GIS and Agent-Based Modeling of Complex Spatial Systems

A Position Paper for the Workshop on Agent-Based Modeling
of Complex Spatial Systems

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It has been long recognized that it is difficult to describe and predict the behavior of a complex dynamic system with an analytical approach. In recent years, simulation with agent-based modeling has become an attractive alternative for studying complex dynamic systems. A complex system may be analyzed through simulation with a set of agents and their environment. Agents act, interact with each other agents, and react to their changing environment according to a set of behavioral rules derived from an underlying theory for the processes and interactions within a particular system. Increasingly realistic models for the behavior of complex systems can emerge from a cycle of simulation, validation and refinement.

Recent development in this area also includes the effort of integrating agent-based modeling with GIS to simulate dynamic spatial systems. Through this integration, researchers are able to incorporate detailed real-world environmental data, to simulate agent behaviors and processes as change and movement conditioned by GIS data representations of space and geography, and to visualize the results in 2D or 3D GIS environment. Furthermore, agent-based models can include real-time GIS data feeds to simulate and visualize situations unfolding in real time.

The Redlands Institute at the University of Redlands has been conducting experiments with the integration of agent-based modeling and GIS technology. We are exploring the potential that this technology integration could offer to the research of modeling and simulating complex spatial systems, as well as to identifying and addressing the gaps that still exit in meeting such research needs. Technologies under consideration include ESRI's *ArcGIS*® coupled with *Repast* (Recursive Porous Agent Simulation Toolkit[1]) via *Agent Analyst* (an ArcGIS extension), and *Cinema 4D*. We developed several experimental prototype models for simulating urban growth, creature movement (such as predator and prey interaction), military maneuvers, bird migration, and other phenomena such as hurricanes, atmospheric particle dispersion, line of sight terrain reasoning, etc.

At the conceptual representation level, these prototype, spatially-enabled / agent-based models combine both object and field modeling. The environments in these models are typically simulated using raster layers from a GIS database, each representing a particular environmental factor, or data surfaces derived through geoprocessing. The agents are typically simulated through GIS vector data objects, such as points (e.g. for moving

[1] REPAST. http://repast.sourceforge.net/

creatures) and polygons (e.g. for parcels). While an 'agent' object is not yet a supported notion in ArcGIS itself, Agent Analyst, through its connection to Repast, provides a framework for easily defining various agent types, their properties, and their behavioral rules. Actual GIS data can easily be "cast" into these agents and their respective property values at a particular state.

To simulate dynamic processes, the agents in these models are able to change (at each simulation interval) their spatial location (thus affecting movement), their orientation and view point, their movement speed, their shape, and the state of their other internal properties. These changes are conditioned programmatically based on behavioral rules which 'sense' and 'adapt' dynamically to the current state of other relevant agents, and in response to the current state of the environment. The environments in these models may change dynamically based on the time factor and/or as a result of the agents' actions. The new state (location, size, various attribute values, etc.) of each of the agents is updated on the GIS data surface, and is visualized in ArcGIS dynamically. Depending on the rate of visualization, these models can simulate movement and state change in near-real time. In effect the role of GIS in this case is to visualize the new state of the model at each simulation interval, while the actual model with the agents and their current state at any given time are maintained in Repast. The actual execution of agent behavior rules is also done in Repast, but it is possible to pass some of the spatial analysis processing to ArcGIS. The state of each simulation interval could also be saved as time stamped data, producing a set of time series data that can be used after the simulation is finished, to be replayed in ArcGIS, or to be presented in dynamic graphs (based on a chosen parameter), or to be visualized in some other tool, such as ArcGIS Tracking Analyst (to visualize the movement trajectory dynamically).

To better represent and simulate various geographic processes, we have also tried to identify generic components that are common to all the processes of a similar type. We have done a preliminary analysis of agent movement. We have identified basic movement types, by defining their movement path specification in terms of some more primitive concepts including: location; distance; direction; the moving agent's orientation; topological relations between the movement trajectory and reference objects; the surrounding environment; speed; and temporal sequence of sub-movement processes within a complex movement type. The formalization of this study into an ontology is still work in progress.

Agent-based modeling of complex spatial systems is one of our main research areas at the Redlands Institute. I have personally participated in this research effort. I hope to have the opportunity to attend this workshop, meet other scientists of the relevant fields and learn about their work, and participate in the discussions on the current issues in this research area.