Embedding spatial agents into irregular cellular automata models of urban land use change to improve scenario exploration and decision making

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1. Introduction

Urban land use change is characterized by complex interactions at multiple levels of a system hierarchy. In this regard, the integration of complex systems theory and cellular automata (CA) techniques have been presented in the published literature as a means to describe and understand the complexity of urban land use change processes (Batty, 2005; Couclelis, 1985; White and Engelen, 2000). Some of the early research efforts in these areas examined model structures with key challenges being to make the CA models computationally feasible and to encode efficient cell transition rules. Conveniently, the existing raster based datasets were a perfect match for the grid structure of CA models and together they were easily integrated with the raster data format of geographic information systems (GIS). This technology integration allowed for more focused analysis of the processes of urban land use change. They are know to create short and long-term patterns that are difficult to quantify and predict because of spatiality, emergence, bifurcation and self-organisation properties among others. Explicit consideration of human behaviour, human-environment interactions and feedback mechanisms have led to the use of agent-based modelling (ABM) approaches to incorporate social dynamics into spatial models (Benenson, 1998; Brown et al., 2004; Parker et al., 2003). ABM uses a bottom-up approach where elements and dynamics at the level of individual and autonomous actors interact among themselves and with the surrounding environment.

Embedding AB and CA models offers distinct advantages for understanding land use change dynamics, including new opportunities for scenario exploration and policy making (Torrens, 2002). However, only a few studies to date have focused on applying these integrated complexity-based models to spatial planning (de Kok et al., 2001; Ligmann-Zielinska and Jankowski, 2007; Waddell, 2002) or decision making (Sengupta and Bennett 2003) contexts. The caution may very well be related to questions about the trade offs between increasing the theoretical sophistication of land use change models versus making them practical as spatial decision support tools.

The objective of this study is to improve the characterization of the urban land use change process by developing a CA model that operates at a finer spatial scales and using an irregular spatial structure. In addition, an integrated CA and AB model within a GIS framework will be developed and implemented as a spatial decision support system to investigate its utility to aid in scenario exploration, policy and decision making.

2. Irregular spatial structure and modelling

The use of a raster grid in CA or AB models assumes a homogeneous environment of regular spatial structure. This is inherited from existing remote sensing and GIS data sets and the relative easiness in performing the computational processing. However, the regular grid cannot precisely represent natural patches of urban land cover or administrative units even for extremely high spatial resolutions. As the spatial resolution increases the urban land-use landscape is best examined and represented with spatial subdivisions such as municipal boundaries, census tracts, postal code areas, cadastral units or individual land parcels. These can all be identified with irregular size and shape. From the planning perspective these spatial shapes coincide better with real world entities and are more understandable from the stakeholders or decision-makers perspective.

Resels were proposed by (Tobler, 1984) and combine elements of the vector and raster data representation. But because of their computationally intensive operations they are not yet fully implemented in GIS or modelling environments. Irregular spatial structure in modelling approaches were theorized (Couclelis 1985) and recently operationalized in a few CA and AB models (O'Sullivan, 2001; Stevens and Dragicevic in press).

The advantage of an irregular spatial structure is that it brings the urban model representation closer to reality. However, other difficulties are also imposed on the modelling procedures. For example, different administrative boundaries exist in the urban landscape for which census and socio-demographic data are collected. This brings into focus the challenges of the ecological fallacy and modifiable area unit problem. The areal discrepancies become even more complicated as the boundary of same administrative units is changed with time. The model design and calibration procedures however require at least two different time independent data inputs. Moreover, urban growth polices are usually top-down processes from federal, provincial or municipal levels but are implemented at micro scale and directly affect local communities or individual households.

3. Methods and results

This study addresses several issues related to irregular spatial structure and spatial scales in order to build a hybrid GIS-based CA-AB model of urban land-use change. The proposed model unfolds at two scales, local community and larger regional scales. At the local or micro scale the *iCity* model framework (Stevens and Dragicevc, in press) is used to address irregular spatial structure and is further extended to include more parameters such as population density, population growth rate, economic factors, housing and land prices, type of residential units and their densities. The agent component of the model incorporates stakeholder preferences from perspectives of municipal urban planner, individual household buyers and residential developers. The multiple census data sources are integrated across multiple years and boundaries using dasymetric interpolation. At a larger scale, interaction analysis is used to simulate regional dynamics and top-down implementation of the regional growth strategy plan. The modelling simulations scenarios are generated for cadastral, census and municipal spatial scales.

The study site chosen is the Greater Vancouver Regional District (GVRD), Canada known by dynamic urban growth and predicted high population increase in the near future. More particularly, smaller regional municipalities including the local communities at the rural-urban fringe of GVRD are targeted. They are known with large environmental

and social impacts associated with the conversion of forested lands and green spaces into residential areas as well as places where the housing is more affordable. As the residential developments are relatively rapid, issues of environmental concern are prevalent in these small neighbourhoods. The preliminary results are generated on empirical data. Further, the application of this model to real datasets serves as a potential test beds for exploring model outcomes, initiation of dialogues and dissemination of information on various land-use change scenarios and potential environmental impacts that can improve community awareness and shared urban decision-making.

This research work contributes to the field of spatial process modelling in the realm of geographic information science and geocomputation. With the increasing availability of geospatial data at multiple scales, improving computational processing power, and efficient techniques that facilitate the integration of CA and AB modelling it can be concluded that more studies are needed in this domain to validate the usefulness of models for real world situations involving spatial decision making and planning.

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