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Multi-agent Model and its Applications in Urban Systems: A Review

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Abstract

This review introduces the background and definition of the Multi-agent Model and gives the definition and internal mechanism of Agent. The principle of Multi- agent Model is also introduced. It introduces two applications of Model, namely, the land use planning and the urban population distribution analysis. Different applications combined with the Multi-agent Model will have different algorithms and processes. In addition, the advantages and disadvantages of the model are also presented.

Keywords

Campus news management system; ThinkPHP; Key words.

1. Introduction

1.1. Background

Since the reform and opening up, urbanization in China has developed rapidly. According to statistics, the level of urbanization has increased from year to year with an average annual increase. With the improvement of urbanization level, important progress has been made in urban infrastructure construction. Urban public service facilities have been constantly improved, and the living standards and civilization of urban residents have improved significantly. However, rapid urbanization has also caused problems such as rapid expansion of land use, excessive energy consumption, and increased environmental pollution [1-4]. In order to solve these problems, it is imperative to carry out quantitative analysis and research on the urbanization process. As a computing platform, geographic information system (GIS) can not only complete the functions of spatial data input, storage, management, display and output, but more importantly have the function of spatial analysis, so it has been widely used in regional urban planning analysis. However, it lacks the ability of self-learning and cannot correct itself. With the multi-source, complex, comprehensive and intelligent requirements of urban planning and analysis applications, the lack of technology in process expression and spatial decision-making capabilities is becoming more and more manifested obviously [5-6]. Therefore, a new research system came into being.

Multi-agent system is a combination of Complex Adaptive System, Artificial Life and Distributed Artificial Intelligence. The multi-agent system has a "bottom-up" research idea, powerful complex computing functions and spatio-temporal dynamic characteristics, making it a very prominent advantage in simulating a complex system of urban space, and has produced many successful application cases [7-8]. By connecting the city planning participants with the environment through the agent, on the one hand, it can support the interactive behavior between the participants and between the participant and the environment, and effectively enhance the spatial decision behavior expression of the city planning participants. On the other hand, it can also better deal with the spatial conflicts between various actors involved in urban planning, so as to improve the scientific nature and rationality of urban planning results [9-10].

1.2. Description of the Mechanism

1.2.1 The Definition of the Agent

An agent can be defined as a mapping from a perceptual sequence to an intelligent mode of action. Suppose it is a set of sensations that the agent O can notice at any time, and is a set of possible actions that the agent can complete in the outside world. Then the function of agent f is: *O→A defines its agent behavior in all environments[11] . The basic function of an intelligent agent is to interact with the external environment, get information, process the information according to a certain technology, and then act on the environment. An agent can be viewed as a black box, sensing the environment through sensors and effecting the environment through effectors. Agent software uses string encoding as a perception and role. Most agents not only interact with the environment, but also process and interpret the received information to achieve their goals.

1.2.2 The Internal Mechanism of the Agent

1.2.2.1 Agent Learning and Adaptation

In agent-based modeling, how to construct the agent learning model, reflecting the agent knowledge acquisition ability and adaptability is an important issue. Researchers built many related models. Firstly, Genetic algorithms were developed in the late 1950s by Holland at Michegan university in the United States. Various variants or versions of a concept description correspond to individuals of a species. These concepts describe the mutation and reorganization of individuals after a certain goal. The function corresponds to the measurement of natural selection criteria to determine which is eliminated and which will exist [12]. The second is the Artificial Neural Network model, which is a learning method to modify the connection strength between neurons and even the structure of the neural network through sample training [13]. Finally, there is the reinforcement learning algorithm, which is a tentative learning scheme. If an action results in a satisfactory situation or improves the situation, the trend of the action will be reinforced and rewarded [14].

1.2.2.2 Agent Evaluation and Decision

The situation assessment in the process of agent cognition is the estimation of the current situation and the prediction of the future situation, including several important systems. The first is the blackboard system, in which the current state is broken down into different parts and added to the appropriate position on the blackboard [15]. With this information, the current situation can be analyzed and the future can be predicted. There is the expert system, which follows a "match – select-apply" loop. Finally, based on the utility theory, the utility value of its state is calculated by the utility function [16].

1.2.2.3 The Principle of Multi-agent Model

Although Agents have certain functions, for complex and large-scale problems in reality, it is often impossible for a single Agent to describe and solve them. Therefore, an application system often includes multiple Agents, and these Agents can cooperate with each other to achieve the common overall goal. Therefore, a multi-agent system is defined as a system composed of multiple Agent computing units that can interact with each other [17]. The Multi-agent system can construct a system model with complex system structure and function according to the

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system local details required by the research problem, the Agent reaction rules and various local behaviors. In a multi-agent system, the global behavior of individual behavior and interaction emerges in a nonlinear way. The combination of individual behaviors determines the global behavior, which in turn determines the environment in which individuals make decisions [18].

2. Applications of the Multi-agent Model -- Take Changsha City as an Example

2.1. Regional Analysis

Located in the central region of China, Changsha is the engine of economic take- off in the central region, and its GDP growth rate is as high as 12%. The current situation of Changsha city has formed an industrial layout based on construction machinery, automobile and parts, electronic information, new materials, food processing, Chinese patent medicine and biomedicine, as well as the home appliance industry. It will become the highland of economic globalization, the polar region of regionalization and the key place of urbanization in central and southern China [19]. The city of Changsha develops rapidly, and MAS model is used in different construction aspects. Therefore, Changsha city is selected as the research object in this review.

2.2. Land Use Apace Optimization

Under the dual pressure of tightening urban land resource supply and increasingly serious environmental pollution, the optimal allocation of space for urban land use is a basic way to alleviate the contradiction between urban land resource supply and demand, and is also an important content of urban planning. In order to achieve a certain optimal goal, the optimal allocation of urban land use space is based on the characteristics of the land, science, technology, and management methods, and the use of limited land resources in the region is arranged, designed, combined, and arranged at a spatial scale. The purpose is to improve land use efficiency and benefits [20-21].

2.2.1 Introduction of Model

The Multi-agent urban land use space optimization configuration model under the set goals and constraints, designed the Multi-agent Genetic Evolution Algorithm and Multi-agent particle swarm optimization algorithm applied to the urban land use space optimization configuration [22]. The basic idea of the model is to solve the problem of Multi-Objective urban land use space optimization allocation based on the ability of various actors participating in the urban land use space optimization configuration to perceive and react to the land use environment. In the model, Agent represents a behavior subject participating in the spatial decision-making of urban land use, and there is fierce competition and cooperation among agents. It is because each Agent uses inherent characteristics to interact with other agents in the neighborhood, and completes the population replacement of the Multi-agent system through the processes of crossover, mutation, death and self-learning, so as to realize the evolution of each generation and finally solve the problem of optimal allocation of multi-objective urban land use space [23].

2.2.2 Algorithm of Model

According to the characteristics of land use space decision-making, a four- element attribute group is used to describe the structure of Agent, and the formula is as follows:

$$\text{Agent}=<\text{Type, Decision Variables, Decision Parameters, Fitness}> \tag{1}$$

Among them, the type refers to various agents involved in urban land use spatial decision-making, such as residents, industrial enterprises, commercial enterprises, etc. The decision variables and decision parameters represent the decision factors selected by the agent in the process of land use spatial decision-making and the corresponding factors weight. Adaptability represents the adaptability of the agent in the land-use spatial decision-making process, and its height determines the competitiveness of agent in the decision-making process. The following is the formula related to the Model, which can calculate the Agent decision satisfaction in the land use grid and final fitness.

In the Multi-agent genetic and evolutionary algorithm for optimal allocation of land use space, the Fitness of intelligent agents is measured by comparing the Fitness of intelligent agents, and the Fitness of intelligent agents can be expressed by Fitness value, which can be obtained by the Fitness Function transformed from the objective Function. The ranking method is used to rank the pros and cons of different objective functions of all agents in the population, so as to calculate the total fitness. With the Z(i)(i=1,2,......,N) represents the target function, and N is the number of targets. For each target I, the intelligent agent X_j (j=1,2,......,N) will generate a collating sequence of feasible solutions according to the function value Hi (Xj) of the target. After sorting each target, the overall performance of the agent can be obtained. and the formula of Fitness is as follows:

$$F_i(X_j)\begin{cases}\left(N - Y_i(X_j)\right) & Y_i(X_j) > 1; \\ kN^2 & Y_i(X_j) = 1; \quad j = 1,2,\cdots,n \qquad (2) \\ Fit(X_j) = \sum_{i=1}^{n} F_i(X_j) & j = 1,2,\cdots,n \qquad (3)\end{cases}$$

Where, n is the total number of objective functions; N is the total number of agents; X_j is the jth agent of the population; Yi is the sequence number obtained after ranking the pros and cons of the targets among all agents in the population; $F(X_j)$ represents the fitness of X_j for the target group i, Fit (X_j) is the comprehensive fitness function of X_j for all the targets [24].

In order to maintain the diversity of the population, avoid the phenomenon of genetic drift, and to explore multiple regions at the same time, a sharing mechanism based niche technique was introduced to reduce the duplication of similar individuals. To estimate the niche radius [25], it uses the formula below.

$$N\sigma_{share}^{\,n-1} - \frac{\pi_{i=1}^{n}\left(F_i(X_j)+\sigma_{share}\right)-\pi_{i=1}^{n}F_i(X_j)}{\sigma_{share}} \qquad (4)$$

After sharing, the comprehensive fitness function Fit (X_j) of intelligent agent X_j becomes:

$$\mathrm{Fit(Xj)} = \frac{Fit_i(X_j)}{\sum_{K=1}^{N} S(X_j,X_K)} \qquad (5)$$

In the process of optimal allocation of urban land use space, the suitability of the land use grid where the agent is located to the desired land use target also has a certain influence on the fitness of the agent. The Fitness function of the agent after considering such influence is shown as follows:

$$\text{Fits}(Xj) = k \times \text{Fits}(X_j) \times P(X_j) \quad (6)$$

Where, k is a constant in the interval of (1,2), which is used to increase the fitness when the function value of the individual is optimal. $P(X_j)$ is the decision-making satisfaction of the intelligent agent Xj to the land use grid where it is located. The specific calculation method is shown in the following equation:

$$P(Xj) = \sum_{k=1}^{i} W_k f_k \quad (7)$$

Where, i is the number of decision variables, Wk is the decision parameter, and fk is the decision variable.

2.2.3 Research Process and Conclusion

Honghui Zhang [26] studied the optimal allocation of land use space in Changsha city according to formula 1 and the collection and processing of GIS data, socio-economic statistics, environmental statistics and other data the city. Firstly, the model defines three types of agents. Secondly, different types of agents have different decision variables and parameters. For example, the main decision behavior of resident agents is to choose an appropriate location for residence, while the main decision behavior of enterprise agents is to choose an appropriate location for enterprise development. Finally, the decision parameters of different decision variables are different and fixed. By combining the collected data, he calculated the fitness of each Agent to the target according to formula 2, and calculate the comprehensive fitness according to formula 3. Then, according to formula 4, 5, 6, the comprehensive fitness of agents to all targets after sharing was calculated. Finally, according to formula 7, he calculated the intelligent decision of agent (Xj) and satisfaction P(Xj) with the land use grid in which it is located, and take into formula 6 to obtain the final fitness.

According to the calculation, the overall Fitness value of the model was 16.75 when the final optimal allocation of urban land use space was obtained. Before the study results show that with the optimization of the three types of land use in Changsha city, compared to the spatial distribution of the optimized residential land and commercial land, industrial land, the overall spatial distribution is more concentrated. Land use patches within the field and suburban sporadic land using plaque reduce greatly, the same type of land use spatial agglomeration degree is higher, and it avoided the excessive expansion of urban land.

2.3. Analysis of Urban Population Distribution

2.3.2 Introduction of Model

The urban population distribution model is composed of three parts: social environment, multi-agent system and urban population density. The three are closely related and interact with each other (Figure 1). The urban population distribution model is actually the population distribution rule of the Agent at the current stage of the city, and the Agent is influenced by the social environment and also acts on the social environment to change its state. This model tries to carry out appropriate abstraction and description of agents, simulate various agents to detect and respond to social environment information, and influence the behaviors of agents with social environment information.

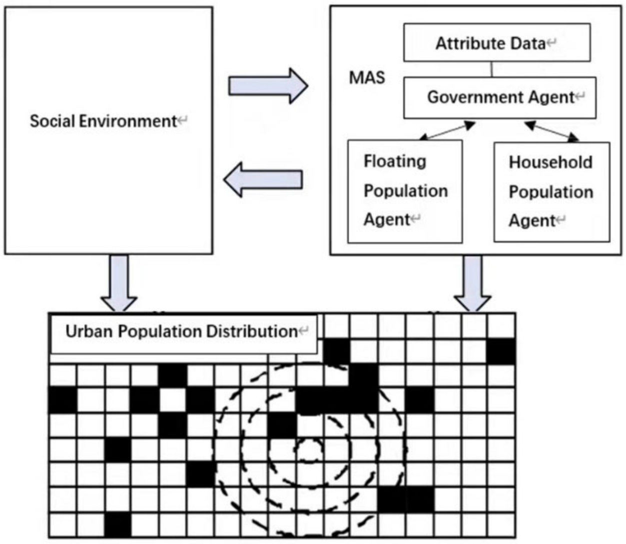

Figure 1. Framework of Urban Population Distribution Model based on MAS

2.3.2 Formula of Model

2.3.2.1 Population Density

The representation of urban population density refers to the digital population model [27], dividing the residential area into 100m×100m grids according to the set principles and methods, and inputting the actual population density in 2018 into the grid accordingly. It can calculate the average population density of the belt according to the formula.

$$\mathrm{Den} = \sum_{i=1}^{n} Area_i * Pop_i \,/ \sum_{i=1}^{n} Area_i (i = 1,2,\ldots\ldots,n) \tag{8}$$

In the formula, Den represents the average population density of the belt, Area is the Area that the belt contains or passes through I street, Pop is the population density of I street town, and n is the number of streets that the belt contains or passes through.

2.3.2.2 Social Environment

Logistic methods are used to automatically obtain CA conversion rules [28], including expressways, primary arterial roads, secondary arterial roads, service facilities, and the distance from the city center. The formula is as follows:

$$R_{ij}^{t} = \frac{1}{1+exp[-(d+\sum_h D_h x_h)]}\Omega_{ij} + \mathrm{X_{ij}} \tag{9}$$

Which $\mathrm{R_{ij}^{t}}$conversion rate for position (i, j), d for logistic regression constant, variable x h for distance, distance d for variable coefficient, Ω_{ij}influence values forfields, $\mathrm{X_{ij}}$ to change position (i, j) land use types of planning. The above two formulas can get the data matrix of population density and distance of Changsha city by substituting the data.

2.3.2.3 Multi-agent Integrated Decision Making

In a self-organizing population distribution system, the change of population distribution is a process of interaction with the surrounding environment. The Floating Population Agent and the Household Population Agent search for a suitable place to live according to their own requirements and the actual situation. The multi-agent comprehensive decision model combines the changes in population distribution and environment to simulate the population density and comprehensive evaluation of the coordinate (i, j) plot and the surrounding 25-hectare plot. The expression is:

$$R_{ij}^{t} = \phi r_{ij}^{t} = \phi\left[w\left(F_{ijk}^{t}, W_k\right)\right] \tag{10}$$

rij is a comprehensive environmental assessment t time population lives Eij, suitability, is impact factor k in (i, j) comprehensive evaluation, Wk is the weight of each influence factor, w is calculated each influence factor of the development of the joint function, Ø is the action function of the Agent.

Model Application and Results

According to the data obtained by Changsha statistical yearbook (2018), Hong Xiao [29] sets the initial properties of urban population agents, adds floating population and household population agents into each street, and enters data such as per capita disposable income and proportion of consumption expenditure into the Agent array for saving. The population and environment data of 49 streets in Changsha city were selected, and the program was programmed based on the digital population model. The simulated population density data and social environment data of each plot in Changsha in 2018 were exported in text format one by one, and the statistics were conducted in SPSS. Combined with the multi- agent model, the population distribution of Changsha in 2018 was analyzed.

To sum up, first of all, the city center population density is in a long-term high growth state, with Wuyi avenue east to west through the streets of dense population. Secondly, the peak of population distribution develops to the circular range of 5 ~ 8km from the city center. The second ring layer with high population density is formed in the south street of Tianxin district, Zuojiatang street in Yuhua district, Gaoqiao street, leek garden street in Furong district and Qingshuitang street in Kaifu district. Finally, in the development process of Changsha city, the ecological environment along the Xiangjiang river has been improved. Therefore, the Tongtai street, Pozi street, Shuyuan street and Shuyuan road along the "riverside scenery belt" have formed a new densely populated area.

3. Advantages and Disadvantages of the Multi-agent Model

This review discusses the advantages and disadvantages of the Multi-agent Model for the applications of Land Use Apace Optimization and Analysis of Urban Population Distribution.

3.1. Advantages

Compared with the traditional urban planning spatial decision-making model, the Multi-agent Model has greatly improved ability to explain the causes of urban spatial system evolution, and it can also make up for the shortcomings of the traditional GIS-based urban planning spatial decision-making or population distribution model in operation. To strengthen expressive power, it helps people understand the mechanism and interaction process under the evolution of urban space system.

Under the multi-objective constraint, the multi-agent system and heuristic algorithm are integrated to construct the multi-agent evolutionary urban land use space optimization model. And it can combine the influence of population density and social environment to act in the multi-agent decision model. The model can obtain reasonable and feasible results of urban population distribution, and has good operation efficiency and multi-objective optimization ability.

3.2. Disadvantages

Due to the complexity of multi-agent system, the spatial decision model and algorithm of multi-agent city planning still need to be further improved. It includes the following aspects. The types, decision-making behaviors and rules in the decision-making process of urban planning space are extremely complex, which need to be further improved and summarized in the following studies. In the actual situation, the Agent acceptance of the information conveyed by other agents depends on the trust, and the decision behavior of Agent is path- dependent. Therefore, based on the path dependence of agents, the spatial decision rules of multi-agent urban planning under the framework of bounded rationality need to be further studied.

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