Temporal GIS for Agent-Based Modeling of Complex Spatial Systems
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Agent-based modeling has become one of the key computational approaches to simulate collective outcomes out of individual decisions in complex spatial systems. Much effort has been devoted to identifying, formulating, and experimenting with rules of local behavior for discovery of emergent, self-organizing global patterns. With emphases on computation, agent-based modeling mostly operates on cell-, lattice-, or network-based data structures (Batty 2005; Andersson et al. 2006; Andersson et al. 2006; Bithell and Macmillan 2007). While agent-based modeling aims at discerning higher orders from complex disintegrated actions, it is limited by these confined data structures that restrict neighborhood geometry and possible locations, spatial interaction structures, and local spatial scale on actions and interactions. On one hand, agent-based modeling attempts to capture spatial complexity, but on the other hand, spatial data structures used for the modeling approach inevitably over-simplify the complex nature of geographic space. In this position paper, my premise is posited upon the need for temporal GIS representation of complex properties that manifest spatiotemporal presence of geographic dynamics.

There are at least three dimensions of complexity in geographic dynamics (Goodchild et al. 2007): changes to geometry, changes to location (movement), and changes to internal structure. Based on the three dimensions, agent-based modeling can be considered a means to simulate individual movements in order to examine aggregated changes to geometry and internal structure. Therefore, agent-based modeling adds another layer of complexity: the inherited hierarchical nature of geographic dynamics that propagates from individuals to the aggregated whole. Furthermore, individuals and aggregates are relative concepts. An aggregate at one level may be considered an individual in a higher level. For example, a residential district is an aggregate of houses, but a district can also be considered an individual that aggregates to a community. Multiple levels of aggregation over geographic semantics, space, and time are outcomes of dynamics that operate at and across different spatiotemporal scales. A hierarchy of geographic dynamics also suggests the potential for distinct rules for actions at different levels in the hierarchy. Group behavior and psychology likely depart from individuals'. If temporal GIS representation can capture the intricate, multi-level and complex structure of geographic dynamics, the temporal GIS can empower agent-based modeling in two significant ways discussed below.

First, rules applicable to different levels of geographic dynamics can be incorporated into agent-based modeling. For example, individual drivers can be regarded as fine-grain agents, and comparably convoys of vehicles like coarse-grain agents. Fine-grain agents apply different rules of actions than coarse-grain agents, even though coarse-grain agents may be aggregates of correspondent fine-grain agents. GIS data representing a lower level of geographic dynamics (such as traffic signs and traffic counts) provide the basis for agent behavior at a finer grain. GIS data representing a higher level of geographic dynamics (such as traffic flows and highway types) offer the condition for agents of a coarser grain. Emergent patterns can then be observed at multiple levels of detail. Simon (1973) argued that any complex system in the world must be hierarchical, or otherwise we would have no way to acquire it. He further elaborated on the importance of hierarchical structures to the sustainability of a complex system, for only hierarchies can evolve efficiently and successfully in a consistently changing world. While reality may or may not be hierarchical, hierarchical structures facilitate observations and understanding (Allen and Starr 1982). Agent-based modeling needs to incorporate the hierarchical nature of geographic dynamics, and temporal GIS needs to support the necessary data in forms that enable the simulation of agent actions within and across levels of geographic dynamics.

Second, temporal GIS can provide empirical support if the results from agent-based modeling can be stored into a spatiotemporal database for query, retrieval, and analysis. The empirical support will allow for comparison of model output and observations and comparison between modeling results from different scenarios or rule sets. Such comparisons can be change-based or development-based. Emphases on change center on the differences in distributions and patterns in space and time. Examples include how spatial distributions of pedestrians change over time, and how emergent patterns (shape and topology) differ based on different sets of behavior rules. Development-based comparisons focus on the evolution of individual agents or groups of agents. For instance, an agent adapts to environmental conditions at finer and coarser grains, and a forest may diminish and become more fragmented over time. When the results can be stored in a temporal GIS database, algorithms can be developed to support queries that seek similarity from empirical observations or from model runs with different rules. A temporal GIS representation framework that combines field- and object-based models to capture precipitation change and rainstorm development (Yuan 2001; McIntosh and Yuan 2005; McIntosh and Yuan 2005) can be revised to enable such empirical support to agent-based modeling.

An integration of agent-based modeling (ABM) and temporal GIS (TGIS) data modeling offers both theoretical and empirical improvements to understand spatial complex systems. Agent-based modeling can effectively represent the distributed nature of actions and reactions at the individual levels and transcend the individual, local decisions to identifiable patterns at a higher level in a complex spatial system. Temporal GIS data modeling have advanced to represent geographic complexity and dynamics and organize spatiotemporal data according to processes measured/recorded by these data. Therefore, the ABM-TGIS integration promises novel approaches to the study of spatial complex systems.

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