Geosimulation and dynamic GI Science

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Bio

Dr. Torrens is an Assistant Professor in the School of Geographical Sciences at Arizona State University, and an Affiliate in the Center for Social Dynamics and Complexity. Torrens leads a research group focused on the cutting edge of GI Science, working on developing advanced methodologies for modeling and simulating complex, dynamic, adaptive, and highly interactive systems and phenomena. Methodologically, our interests lie at the intersection of automata modeling (agent-based models, multi-agent systems, finite state machines, cellular automata), geocomputation, artificial intelligence, object-oriented programming, animation, and visualization. The primary substantive foci are on urban systems and urban dynamics: urban growth, suburban sprawl, residential relocation behavior, community dynamics, gentrification, property markets, civil violence, social and anti-social crowd behavior, and ubiquitous computation. These topics are the subject of a recent book published with John Wiley & Sons, *Geosimulation: Automata-Based Modeling of Urban Phenomena* (2004).

The importance of simulation to the geographical sciences and GI Science

Much of my work is centered on and around spatial modeling and simulation, which I regard as fundamental to the geographical sciences, as well as being central to advancing Geographic Information Science.

Statements to the effect of, “The best way to understand a phenomenon is to mimic, replicate, reproduce, model it” have been echoed across disciplines, and the geographical sciences are no exception to that mantra. Models and simulation remain the best way to explore, query, and observe (albeit in a counterfeit manner) things that are simply inaccessible in the real world, because of the time-scales involved, the spatial scales and ranges, because of their hazardous nature, or because of the social and economic repercussions of interfering with them. Models serve as artificial laboratories in this sense, allowing us to test theories, plans, and policies regarding systems that we could never experiment with on the ground. They serve other uses as media for forecasts, hindcasts, and what-if analysis for the purposes of rehearsing and giving life to alternative scenarios.

Spatial simulations are also beginning to take on a significant disciplinary role in the geographical sciences. Geographers have never been shy to borrow methods from other fields: statistical mechanics, physics, computer science, philosophy, economics, and so on. There has been somewhat of a reversal, however, in recent years. There has been an infusion of space into the social sciences in particular, with geography taking center stage in an emerging specialization around computational social science (Ball 2004; Epstein 1999; Epstein & Axtell 1996; Gimblett 2002), much of it using spatial simulation as a conduit.

Spatial simulation is also important to Geographic Information Science. Indeed, it pushes and prods us to work at the current limitations of GI Science (Albrecht 2005; Longley 2004).

Geosimulation

There is a general problem with the traditional stock of spatial models: the tools dictate the questions that may be asked with them, rather than the tool being built to satisfy our most burning questions. The cadre of models available in human geography is largely designed to represent exchange of goods, population, and jobs between coarsely-represented divisions of space over comparative snapshots of time. This is largely out-of-touch with the substantive needs of the field and the reality of phenomena on the ground, which are made-up of massive volumes of entities, driven at their own atomic spatio-temporal scales, connected and interacting dynamically in a range of "spaces" that might be simultaneously economic, social, psychological, environmental, biological, and so forth.

Geography has firm needs of models. A varied ontology of entities is required that can flexibly capture entities based on their appearance in space-time and their use of space-time. Extensible expression of spatial relationships is also needed, accommodating diversity in representation of spatial and temporal interaction. Models should be comfortable handling processes as well as patterns, interchangeably. These process models should be capable of determining entity state change as their location changes and their interactions change in space and time.

Geosimulation has emerged as a trend in spatial simulation, focused on tackling the inherent complexity of geographical phenomena with focus on entity representation, entity behavior, entity interaction in space and time, and entity dynamics and evolution (Benenson & Torrens 2004b; Benenson & Torrens 2004a). Automata (cellular automata, agent automata, multi-agent systems, finite state machines) are frequently used in these endeavors. They have a great deal of flexibility in representing spatial relationships. Automata models can be run with spatially–non-modifiable units; geographers can simulate a wide variety of spatial entities. Automata models also afford a broad treatment of spatial relationships. Time is handled flexibly and can be specified in packets of change or with true dynamic evolution. There is also a shift in the philosophy adopted under geosimulation, a move from thinking of models as predictive tools to simulation as theory- and scenario-building.

Geographic Automata Systems

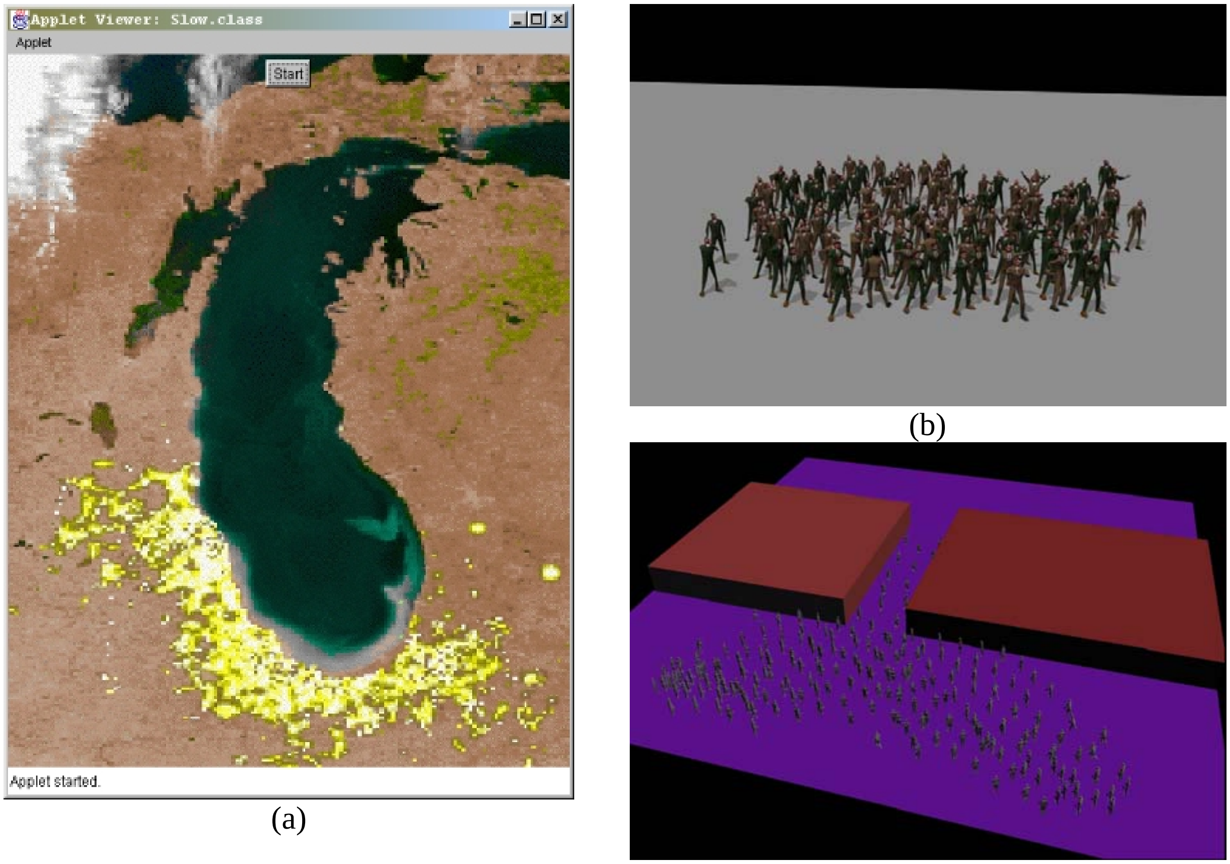
While often loose-coupled to Geographic Information Systems generally, and spatial databases specifically, automata models used in the geographical sciences have been developed at somewhat of a distance from GI Science. We have developed Geographic Automata Systems (GAS) as a seamless bridge between the two (Torrens & Benenson 2005). The general idea, with GAS, is to strip the automata concept down to it s basic principles, and to re-build within GI Science, with the range of questions that need to be asked in the geographical sciences as a guide. Objects and entities are conceptualized as GA with focus on their spatio-temporal representation, properties, processes, and behaviors. Geographical phenomena are treated as ensembles/systems of interaction GA.

We add some functionality to the basic automata skeleton to achieve this. Basic computational automata contain states and transition rules; cellular automata add cells as a bounding mechanism (and neighborhoods as watersheds for information input), with systems of cells forming a lattice arrangement. We add a strict ontology of automata types based on fixture in space and time. Neighborhood transition rules are introduced, such that neighborhoods need no longer be symmetrical or statically-defined. Flexible location conventions are employed, enabling direct and relative positioning of entities relative to other entities in space and time. A specific movement rule mechanism is also added to drive transition of entities through locations in space and space-time. Exploration of geographical systems with GAS then becomes a matter of quantitative and/or qualitative investigation of the *space-time behavior of modeled entities*, given these components (Benenson & Torrens 2005).

Studying urban dynamics with Geographic Automata Systems

We have set about to apply GAS to the study of complex and highly-dynamic urban phenomena. Thus far, we have developed models of urban growth (Torrens 2003), suburban sprawl (Torrens 2006b) (Figure 1(a)), residential mobility behavior (Torrens 2006a), and gentrification (Torrens & Nara 2006). We are also working on modeling very micro-scale dynamics of human movement (Torrens 2005) and social and anti-social crowd behavior (Figure 1(b, c)).

Visualization has grown increasingly fundamental to the design of simulation experiments with these models, for sweeping the parameter-space of what are often intricately detailed and terrifically complicated models and for conveying output to those interested in using the models as tools to theorize with.



(a)

(b)

(c)

Figure 1. (a) A model of suburban sprawl over the Midwestern Megalopolis, from 1800 to present day. (b) A model of mob behavior. (c) A model of crowd evacuation under panic scenarios.

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