geosensor networks in general. Today’s spatiotemporal information technology is based on the notion of a temporal sequence of snapshots of object configurations, or, one step further advanced, on a collection of histories of object changes. This focus on snapshots, or objects and their histories, makes the more complex interactions in our list of queries, couched in the language of events, difficult to answer. This paper describes work that provides the foundation for models and database interaction languages, in which occurrences can be directly treated.

3. An upper-level ontology of the dynamic world

From an ontological perspective, we can make an high-level distinction between those entities, *continuants*, that endure in the world through time (e.g., tables, houses, and people), and those entities, *occurrents*, that happen or occur (e.g., lectures, people's lives, boat races). The former class comprises of the ‘objects’ of traditional information systems, while the latter are less easy to place in current systems. In the case of dynamic aspects of the world, there is a difference between a city, whose characteristics are recorded by census and survey once each decade, say, and the processes of urban growth and decline, migration, and expansion, that constitute the city in flux. This general distinction is well understood in medicine, resulting in two fundamentally different sub-disciplines – anatomy and physiology. A bone (object) is part of our anatomy, while a headache (event) is part of our physiology. Grenon and Smith (2004) label temporal sequences of object configurations the SNAP ontology, and the event/action/process view, the SPAN ontology.

When we talk about entities in the SPAN ontology, we encounter a problem of terminology. Almost every account uses different definitions for event, process and action. There is also a distinction to be made about events/processes/actions and their specific occurrences at given times (compare the distinction between types and instances of objects). For simplicity, we will assume that all occurrents are *events* (we will use the term ‘process' to be synonymous with ‘event'), and that events initiated, and sometimes terminated, by human or non-human agents may be referred to as *actions*. (It should be emphasized that there is no claim here to the ‘correct' use of this terminology, just a fix on one usage.

There are interesting modeling issues concerning the similarities between events and objects. Certainly, events may have instances (occurrences), attributes, belong to a subsumption hierarchy, have temporal parts, and complex relationships (e.g., causality) to other events. Event identifiers may be more problematic, due to the ephemeral nature of events. There is a literature on extensions of traditional modeling techniques, such as entity-relationship modeling, to SPAN ontologies (see, for example, Gregersen and Jensen, 1999, Theodoulidis *et al*. 1992, Worboys 2001). Object-event interactions are also complex and need to be cataloged.

4. Approaches to representing and reasoning about events

When we think about introducing events into the system as first-class objects, we have at least the following considerations:

- Representations and reasoning systems for events
- Event-event relationships
- Object-event participation relationships

- Translation between event models and snapshot models (for examples, mapping events onto object histories)

One of the first formal reasoning systems for events was the event calculus (Kowalski and Sergot 1986). This is a narrative based formal system, in the sense that it is dependent on an independent time domain, usually isomorphic to the reals, rationals, or integers. The sorts include events, fluents (time-varying propositions), and times. The basic predicates are Occurs (event, time), HoldsAt (fluent, time), Initiates (event, fluent, time), and Terminates (event, fluent, time).

Examples of the ensuing theory are: “A fluent is true once it has been initiated by an event”, and “A fluent is false once it has been terminated and before it has been initiated”.

Work by Allen (1984) on a calculus of temporal intervals leads to a more sophisticated logical formalism for representing and reasoning about events.

The principal direction of our work is to apply the process calculi of Milner and others (see, for example, Milner 1999) to the dynamic real world. The notion of process (for us, event) is primitive in these calculi, and examples of the primitive constructor operations on processes P, Q, and R, include:

- Composition a.P
- Disjunction P+Q
- Parallelism P|Q
- Reaction ((in a)P+Q)|((out a)R+S) $\rightarrow$ P|R
- Replication !P
- Ambient n[P]

Spatiotemporal entities

In Worboys (2003), many of the details in the above description are given, along with an approach to use the process calculi above to represent and reason about real-world occurrences. Process calculi were originally designed primarily as models of distributed computational processes. We have shown that such processes can model moving object information, as well as more complex traffic protocols. Our key idea is that everything, even locations and times can be represented as processes.

Conclusions

The principal argument of this paper is that current spatiotemporal information systems only go part of the way in allowing representations and reasoning with the dynamic real world. We have been developing an approach using events as first-class entities. This approach is being applied to the construction of models and language for users of interfaces to geosensor networks to express queries naturally in terms of events, actions and processes. The research agenda related to this work is large, and some topics are listed below:

- Further development of a calculus for spatiotemporal entities
- Construction of event-oriented models and query languages for spatiotemporal databases and geosensor networks.
- Analysis of object-event and event-event relationship types.

- Application to specific domains, such as homeland security, and environmental change detection

This work will have impact in understanding physical aspects of the global security environment, because event-based models are needed for effective extraction, filtering, synthesis and communication of geospatial intelligence information.

Acknowledgments

This work was partially supported by the National Science Foundation under NSF grant number EPS-9983432.

References

ALLEN, J. F. Towards a General Theory of Action and Time. *Artificial Intelligence*, **23**, 123-154**,** 2004.

GRENON, P. and SMITH, B., SNAP and SPAN: Towards dynamic spatial ontology, Spatial Cognition and Computation, forthcoming, 2004.

GREGERSEN, H. and JENSEN, C. S. 1999, Temporal Entity-Relationship Models - a Survey, IEEE Transactions on Knowledge and Data Engineering, 11 (3), 464-497.

KOWALSKI, R. and SERGOT, M.J. A Logic-based Calculus of Events. New Generation Computing 4(1): 67-95 1986.

MILNER, R. Communication and Mobile Systems: The Pi-calculus. Cambridge University Press, 1999.

THEODOULIDIS, C., WANGLER, B. AND LOUCOPOULOS, P., The Entity Relationship Time Model. In *Conceptual Modelling, Databases, and CASE: An Integrated View of Information Systems Development*, pp. 87–115, 1992.

WORBOYS, M.F. Modelling changes and events in dynamic spatial systems with reference to socio-economic units, in *Life and Motion of Socio-Economic Units*, ed. Frank, A. U. Raper, J. and Cheylan, J.-P., Taylor and Francis, ISBN 0748408452, pp. 129-138, 2001.

WORBOYS, M.F. Event-oriented approaches to geographic phenomena, under review, 2003.