Simulation of Urban Land Development Based on Multi-agent System and GIS Technology

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Abstract. MAS(Multi-agent System) is a new modeling method developed in recent years. This article aims to use MAS technology to simulate the development process of urban land. Five factors, which may have impact on the choices of agents, are defined. Spatial analysis and multi-factor evaluation technique is employed to determine the weights and utility value for each factors. On the basis of an MAS platform named RePast, combining with other open source GIS component, the model proposed is implemented through second development using Java language. Finally, the status quo of Wuhan City in 2003 as initial value, future land-use changes are simulated. The result of primary experiment seems promising, and the outcome of model simulation is interpretable and reasonable. So we can conclude that MAS can be used to simulate urban land development, and the simulation results will provide decision basis for urban managers.

Keywords: urban land development, multi-agent system, GIS.

1 Introduction

Multi-agent system (MAS) is a modeling and simulation technology developed in the recent years on the basis of artificial intelligence and the theory of complex adaptive system (CAS). The CAS is a theory proposed by the computer scientist John H. Holland in 1994. Inspired by biological science, its fundamental concept is the agent. An agent is proactive, adaptive, and in mutual interaction with its environment, which differentiates it from the elements or subsystems in traditional models. The theory immediately attracted attention and responses from a wide range of researchers, and was soon employed by economists in the observation and study of economic systems. The most prominent example of such an application is the Aspen system developed by Sandia National Laboratories, an agent-based macroeconomic model of the United States [1]. The system modeled the relations and interactions of tens of thousands of agents encompassing the companies, the banks and the state, and simulated the development path of the entire American economy. The fact that realistic phenomena, such as the cycles and fluctuations of economic growth, have been observed in its simulation, have garnered worldwide interest. To researchers of geography and urban

F. Bian and Y. Xie (Eds.): GRMSE 2014, CCIS 482, pp. 724–731, 2015.

planning, the breakthrough in both theory and modeling methodology brought on by MAS has ensured its place as an important approach to urban simulation after the cellular automata method [2-8].

This paper is aimed at the dynamic simulation of urban land development based on MAS and GIS technology.

2 Theoretical Model

2.1 Defining the Agents

The dynamic agents that influence China's urban land development have been categorized as the following:

① .the government; ② .owners of collective-owned land; ③ . real estate developers; ④. industrial entrepreneurs; ⑤. commercial entrepreneurs; ⑥.urban residents; ⑦. urban planners.

2.2 Environment of the Model

The environment of the agents is defined by three elements: point, line and area. The point refers to the nodal points of the city network, which are generally large centers of commerce or major transportation hub in the city. Since the connections between the nodes form the main development axis of a city, the relative location of a given land to the nodes is an important factor in its development. The line refers to the roads and other traffic routes of the city. Obviously, the main traffic routes have a significant effect on the development of surrounding areas, and the development potential of a land depends heavily on its accessibility. The area refers to the attributes of the lands neighboring a land in particular, and to the conditions and attributes of the location of the land in general.

In the model, the nodal points, the traffic routes, and the land blocks are represented using the entity types of point, line and area respectively. An agent-based model (MAS) system was utilized for the construction and running of the agents. The GIS and the MAS are integrated through a loose coupling, where data are shared using files.

2.3 Socioeconomic Analysis of the Model

From the perspective of urban spatial structure and urban economic system analysis, the evolution of the model should be guided by two principles, namely the competition and symbiosis of agents [9][10]. As the spatial structure of the city changes due to the effects of both competition and symbiosis, the usage of urban land would also change.

The principle of competition represents the natural selection in the urban economic system, which results in the replacement and change the function of urban land. In the process of urban development, with the rising land value at city center and improving living standard of its residents, continuing industrial development in city center becomes unfeasible in terms of both economic and environmental benefits, meaning the manufacturing industries would gradually move out of the center. This is why many Chinese cities have employed a development policy of “exiting the secondary, entering the tertiary”. That is to say, the industries of the secondary sector are moved out from within the city limits, replaced by the services of the tertiary sector, with the effects of reducing pollution, protecting the environment, increasing the efficiency of the businesses, and improving urban land use. The economic basis for the removal and replacement of industries in city center is the difference in profit per unit area between industrial and commercial land. Running a commercial business in city center would gain location benefits: first, it reduces the consumers’ travel distance and traffic costs; second, it allows the largest coverage area for commerce, meaning the highest turnover; additionally, the overlap of commerce and other tertiary sector businesses is more attractive than a single type of business, which would also increase the revenue; lastly, commerce and other tertiary sector businesses make better use of the vertical space, which would both increase the effective area of business and decrease the land cost.

In addition to competition, symbiosis, or harmony or cooperation is another important type of relation between agents. As Gu Chaolin observed [9], aggregation and dispersion can serve as a basic framework of system dynamics for the distribution of population within in the urban spatial structure. Aggregation creates an economy of scale, as the proximity of various businesses in the city both reduces the costs of investment and strengthens the social communication between businesses, allowing the creation of many institutions of commerce, finance, research and education which provide a good environment for businesses, and as a result create a great boost to social productivity.

In addition to the self-governed “adaptive” changes, human intervention and regulation are indispensable for urban land development. In the model, such regulation and control are represented collectively as urban administrators. Each group of the urban system seeks to maximize its own profit, but as the total amount of resources is limited, the urban system can only stay in a virtuous circle by maintaining some sort of dynamic balance. The administrators act as levers that balance the interests of all groups to maximize the total economic, social and environmental benefits of the city. In the model, the function of the land occupied by urban administrators is fixed and unchanging.

3 Implementation of the Model

The model was built in Java language using the Repast modeling toolkit [11], in combination with open-source GIS components, including functional components from Geotools and Java Topology Suite. The model consisted of three main modules: Agent, Main and GIS. Two main functions were implemented, on one hand the input, output, and basic management of spatial data, on the other hand the construction of agents, and simulation of the agents’ dynamic decision making processes. The Agent module is responsible for the simulation of the agents; the Main module is responsible for creating the model framework, and is also the external interface of the model; the GIS module manages the spatial information. Data is inputted in Esri’s “shapefile” format, and outputted in MapInfo’s MIF/MID file format.

3.1 Parameter Settings

(1) Designation of target set (estimated future function of the land):

$A=\{A_k\}$, k=1, 2, 3, 4, 5, 6, 7, 8

A_1 is residential, A_1=R;

A_2 is commercial and public services, A_2=C2;

A_3 is other public works, A_3=C;

A_4 is industrial, A_4=M;

A_5 is warehouse, A_5=W;

A_6 is green space, A_6=G;

A_7 is for other urban constructions, A_7=Z;

A_8 is land to be developed, A_8=E.

(2) The following parameters are defined:

I: Node, representing the relation between a land and urban nodal points, or the attraction from nodal points, with $0 \le Node \le 1$. The attraction is determined using IDW interpolation or buffers based on the spatial distribution of the tiered nodal points.

II: Traffic, representing the relation between a land and traffic routes, or the attraction from traffic routes, with $0 \le Traffic \le 1$. This is determined using buffers.

III: Grade, representing the grade of urban land development. There are 8 grades, represented by the numbers 1 to 8.

IV: Radius, representing the radius of a given land's neighbors.

V: XRate, representing the ratio of X-type land in the area centered around the given land, with the Radius as its radius, where X represents the function of land development. $0 \le XRate \le 1$.

The first 3 parameters are attributes of the land development, and inputted into the model as initial values. The 4th and 5th parameters are computed through running.

(3) The behavior rules of agents

I: The closer an agent is to a nodal point or a main traffic route, the more likely the land will be developed to commercial, with residential as the second highest possibility.

Nodal points and traffic routes exert a powerful draw upon the surrounding land development. They bring in the flows of population, materials and information to create the core of the city with the highest density and the most energy. These core zones would generally be composed of commerce, services and administration sectors, and provide various services for residents, businesses and institutions. The growth of manufacturing industries located in city center tends to be limited by their heavy pollution, obsolete manufacturing processes, or lack of space for further development. Therefore it is likely for them to move away from nodal points, with their land utilized for commerce, services or residence.

II: The land development tends to be the same function as surrounding lands.

The principles mentioned above mean that urban land development tend to form into homogenous zones. It can be seen through studying the spatial structure of cities over time that while the function and degrees of homogeneity differed for zones, and the degrees of homogeneity also differed for the same type of zones in different eras or stages of urban development, the zones have always tend to maintain their homogeneity and reject heterogeneity within themselves, creating continuous spatial strips that serve clearly different purposes from their neighbors.

III: The irreversibility of urban land development means different behavior rules for different types of agents, as shown in Table 1:

Table 1. Changes to agents

Agent Type	Possible States in the Next Moment
E	R, C2, C, M, W, Z, G
M	R, C2, C, M, Z, G
W	R, C2, C, W, Z, G
Z	R, C2, C, Z, G
R	R, C2, C, G
C	R, C2, C, G
C2	C2, G

A linearly weighted evaluation equation can be used:

$$p_i = \sum_{j=1}^{n} w_j l_{ij} (i = 1, 2, \ldots, m)$$

Where w_j is the weight for n parameters, and l_{ij} is the effect of the ith unit for the jth parameter.

The probabilities for an agent to switch types can be determined using the equation. Two methods can be used to determine its final state, either using the result with the greatest probability, or normalizing the probabilities for random determination. Through multiple tests, the former proved better than the latter method.

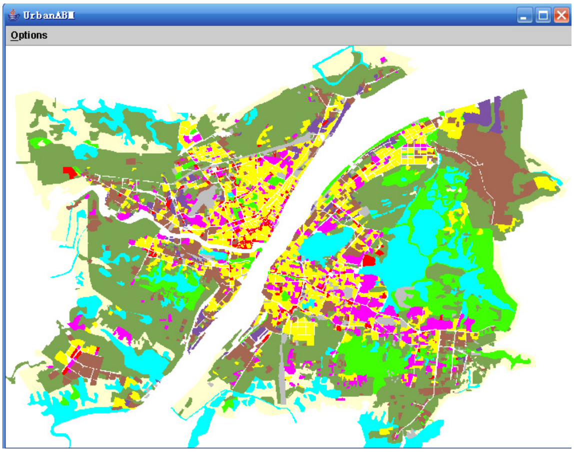

Fig. 1. Initial state of the model (t=0)

3.2 Simulation Experiment

The city of Wuhan was chosen as the experiment area. The land usage data of Wuhan in 2003 were used to simulate its future urban land development. Taking into account the general urban planning of Wuhan, the ratio of each type of land was controlled at:

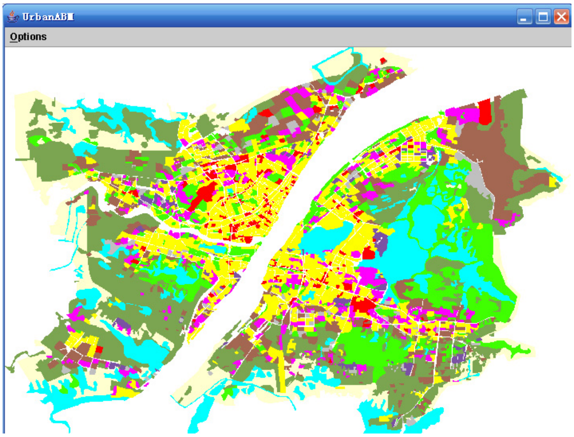

Fig. 2. State of the model at moment t

residential 30%, commerce and services 5%, other public works 9%, manufacturing industry 18%, storage 3%, greenery 31%, other urban constructions 4%. The results from the experiment using these values include an overly large greenery area, which is not realistic. Hence the ratio of green space was adjusted, resulting in the following ratios: residence 32%, commercial and public services 5%, other public works 11%, industrial 20%, warehouse 3%, green space 25%, other urban constructions 4%.

The future land development of Wuhan was simulated on the basis of these parameters:

3.3 Result Analysis

A land balance sheet can be obtained from the simulation results in Fig. 2:

Table 2. Land balance sheet

Type Code	Type Name	Present Area (m2)	Ratio
R	Residential	109,183,272	31.80%
C2	Commercial and Public services	17,273,953	5.03%
C	Other public works	37,861,824	11.03%
M	Industrial	69,115,838	20.13%
W	Warehouse	10,397,910	3.03%
Z	Other urban constructions	13,683,632	3.99%
G	Green space	85,789,264	24.99%
Total		343,305,693	100.00%

Result analysis:

It can be seen from the map that the manufacturing industries have mostly moved out of inner city, now concentrated at fridge areas, and the replacement of functions for land at city center has taken place. Other public works also tend to be concentrated at city fridge, which may be explained as certain administrative or education institutions moving out of city center. However, it is difficult to tell whether the over-concentration of residence land in inner city, and continuous commerce zones at fridge shown in the results would occur in the future. In overall, the results of the model are explainable, and prove to be of use for reference.

4 Conclusion

In this paper, a city model was constructed based on MAS technology and GIS technology, the model is used to simulate the evolution of urban land development. The following factors that affecting choice of agents is defined: the relation with nodal point, the relation with main traffic route, urban land level, the relation with its neighbors, etc. Spatial analysis and comprehensive evaluation method are used to quantitatively determine the weight and utility values of factors, which can determine behavior rules of agents. The model was built in Java language using the Repast modeling toolkit, in combination with open-source GIS components, including functional components from Geotools and Java Topology Suite. The city of Wuhan was chosen as the experiment area, the land usage data of Wuhan in 2003 were used to simulate its future urban land development. By preliminary tests, the results of the model are explainable, and the model proved to be of use for reference

Acknowledgments. This paper is based in part on work supported by the National Natural Science Foundation of China (50808089), National Social Science Fund (09BZZ045), National Natural Science Foundation of China (51278211).

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