Uncertainties In Urban Simulation Using Cellular Automata And Gis

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Introduction

Errors and uncertainties are important issues in GIS literature. Compared to traditional methods (e.g. manual overlay), GIS provide more powerful functions and accurate information based on computer technology. However, GIS are not free of errors and uncertainties because of human errors, technical limitations and complexity of nature. GIS databases are the approximations to real geographical variation with very limited exceptions (Goodchild et al., 1992). Understanding of errors and uncertainties of GIS is required for successful applications of GIS techniques. There are two main types of studies of errors - a) data source errors that exist in GIS databases and b) error propagation through the operation performed on the data by using GIS functions.

There is a growing trend to use cellular automata (CA) to study geographical phenomena. Cellular automata were originally developed for simulating complex systems in physics, chemistry and biology. Recently, a series of urban cellular automata have been developed for modeling complex urban systems with the integration of geographical information systems (GIS). The application of CA in urban modeling can give insights into a wide variety of urban phenomena. Urban CA models have better performance in simulating urban growth than conventional urban models because they are much simpler than complex mathematical equations, but produce results that are more meaningful and useful. Temporal and spatial complexities of urban systems can be well modeled by properly defining transition rules in CA models. CA simulation provides important information for understanding urban theories, such as the evolution of forms and structures.

An often neglected issue in urban CA models is their errors and uncertainties. The issue is important because a huge volume of geographical data is usually used in urban simulation, especially for modelling real cities. Spatial variables are usually retrieved from GIS and input to urban CA models. It is well known that most GIS data are affected by a series of errors. Like many GIS models, urban CA simulation is not without problems because of the inherent data errors and model uncertainties. These errors will propagate in CA simulation and affect the simulation results. There is a need to assess the influences of source data errors on CA simulation. Although there are many studies on errors in GIS data and error propagation in GIS overlay analysis, little research has been carried out to examine error propagation in CA simulation.

This paper discusses the issues of errors and uncertainties in urban CA models. There is a need to identify and assess the influences of different types of errors and uncertainties on different types of CA models. Some uncertainties may be necessary because they reflect the features of nature. Other uncertainties from human and model errors should be reduced as much as possible. There are generally three types of urban CA models. The first type of urban CA models is to test ideas and assumptions related to urban theories (Batty et al., 1999; Couclelis, 1997; Webster and Wu, 1999; Wu, 2000). There is not much concern about uncertainties since these models are not for real cities. The second type of urban CA models is to simulate real cities (Batty and Xie, 1994; Clarke and Gaydos, 1998; White et al., 1997; Wu and Webster, 1998). These models need to use many spatial data which are subject to a series of data errors. The third type is to use CA to develop normative planning models to simulate different urban forms based on planning objectives (Li and Yeh, 2000; Ward et al., 2000; Yeh and Li, 2001). A lot of environmental data may be used as constraints for the simulation. This type of CA models is also subject to errors and uncertainties of spatial variables. As the second and third types of CA models utilize a lot of GIS data to simulate real cities, errors and uncertainties are more important because they will affect the simulation accuracy and planning decisions.

Data Errors In Urban CA Models

Spatial modeling with GIS is an important topic in researches and applications in geography. It uses GIS powerful functions to simplify mathematical representation of reality. In recent years, a class of dynamic spatial modeling is developing very rapidly with the integration of cellular automata (CA) and GIS. CA are dynamic spatial models which have powerful capabilities in modeling complex systems in physics, chemistry, biology and geography. Particularly, CA and GIS have been used to simulate urban systems for testing urban theories (Webster and Wu, 1999) and formulating development plans for urban planning (Yeh and Li, 2001; Yeh and Li, 2002).

A major concern for urban CA models is their errors and uncertainties if they are applied to real cities. CA models for geography and urban simulation are significantly different from Wolfram's deterministic CA models (Wolfram, 1984; Wolfram, 1986). Wolfram's models have strict definitions and use very limited data. This allows CA models to produce stable outputs without any error and uncertainty. However, urban CA models usually need to input a large set of spatial data for realistic simulation. The outcome of CA models will be affected by a series of errors and uncertainties which come from data sources and GIS operations.

Model Uncertainties In Urban CA Modelling

The error problems of CA models are further exacerbated by taking into account model uncertainties. There are other types of errors which are not produced physically during the process of data capture. These errors come from models themselves due to poor human knowledge, complexity of nature and limitation of technology. In CA simulation, not only input errors propagate through the simulation process, but model errors as well. Like any computer models, CA models could disagree with reality even when the inputs were completely error-free. CA models are only approximation to reality. Most of the existing CA models are just loosely defined and a unique model does not exist. Various types of CA models have been proposed in accordance with the variance of individuals' perception and preference, and requirements of specific applications. Different results may be obtained among different models although the target to be simulated is the same.

A series of inherent model errors can be identified for CA models. They are related to the following aspects:

- Discrete entities in space and time;
- Neighborhood definitions (types and sizes);
- Model structures and transition rules;
- Parameter values;
- Stochastic variables

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