

Chapter VII

Simulating Urban Dynamics Using Cellular Automata

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ABSTRACT

This chapter introduces the concepts of cellular automata (CA) which have been increasingly used for simulating urban dynamics. Simulation and prediction of urban evolution can provide the useful inputs to crime models. However, calibration of urban cellular automata is crucial for simulating realistic cities. Simulation of multiple land use changes using CA is difficult because numerous spatial variables and parameters have to be utilized. The incorporation of neural networks with CA can alleviate the calibration problems. This chapter illustrates how complex land use dynamics can be simulated by the integration of CA and neural networks.

INTRODUCTION

Urban environments have great effects on the distribution of crimes in cities. The simulation and prediction can provide useful information for crime analysis. Urban dynamics is a complex system with open, nonlinear, and uncertain features. The common “top-down” approaches using mathematical equations are considered to be inappropriate in simulating complex urban systems because these approaches cannot capture complex local interactions (Batty, & Xie, 1994). In recent years, there are increasing studies on

the development of geographical cellular automata (CA) for simulating complex systems. CA have been applied to the simulation of wildfire propagation (Clarke, Brass, & Riggan, 1994), population dynamics (Coclelis, 1988), and urban evolution and land use changes (Batty, & Xie, 1994; White, & Engelen, 1993).

Cellular automata (CA) were developed by Ulam in the 1940's and soon used by Von Neumann to investigate the logical nature of self-reproducible systems (White, & Engelen, 1993). However, CA has great potentials in simulating urban growth and exploring alternative development forms by

using predefined rules. In the last two decades, a set of urban models based on CA techniques were reported with interesting outcomes, such as simulating emerging phenomena and fractal properties of cities (Batty, & Xie, 1994; Batty, & Xie, 1997; Couclelis, 1997; Deadman, Brown, & Gimblett, 1993; Li, & Yeh, 2000; White, & Engelen, 1997; Wu, & Webster, 1998).

Urban CA models differ from the typical CA models to a great extent as described by Wolfram (1984). Some of the strict conditions attached to conventional CA models have to be relaxed to meet the specific requirements of urban simulation. For example, typical CA models have a very limited total number of cells and a small number of temporal iterations (Batty, & Xie, 1994; Wu, & Webster, 1998). Urban CA models involve the use of a large number of cells and iterations. Urban CA models adopt heterogeneous cellular space which is different from that of conventional CA models. There are significant differences between urban CA models and other conventional CA models that have been developed for physics, artificial life, chemistry and biology.

Actually, Hägerstrand's model (1967) could be regarded as an early CA-like model for geography because he used neighborhood effects. Hägerstrand developed diffusion models through "Monte Carlo" simulation techniques. His models were specifically for human migration based on historical population records by using action-at-distance through gravitation effects. It relied on microscopic behavior to describe macroscopic behavior of the system by using simple predefined rules.

Tobler (1979) was perhaps the first to recognize the advantage of CA models in solving geographical problems (White, & Engelen, 1993). In his cellular space model, the state of a cell is determined by the states of a set of "neighbor" cells according to some uniform location-independent rules. The basic principle of such type of models is to use a cell-space representation to realize spatial dynamics.

Couclelis (1985, 1988, 1989) subsequently carried out some pioneering researches on urban simulation using cellular automata. Her studies attempted to explore the links with the theory of complex systems, and examine the possible uses in an urban planning context (White, & Engelen, 1993). She demonstrated that the perplexing dynamics of vole behavior could be simply explained by using CA models (Couclelis, 1988). She showed that CA might be used as an analog or metaphor to study how different varieties of urban dynamics might arise.

Batty and his colleagues (Batty, & Xie, 1994; Batty, & Xie, 1997; Batty, Xie, & Sun, 1999) have also carried out interesting researches on urban CA models. In their early studies (Batty, Longley, & Fotheringham, 1989), a closely related technique, diffusion limited aggregation (DLA) was used to model the growth of built-up areas. DLA models can generate complex forms by using a simple process like CA models. They also develop a general class of CA models which emerged through insights originating in computation and biology (Batty, & Xie, 1994). Their models are very similar to the *Game of Life* (Martin, 1970) because each cell can only take on one of two states (dead or alive). However, these models have different features in three ways. First, they are nondeterministic because births and deaths at time t are computed stochastically. Second, a system-wide survival rate is used to control the whole pattern—actual survival rate. Third, a threefold hierarchy of neighborhood is used to decide an actual birth locally. The simulation demonstrates that microprocesses can lead to aggregate development patterns.

CA models can be used for testing hypotheses, simulating urban forms and dynamics, and generating alternative land use plans. However, most of CA models to date have been developed for hypothetical applications (Couclelis, 1997; Batty et al., 1999). They have been focused on testing ideas without providing enough details for realistic representation (White et al., 1997). Most

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