Integrated Dynamic Urban Evolution Modeling

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Biography

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Introduction

Urban areas have long been recognized as having nonlinear, dynamic properties (Crosby, 1983). Capturing the dynamics of complex urban areas, however, is one of the most delicate problems in landscape modeling. Only very recently have the conceptual and mathematical foundations of substantive inquiry into urban dynamics been made possible due to the growing understanding of open systems structures and human decision processes. The applications of systems theory to dynamic urban systems was made possible largely by the work of Nobel Laureate Ilya Prigogine and his dissipative structures theory (Nicholas and Prigogine 1977, Prigogine, Allen and Herman 1977, Allen 1980). Prigogine postulated that the flow of energy and matter into open chemical systems resulted in a continuous process of spontaneous self-organization. This self-organization is characterized by a series of structural configurations called "dissipative structures". Peter Allen applied this physical analogy to urban planning to conceptualize two types of urban states: stable and unstable, or, in other words, organization and reorganization (Allen et al, 1978, 1979; Allen 1982). This work has provided the basis for developing such new conceptual tools as Agent Based Modeling (Holland 1975) and Cellular Automata, in what has become known as Complex Systems Science. The latter approach, Cellular Automata (CA) has recently been identified as the basis for taking a new look at a wide range of applications to scientific inquiry (Wolfram 2002).

Despite the emergence of CA as a powerful simulation tool in urban dynamics studies, most CA-based research focuses on physical processes of urban systems and simulates land use changes through rules acting upon immediate neighboring cells (Batty 1998, Batty *et al.* 1999, Bell *et al*. 2000, Clarke and Gaydos 1998, Li and Yeh 2000, White and Engelen 1993, Wu and Webster 1998, Wu 2002, Xie 1996). Though many innovative ideas (such as generic algorithm and standard software approach, neural network method for determining parameters, and stochastic calibration) were successfully developed, these CA models are essentially heuristic and simplistic.

There are several profound challenges to CA-based urban simulation models. Urban systems incorporate both physical and socioeconomic processes that interact with each other and their surroundings in complex, non-linear, and often surprising ways. The physical or socioeconomic processes have subsystem elements that, in turn, may be complex and operate in different ways in precisely the same geographical space. Different urban elements are working in different ways to contribute to the emergent properties of the entire system (Wilson 2000, Kivell 1993). Each component of a complex urban system may itself be complex. However, current CA urban models are to large degree limited to physical processes and land development in particular.

Secondly, a cell is usually defined as a basic unit of land development characterized by a binary state of developed or undeveloped, or by a type of land use in multiple land uses simulations. This basic land unit does not carry attributions, such as, the number of people or households that reside on it, the behavior of its residents, the value of property or rent, the amenity of surrounding community, or environment, etc. The exclusion of socioeconomic features of land is a serious limitation to realistic application or adoption of CA models in urban and regional planning or decision-making.

Thirdly, it is difficult to establish the compatibility of a cell with an urban entity in reality. Despite increasingly higher resolutions or finer cell sizes adopted in CA models because of advancement of computing power, the pixel-based cellular dynamics are seldom matching with area-based socioeconomic phenomena. The scales and longitudinal changes of socioeconomic geography further complicate the calibration and validation of CA models.

Research Design

This research develops a new urban simulation algorithm (IDUEM - Integrated Dynamic Urban Evolution Modeling) to forecast the location of population growth and housing development in edge cities. IDUEM builds a new generation of CA model coupling demographic movement with housing and residential land use development. The cellular automata in IDUEM are ***objects representing basic urban units***, which are characterized by two groups of properties. The physical properties are the characteristics of housing stock, land property value, land availability, environmental amenity, accessibility to development stimuli, and adjacency to existing development. The socioeconomic properties include the attributes of population, the number and size of households, age composition, economic situation, employment status, travel time to work, and recent changes of these demographic and socioeconomic characteristics. The socioeconomic subsystem interacts with the physical subsystem following the classic equilibrium of demand and supply. The socioeconomic subsystem takes into consideration of demographic and socioeconomic changes, predicts probable movement of people, and determines the demand for housing and land development. The physical subsystem simulates the supply of housing and probable location of future development based on land suitability. The IDUEM will be the first object-oriented CA model to investigate the interactions of two most important phenomena of urban growth, people’s movement and subsequent land development.

This research also develops a new generic object-oriented CA software to support the proposed study. The IDUEM software creates a CA simulation engine incorporating GIS functionality that delivers a seamless interface between data processing (including areal interpolation), CA modeling (including calibration and validation), spatial analysis, and visualization.

This paper will use City of Detroit, Michigan, USA as a case study to predict the location of population growth and housing development between 1985 and 2020, and to test the IDUEM algorithm.

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