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Role of human moving on city spatial evolution

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HIGHLIGHTS

- Considering the carrying capacity of community in the city evolution, we find that the distribution of population in the city is more uniform.
- The maximum movement distance has a great influence on the centralization of population distribution.
- Preference and higher migration rate will lead to the generation of larger communities.
- The randomly exploration will cause the dispersed population distribution.

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ABSTRACT

Human migration plays an important role in the city spatial evolution. This paper presents a new simulation model of city spatial evolution that explicitly considers preference and exploration in the migration choice decision process. In the model, the preference means that human prefer to move to the communities which have more people, while the exploration implies that human wish to explore the unknown communities randomly. By introducing the carrying capacity (CC), maximum movement distance (MMD), migration rate (MR) and random migration parameter (RMP), we investigate the effects of them on the city spatial distribution. All of the parameters can govern how many people can live in each community, how far people can explore and how many people move per time step, etc. A numerical simulation experiment is presented to illustrate that the form of the city is centralized with the increase of CC, MMD and MR, while it will be decentralized as the RMP grows.

1. Introduction

There are some complex driving forces in city spatial evolution processes [1–3], such as social, economical, political, and physical ones. The interactions between these driving forces are so complicated that it is generally difficult to describe them. To the best of our knowledge, very few works have been done in applying the quantitative prediction theory to investigate city dynamics, organization and estimate future trajectory and stability so far. City spatial evolution is reflected by the population distribution which is depended on the human dynamics [4]. Human dynamics is a main body of knowledge that presents the complexities and wonders of how we individually process information, learn, undertake tasks, communicate, relate to others, keep well-being, respond to stress, and above all develops as whole systems of mental–physical–spiritual functioning, so that we may readily realize our individual and collective human potential.

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How do human dynamic patterns shape and impact the city spatial evolution? To figure that out, it is necessary for us to understand the mechanism of the human mobility. By studying the trajectory of 100,000 mobile phone users whose position is tracked for a six-month period, González et al. [5] demonstrates that, in contrast with the random trajectories predicted by prevailing Lévy flight and random walk models, human trajectories show a high degree of temporal and spatial regularity, each individual being characterized by a time-independent characteristic travel distance and significant probability to return to a few highly frequented locations.

City spatial evolution is at the core of many city planning problems and has been extensively studied in the past few decades. A comprehensive review of various city spatial evolution models can be found in Ref. [6]. Over the last years, various approaches have been proposed to simulate city spatial evolution process. Typically, the methods used mainly included GIS spatial analysis [7–9], cellular automata (CA) [10–13], agent-based method [2,14], and dynamics [15–21]. This paper falls into the latter category and presents a dynamic model for city spatial evolution.

GIS spatial analysis is a rapidly changing field, and GIS packages are increasingly including analytical tools as standard built-in facilities. The increased availability has created a new dimension to business intelligence termed 'spatial intelligence' which openly delivered via intranet, democratizes access to geographic and social network data. Recently, some papers have used the GIS spatial analysis technique to characterize the city spatial evolution model. For example, Fragkias and Seto [7] applied a combination of time-series satellite imagery, GIS, and a time-series of spatial pattern statistics based on rank–size distributions to evaluate the evolving nature of urban clusters in South China.

In the last decade, CA has been used within city spatial evolution to capture microscopic properties for the city spatial distribution. It is a microscopic model, which consists of a lattice of discrete cells whose values change in discrete time steps according to the rules that explicitly take into account neighboring effects. A comprehensive review of CA theory is provided in Ref. [11], with a discussion of its application in environmental modeling and simulation. White [12] presented a CA model to develop the city spatial structure evolution. However, in the city spatial evolution process, CA is inadequate to capture all the influence factors, especially socioeconomic factors. Therefore, it is necessary to incorporate the other models on CA to better model the realism. For example, GIS and CA are always integrated to study city spatial evolution problem. For example, Batty et al. [8] proposed a class urban model whose dynamics are based on theories of development associated with GIS-based cellular automata (CA). Li et al. [9] developed how to extend CA and integrate with GIS to help planners to search for better urban forms for sustainable development. Xie [13] proposed a generalized GIS-based CA model of urban spatial evolution problem for describing urban complexities and dynamics.

Agent-based model is a class of computational models, which simulate actions and interactions of autonomous agents to evaluate their effects on the system as a whole. It focuses on agent-based for generation of model behavior in system evaluation. There is an increasing body of relevant literature on the agent-based model for city spatial evolution problem. An example of the agent model is a spatial planning model combining multi-simulation approach with cellular automata developed by Ligtenberg et al. [2]. In their model, individual actor behavior is taken into account according to a bottom-up modeling concept, and spatial planning intentions and related decision making of planning actors are defined by agents. Furthermore, Mansury and Gulyás [14] proposed a spatial agent-based model to generate a system of cities that exhibits the statistical properties of Zipf's law, which studies the population distribution between cities. Some specific features, such as, explicit treatment of space, externality-driven migration, limited spatial reach, and heterogeneity of agents' mobility, are included in their model. They showed that restrictions on the probability distribution of agents' spatial reach together with selected parameter values are sufficient for the emergence of the Zifp's law. However, the model developed by Mansury and Gulyás [14] is the intra-metropolitan urban clusters, and it cannot be applied to the population distribution of communities in a city.

Numerous research efforts focused on dynamic model for the city spatial evolution problem in recent years. For example, Lucien and Blumenfeld-Lieberhal [15] presented a new dynamic model to develop the city size distribution (CSD). Lucien and Blumenfeld-Lieberhal [16] proposed a growth dynamic model for a system of cities, which takes into account not only Zipf's law but also other kinds of CSD. Furthermore, Lucien and Blumenfeld-Lieberhal [17] further used the dynamic model proposed by them [16] to analyze the evolution of CSD and provide a quantitative interpretation for them. Carlos [19] provided a simple and locally optimal test for Zipf's law, which uses the largest US metropolitan areas to illustrate it. Henderson and Venables [22] presented a dynamic model to develop the problem of city formulation and city size in an economy in which total urban is increasing, an environment relevant for many developing countries experiencing rapid urbanization. Li et al. [20] formulated a macro dynamic model for urban expansion by comparing urban growth to a physical process. Schelling [23] proposed a microeconomic dynamic model that shows how an integrated city could unravel to a rather segregated city, notwithstanding relatively mild assumptions concerning the individual agents' preferences, i.e., no agent preferring the resulting segregation.

However, the above literatures have not accounted for the human movement dynamics behavior in the city spatial evolution research. On the other hand, the community's CC is an important factor in the city spatial evolution research. For example, Zhang et al. [24] established an indicator system to evaluate the capacity of the urban material metabolism and proposed a new model for the urban material metabolism to define the production possibility curve using a wealth index (WI) and an ecological efficiency index (EEI). However, the human movement dynamics behavior is ignored in their paper. In this paper, we presented a dynamic model that explicitly considers both human movement dynamics behavior and community's CC aspects of city system in migrate decision process. In addition, the given number of population and community is assumed in above literatures. However, this assumption is relaxed in this paper.