Personal Perspective on the Workshop on Agent-Based Modeling of Complex Spatial Systems

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In 1988, Mark Weiser, a chief technologist at Xerox's Palo Alto Research Center, introduced the term ubiquitous computing, and heralded "the age of calm technology, when technology recedes into the background of our lives." This vision is now fast becoming a reality. Computing will soon be embedded everywhere in the fabric of our lives: in our bodies, phones, homes, and the environments in which we live. Physically located sensors will be collecting data from a multiplicity of diverse sources using a variety of sensor technologies. Sensors will be mobile and the sensed phenomena are dynamic. Computing is expanding from people’s desktops to wherever people are, making it an integral part of people’s lives. At the same time, computing is also spreading to everywhere independent of the presence of people, leading to ubiquitous computing environments. Such anytime-anywhere computing revolutionizes the way people will use and interact with computers in the future outside their traditional office or home environments. Example scenarios for the use of such technology include emergency response, smart transportation systems, and real-time environmental monitoring.

Complex spatial models also manifest in dynamic field applications. Natural hazards, such as floods, fires, earthquakes, and volcanic eruptions provide significant threats to health and the economy. Pollution, such as that caused by carbon dioxide emissions, poses similar problems. Some of these phenomena are infrequent, but require intensive observation over short periods. Others are chronic and require different spatio-temporal patterns of monitoring. What many such phenomena have in common is the creation and dispersal of *dynamic fields*, whether of a gas, a level of temperature, of seismic activity, or water level. Ubiquitous spatial computing technology, in the form of sensor networks, also provides support for these applications.

Does geographic information science have a role to play in these new technological developments? My strong belief is that spatial and spatio-temporal issues lie at the very heart of ubiquitous computing. Unlike the virtual reality paradigm, ubiquitous computing is computing in the real, physical world. Event-based and agent-based models are key.

The perspective described here concerns the information-theoretic foundations upon which useful explanatory and predictive models of dynamic geographic phenomena sensed in ubiquitous computational environments can be based. We see a development of these foundations, from sequences of temporal snapshots, through object life histories, to event chronicles. A crucial ontological distinction is drawn between “things in the world” and “happenings in the world”; that is, between continuant and occurrent entities. Up to now, most research has focused on representing the evolution through time of geographic continuant entities, whether objects or fields. This paper argues that occurrents should be upgraded to an equal status with things in models of dynamic phenomena.

We propose several approaches to the resulting modeling questions. The underlying framework is provided by a formal approach to dynamic topology. The entities under investigation here are topological occurrents, such as splitting, merging, hole development, and other changes to connectivity relationships. This framework provides the basis for developing an approach to dynamic object-based and field-based views.

It is possible to develop a pure event-oriented theory of space and time, where spatio-temporal locations and agents situated in the space are all viewed as processes. We can then apply algebraic methods, such as the various process and event calculi developed by computer scientists. However, so far, it has been difficult to demonstrate the scalability of such an approach: the complexities of formal representation of even simple real-world events become quite forbidding. Nevertheless, we believe that a modular approach to such representations provides a way forward in this area, in a similar way that object encapsulation and modularisation provided a way forward in object-oriented approaches. The advantage of such an approach is that the formalism has a great deal more power, both in terms of representing complex processes and in reasoning about them.

Another area of interest in complex spatial systems is the modeling of sensor networks in dynamic fields. We have been working on an approach to information management that uses a qualitative approach to identifying and tracking continuous environmental phenomena such as toxic clouds or oil spills. One of the key elements of our approach is the modeling of the information management infrastructure in the underlying sensor network by the use of combinatorial maps. A sensor node locally stores information about the nodes in its communication neighborhood as a set of “darts”. These darts are ordered based on their spatial direction in a cyclic order around the sensor. We are researching the underlying theory and algorithms associated with this continuously adapting information management infrastructure. These algorithms assume no centralized control and are highly distributed. Key components of this research are:

- Detection of qualitative changes to the dynamic field by a sensor or group of sensors.
- Appropriate response to these changes in terms of local reconfigurations of the network and data routing.

The common theme throughout this work is models complex, dynamic phenomena, with emphasis on models that are:

- Agent-based, focusing on the processes that agents can perform, and their properties.
- Event-based, focusing on the occurrent entities in the phenomena, and their relationships.
- Distributed, not admitting centralized control, and therefore concerned with emergent properties.
- Rich, allowing a high degree of representational and reasoning power.