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Let's talk objects: generic methodology for urban high-resolution simulation

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"Much of the behavior of systems rests on relationships and interactions", Jay W. Forrester (1969). Urban Dynamics. Cambridge, MIT Press, p. 114.

Abstract

An object-based approach to portraying urban systems, based on the priority of spatial relationships, is proposed. Real-world entities are represented by means of unitary fixed and non-fixed objects. Fixed unitary objects are located directly, by coordinates, while non-fixed unitary objects are located by pointing to fixed objects. Self-organizing spatial ensembles of unitary urban objects are represented by means of emerging domain objects. Software objects represent unitary objects and domains as well as the relationships between them. The user is responsible for formulating rules of object creation, updating, and destruction, while the system automatically updates relationships following movements of non-fixed objects, domain self-organization, change, and destruction. A prototype software system for simulating housing dynamics is presented.

Keywords: Urban modeling; Modeling software; GIS; Cellular automata; Multi-agent systems; Object-oriented programming; Entity-relationship data model

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1. Urban modeling: from regions to cells and agents and further to objects

During the first two decades of their development (1960s–1980s), urban modeling and simulation were almost exclusively based on flat partitions of urban space into regions that served as aggregates for lands, population, jobs, and transportation (Allen & Sanglier, 1979). Regional models concentrated on the redistribution of population and resources; their dynamics were represented by non-linear differential or difference equations formulated in terms of region state variables—population size, jobs, etc. Although providing a basic outline of urban dynamics, reconsideration of these models raises fundamental reservations regarding the adequacy of the aggregate view of the city (Lee, 1973, 1994). Recent intensive development of Cellular Automata (CA) models of urban land use dynamics can be considered a reaction to this dissatisfaction (Torrens, 2000). The idea behind CA is to approach high-resolution partitioning of urban space as a regular grid of internally homogeneous cells, each uniquely characterized by its states, where the future state of a cell depends on its current state and the states of its neighbors (Phipps, 1989; Tobler, 1979). The analogy between cells and states on the one hand and land parcels and land uses on the other provides a salient incentive for CA land-use models (White & Engelen, 1997).

To overcome the weakness of aggregation, regions in regional models are characterized by as many properties as possible. They consequently demand weighty data support and lengthy periods of calibration (Benenson, 1999). In contrast, CA models employ few cell states only, base on simple local relationships, and demand a handful number of parameters for plausible imitations of urban reality. Recent trends strongly favor CA modeling for theoretical and applied simulations alike (Batty, 1997; Torrens & O'Sullivan, 2001; White & Engelen, 2000), accompanied by new approaches to parameter estimation and calibration (Clarke, Hoppen, & Gaydos, 1997).

Urban CA models have one evident and principal limitation: the *immobility of cells*. Housing and transport dynamics are ready examples of the necessity for *mobile* or, more generally, *non-fixed* entities in urban models. Non-fixed units are obliged to make decisions regarding their location (in the broadest sense) and relocation. In an urban milieu, all these entities—landowners, householders, firms, pedestrians and cars make location and relocation decisions autonomously or semi-autonomously. Hence, they are all considered as *agents* and their dynamics are consequently studied with Multi-Agent Systems (MAS) (Ferber, 1999). Geographic MAS agents are automata just as are CA cells; the specificity of *geographic* agents is their location. To simulate a geographic agent, its state should include location information whereas automation rules should include a description of the agent's relocation.

Urban systems contain fixed and non-fixed entities. The fusion of CA and MAS approaches is therefore a natural further step in urban high-resolution modeling. Recent urban models of this kind have usually been based on cellular automata, populated by agents migrating between cells (Portugali, 2000; Portugali, Benenson, & Omer, 1994, 1997). This view is evidently constrained: their basis, a regular grid of cells, does not allow for direct representation of infrastructure entities and agents