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Integrating macro and micro scale approaches in the agent-based modeling of residential dynamics

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ABSTRACT

With the advancement of computational modeling and simulation (M&S) methods as well as data collection technologies, urban dynamics modeling substantially improved over the last several decades. The complex urban dynamics processes are most effectively modeled not at the macro-scale, but following a bottom-up approach, by simulating the decisions of individual entities, or residents. Agent-based modeling (ABM) provides the key to a dynamic M&S framework that is able to integrate socioeconomic with environmental models, and to operate at both micro and macro geographical scales. In this study, a multi-agent system is proposed to simulate residential dynamics by considering spatiotemporal land use changes. In the proposed ABM, macro-scale land use change prediction is modeled by Artificial Neural Network (ANN) and deployed as the agent environment and micro-scale residential dynamics behaviors autonomously implemented by household agents. These two levels of simulation interacted and jointly promoted urbanization process in an urban area of Tehran city in Iran. The model simulates the behavior of individual households in finding ideal locations to dwell. The household agents are divided into three main groups based on their income rank and they are further classified into different categories based on a number of attributes. These attributes determine the households' preferences for finding new dwellings and change with time. The ABM environment is represented by a land-use map in which the properties of the land parcels change dynamically over the simulation time. The outputs of this model are a set of maps showing the pattern of different groups of households in the city. These patterns can be used by city planners to find optimum locations for building new residential units or adding new services to the city. The simulation results show that combining macro- and micro-level simulation can give full play to the potential of the ABM to understand the driving mechanism of urbanization and provide decision-making support for urban management.

1. Introduction

As the urban areas and population rapidly increases over the past century, the need to better understand urban areas grows has gained an urgent attention (Bakker et al., 2015; Huang et al., 2014; Valbuena et al., 2010). Urban growth or change is driven by the interaction in space and time between biophysical and human dimensions that produce different patterns (Wise et al., 2016; Huang et al., 2014; Tayyebi, 2013). Urban dynamics simulation as a field has developed in response to this need, utilizing new technologies to explore the complex interdependencies in urban system. Although there are a wide variety of approaches for modeling urban dynamics, the relevant models fall into two general categories: 'conventional' simulation methodologies that operate at macro- and meso-levels with a 'new wave' of geo-computation methodologies at a micro-scale (Bourguignon, 2001; Billari, 2015). In studying a complex urban dynamic system, considering both these simulation approaches in macro and micro-level is useful in understanding the behavior of residence. Urban regional land-use models with feedback from micro-level simulation using bottom-up learning strategies from the reactions with the small elements of the system such as human, household, vehicles and etc. can help address the challenges faced by traditional models. Moreover, the macro scale simulation models can be used as a reference model for micro-level simulation, calibrate them and evaluate them to generate reliable results.

Land use/land cover change (LUCC) results from the complex interaction of social, ecological and geophysical processes (Tayyebi et al., 2010). Exploring the urban dynamics is a necessary part of understanding the possible future impacts of humane environment interactions (Rounsevell et al., 2012). On the other hand, residential dynamics is the accumulative outcome of householders' choices (Bae et al., 2016; Benenson, 2004) and the models of residential dynamics try to simulate households' interactions and behaviors in finding optimum dwelling

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places considering their physical, social, and economic preferences (Huang et al., 2014; Torrens, 2007). These complex socio-economic processes are most effectively modeled using micro-level simulation with various parameters dynamically changing. In this context, both macro and micro-level strategies have to be developed in order to balance the interaction between humans and environment and at the same time to ensure a sustainable development of human societies and cities.

This paper describes a relatively new approach to urban simulation; it describes a hybrid geo-computation model designed to support the exploration of LUCC with particular emphasis on modeling residential location dynamics within the context of an interactive urban system. This hybrid approach fuses 'conventional' simulation methodologies for land use modeling with an ABM for simulation of households. In the proposed model, the motivation for the agents' movements is event-driven, *i.e,* the household moves whenever significant events (turning points) happen inside the family. Moreover, urban land use changes over time which is modeled by an ANN to predict agent's changing environment. The ANN algorithm is used as a tool to predict the land use change based on historical satellite images. Having urban land use change between 1980 and 2000 and assuming the existence of the same rate of urban change, urban land use of Tehran has been predicted for each year. The following factors were found to affect urban growth in different degrees: distance from road, built-up area, service center, green space, elevation and slope. To demonstrate some of the capabilities of such a hybrid method using multi-agent systems, a prototype of residential dynamics simulation is developed, fusing the micro- and macro-scales.

2. Literature review

In the past two decades, the urban growth modeling and simulation has been remarkably progressed due to the following reasons: 1) the advanced technologies in geospatial data production has made them accessible more frequently with the spatial resolution of centimeters, 2) computer hardware and software are substantially improved to process complex simulations and big data analyses in seconds, 3) advances in artificial intelligence, machine learning, and statistical modeling provide appropriate tools to study nonlinear patterns of data. However, understanding human behavior and residential dynamics are still under progress in the urban dynamics. This chapter summarizes the models that are being used to simulate urban and residential dynamic simulation (Fig. 1). These models categorized as conventional approaches which are widely used in the regional macro-level simulation, geo-computation approaches which are typically applied in bottom-up learning and micro-level simulation and hybrid methods which integrate both of them. Models have been summarized in this section with a brief description of their application.

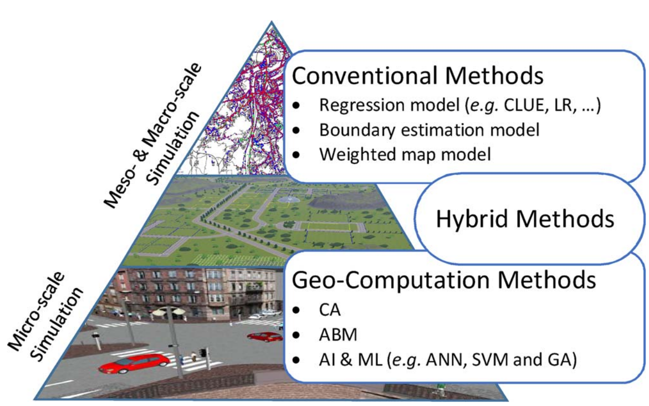

Fig. 1. Summarization of urban dynamic Modeling and Simulation methods.

2.1. Conventional methods

'Conventional' urban models, developed in the style of the spatial interaction of various variables using land transformation rules and statistics. The models use less computing power and basic units of the model are urban regions in the larger area. Flows of assets, including urban facilities, jobs, information, and population occur in these regions (Benenson, 1998). Averaging over these regions brings about the modifiable areal unit problem described by Openshaw (1984). Based on his opinion "The areal units (zonal objects) used in many geographical studies are arbitrary, modifiable, and subject to the whims and fancies of whoever is doing, or did, the aggregating." (Openshaw, 1984). Some researchers have tried to change the regional approach by introducing the new regional geography (Paasi, 1991). This involves a complex definition of regions and their interactions with other scales (MacLeod and Jones, 2001).

One of the most useful models in the conventional approach is regression to estimate the regional variables and transitions. Logistic Regression (LR) estimates the output of a utility function at time t_{n+1} based on the suitability values of its predictor variables at time t_n, while the output indicates change/non-change between t_n and t_{n+1} (He and Lo, 2007). The LR has a nonlinear form but can be transformed into a linear form with the simple transformation (Tayyebi, 2013). If one of the regression coefficient is zero, then the corresponding explanatory variable is not associated with the occurrence of the response. The Conversion of Land Use and its Effects modeling framework (CLUE) (Verburg et al., 1999) was originally developed to simulate LUCC. This model has been applied at the national scale for Ecuador, China, and Java, Indonesia. The second version of the model has been developed for the regional application (Verburg and Veldkamp, 2004). A statistical approach (*e.g.* LR) is usually used to quantify the relations between LUCC locations and a set of independent drivers. To run the model, it is minimally needed to have data for at least one time; however, to validate the model, it is necessary to have a spatiotemporal dataset. Another category of methods to predict urban dynamic patterns using a series of if-then-else rules is Classification and Regression Tree (Tayyebi, 2013). The location of the nodes in the decision tree at the hierarchical level shows the contribution of each variable. The nodes at the top/bottom have higher/lower contribution for modeling. Multivariate adaptive regression splines (MARS), which is a regression model, generalize the recursive partitioning approach with more flexibility and capture interactions (Friedman, 1991). MARS splits the data into sub-regions using different knots, where the coefficients can change (Tayyebi, 2013) and uses basis functions to automatically find the relationship between the inputs and outputs (Friedman, 1991).

Weighted-Map Models are evaluated in various research works to select spatial drivers and integrate them using weighted linear combination (Wu, 1998; Saeedi et al., 2008). They can find a set of influential criteria and combine them using multi-criteria decision making techniques. Multi-criteria decision making can consider drivers such as proximity, accessibility and environmental protection. In this category of multi-criteria decision rules, Geomod is used for raster-based LUCC spatial-temporal model (Pontius et al., 2001). This model has been applied at the continental scale (Africa, Asia and Latin America), country scale (Costa Rica and India), and at the local scale (India, Egypt, United States and several countries in Latin America. Urban growth boundary (UGB) models are another class of land change models that simulate urban boundary locations and configurations; so, development proceeds only within these designated zones. Two rule-based spatial-temporal models, one which employs a distance dependent method and the other a distance independent method, were used to simulate UGBs (Tayyebi, 2013).

2.2. Geo-computation methods

Geo-computation is able to show urban systems in a more realistic

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