Computer simulation of urban land use growth: a spatial Genetic Algorithm method

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Abstract

Cities are the engines of creativity, wealth creation and economic growth in our society during the last few decades. The understanding of city land use growth is very important for urban planning and city management. Dynamic simulation modelling, such as Cellular Automata and Agent-based Modelling have been widely used to delineate the process of urban land use expansion. In addition to a large number of widely used models, this research proposes an agent-based and spatial Genetic Algorithm method coupled model to simulate the multi-objective land use development processes of a city. In the model, citizens' household location-allocation strategies trigger the need of urban land development. At the same time, local governments try to cater those needs while minimizing prime agricultural land conversion, infrastructure construction cost, and maintaining an amount of land sales revenue. The model is implemented in Jiading District of Shanghai, China. Historical population and urban land use data are used to verify and generate alternative development strategies. The expected results of this research include model comparison and land use policy analysis.

Background and Relevance

Simply, urban growth is the increase of urban population and urban land-use demand. The growth of urban drives the spatial urbanization process and evolution of social and economic status of a city (Black and Henderson 1999). With the inevitable cycles of prosperity and decline, the urban land-use of a city continue to evolve. Contemporary cities around the world are results of the ongoing growth and evolutionary dynamics.

Dynamic simulation models are good at delineating the process of structure evolution (Batty 1971). From the middle of 20th century, with the rapid development of computer science technology, researchers started to do a lot of experimental research on urban simulation. However, those research were either "too simple" or "not simple enough" (Batty 2013). At the same time, complexity theory and system thinking started to catch researchers' attention with the fast expansion of interdisciplinary research. The research of complex systems are frequently instrumented by spatial simulation modeling techniques, like Cellular Automata (CA) and Agent-based Modeling (ABM). The advantages of adopting those methods exist at their abilities to incorporate nonlinear, unorganized processes, cross-scale environment that can exhibit emergent properties, dynamic local interactions with spatial references, and indirect impacts and pattern-process linkages (Parker, Manson et al. 2003).

Generally, two different approaches of CA and ABM have been widely used to simulate the dynamic processes of urban growth and evolution by far: designed and analyzed (or generative and fitted) (Couclelis 2001). Designed models mainly focus on the intrinsic metaphors of urban growth. This group of research (White and Engelen 1993, Batty and Xie 1994, Clarke, Hoppen et al. 1997, Clarke and Gaydos 1998) adhere to bottom-up theory and regard the suitability of land determines the growth and evolution of urban land use. For example: In 2005, Dietzel, Herold et al. (2005) built a CA model on the basis of Clarke's work to test the diffusion and coalescence theory of urban land use development. Sasaki and Box (Sasaki and Box 2003) built an agent-based model to verify Thünen's location theory. Filatova, Parker et al. (2009) built a bilateral agent-based land market model on the land-market and land price theory to test Alonso's model. Analyzed models build model rules according to observed urban land-use development behaviors. For example, some of the research (Wu 1998, Li and Yeh 2000, Wu 2002, Yeh and Li 2002) take internal city administrative policies and external social-economic environment influences as very important roles that determine land use growth and evolution of a city. White, Uljee et al. (2012) used historical (1990-2000) population and land-use data to calibrate corresponding parameters to evaluate neighborhood influence on central cell during the simulation of Greater Dublin Region of Ireland. Deadman, Robinson et al. (2004) built a colonist household decision-making and land-use change model to explore the development of Amazon rainforest.

In addition to these two approaches, land use optimization method is attracting more and more attention (Cao, Batty et al. 2011, Cao, Huang et al. 2012, Liu, Tang et al. 2015, Tan, Liu et al. 2015). The method sits on the classic land-use location-allocation theory, using multi-criteria optimization methods to allocate land quotation to specific units on a region, city, or neighborhood scale. This method has demonstrated its advantage in city land use strategic planning with multiple optimization goals (Liu, Yuan et al. 2014, Yuan, Liu et al. 2014).

Methods and Data

This research proposes a new computer simulation model that couples Agent-based Modeling and Spatial Genetic Algorithm optimization method (Figure 1). In the model, citizen agents make their location and allocation decisions based on their social-economic statuses. This will lead to the shift of social, economic, and environment status of communities and urban region. Government agents will make development strategies and policies to balance citizens' need and local sustainable development goals based on the social, economic, and environment status of the region. Then the development strategies are paraphrased into objective functions that need to use optimization methods to solve. Spatial Genetic Algorithm is used to optimize those development strategies spatially, which determine the development or redevelopment of city land use.

The model is built on one of the popular simulation platforms, Netlogo. Statistic software R is embedded for optimization processes and simulation results output. The study area of this research is selected as Jiading District, Shanghai, China. As one of the 17 county-level sub-districts, Jiading has undergone rocket-like urbanization process during the last two decades. The urbanized area of the district almost tripled since 1990. The study of this area can help us understand the development process of the city during the last two decades. In the research, detailed community-level population statistics (2000 and 2010) data are used to project and model population's (household) location-allocation activates. The historical urban land use data of the study area, which come from time series remote sensing data interpretation and urban land use survey, are used to calibrate, test and validate the developed model.

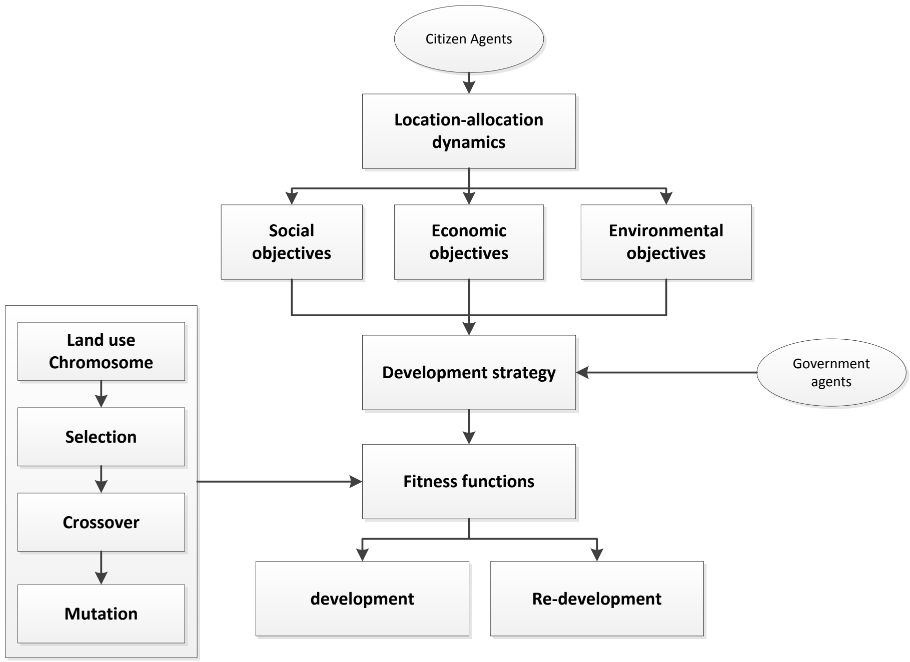

Figure 1 Model framework.

Results

Due to this is still an on-going research. The expected results of this research include model implementation analysis and model comparison analysis. The research is going to use historical urban detail land use planning data (urban detail plans of Jiading District from 2000 to 2010), which include development and re-development planning, to verify the simulation results. Alternative urban development strategies will be simulated and several urban development policies will be tested and proposed.

Conclusions

This study has proposed a new urban land-use growth and evolution simulating model that couples Agent-based Modeling method and Spatial Genetic Algorithm. The model is implemented in Jiading District of Shanghai, China. The model will be verified and implemented with the historical urban detail planning data and government administration policies.

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