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The evolution of human mobility based on the public goods game

Shiqing Yan

Yancheng Teachers University, College of Urban and Planning, Yancheng 224051, PR China

HIGHLIGHTS

- We construct a novel model to describe the human mobility in the real world.
- By using mean field method, the commuting patterns is theoretically analyzed.
- There is a great relation between the total population and the fairness in a specific region.
- Human migration is beneficial for the population balance in different regions.

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ABSTRACT

We explore the evolution of human mobility behavior based on public goods game. By using mean field method, the population distribution in different regions is theoretical calculated. Numerical simulation results show that the correlation between the region's degree and its final population is not significant under a larger human migration rate. Human mobility could effectively promote cooperative behavior and the population balance of different regions. Therefore, encouraging individuals to migrate may increase the total benefits of the whole society. Moreover, increasing the cooperation cost could reduce the number of cooperators, and that would happen to the correlation between the region's degree and its final population. The results indicate the total population could not dramatically rise with the region's degree under an unfair society.

1. Introduction

It is fascinating to observe the social behavior of human being. In our daily life, people often move from one region to another. Those places where we have been visited can better reflect our way of life and relationship networks. The mobility pattern analysis and prediction of human behavior has been a hot topic in the research of mobility location information. The movement of one person in the geographical space seems random and does not have regularity, however, the mobility of a large number of individuals may hidden in a specific pattern. Complex networks provide a powerful representation to understand the individuals' social behavior in a given community or population [1–7]. According to the complex networks theory, constructing a model to simulate the human mobility, not only can increase human's understanding of themselves, but also can improve the understanding of the effect of human behavior on the evolution of social system [8].

The recent accumulation of large amounts of data on human mobility from the scale of single individual to the scale of entire populations presents us with new challenges related to the high level of predictability and recurrence found in mobility and diffusion patterns from real data [9–12]. Most models assume that human mobility behavior is a Markov process and it is memoryless. However, Etter et al. [13] observed data from cell phone towers and found human mobility

E-mail address: 18360494968@163.com.

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has a non-Markov characteristic, that means human mobility has a memory. This implies human beings tend to go to places where they have been arrived. Under the complexity of human mobility and interaction, the individual's decision whether or not to cooperate can evolve in time depending on their surroundings [14–17]. Game theory provides a new and well framework to understanding human behavior. Evolutionary game theory on graphs or networks has attracted much interest from physicists in the last decades [18–25], both because of the new phenomena that such a non-Hamiltonian dynamics gives rise to, and because of its very many important applications [26–30]. Although cooperation is ubiquitous in social life and an important topic for all kinds of economic interaction, field data rarely allow for a clean discrimination among competing theories. Because carefully designed laboratory experiments do allow for such rigorous comparisons, laboratory experiments have provided numerous important insights into cooperative behavior, and the resulting rich literature forms the basis of most of our knowledge on human cooperation. Flavio investigated the linking individual and collective behavior in adaptive social networks [31]. The results indicated that the faster the relative rate of adaptation of the network, the smaller the critical fraction of cooperators required for cooperation to prevail. Dong studied the dynamics of human behavior in the public goods game with institutional incentives [32]. The results showed that institutional incentives promote cooperation by affecting the self-regarding preference and that the other-regarding preference seems to be independent of incentive schemes. Sarah researched how the cultural history and ecological environment affect human behavior [33]. Their results indicated that it is critical to disentangle the role of ecology and cultural inheritance in a cultural species like humans. Based on game theory, Annemarie introduced the non-cooperative game theory and the Nash equilibrium as a framework to model the decision process behind human interaction-aware behavior [34]. The results showed that both presented game theoretic models outperform the prediction based decision model. Adaptive social structures are known to promote the evolution of cooperation. Much research has been devoted to explain the dynamics of human behavior in public goods game (PGG) [35]. In the PGG, the only Nash equilibrium that is based on monetary considerations is for all players to free ride. However, in PGG experiments, most individuals contributed approximately half of their endowment to the public pool, and this contribution tends to decrease as individuals play the game repeatedly [36].

The population distribution has a close relation with the fair of social. Considering that people may migrate to other places when they suffer injustices, we present the evolution of human mobility behavior based on public goods game. Firstly, the mean field method is used to calculate the population distribution. Then numerical simulations are presented to show some meaningful results: (1) The correlation between the region's degree and its final population is not significant when the human migration rate is relative large; (2) The individuals' migration promote the cooperative behavior and improve the whole society benefits and the balance of the population distribution; (3) The final number of cooperators decrease with the increase of cooperation cost; (4) A region with a larger degree may not have more population under an unfair society.

The rest of the paper is organized as follows. In Section 2 the proposed model is described. In Section 3 we analyzed the human mobility behavior through numerical simulation. Finally, a summary is given in Section 4.

2. Modeling

Human behavior is the driving force behind many complex social phenomenon, and it is an important research topic of modern science to quantitatively analyze human behavior [37–40]. Human mobility behavior describe the patterns of human movement, to some extent, it reflects the regional differences. Mobility behavior that driven by external factors or spontaneous (such as human psychology, social welfare, climate and other factors) may result in unbalanced population distribution in different regions. For example, the Chinese population mainly concentrate in the developed southeast coastal and central regions (see Fig. 1), however, the population in the less developed western regions are relatively small. In what follows, we will investigate the human mobility model based on public goods game, and provide theoretical frame to calculate the region size that formed by human mobility.

2.1. Basic model of human mobility

To begin investigating the effect of regular mobility patterns in reaction–diffusion systems [42], we consider the prototypical example of the spread of biological agents and information processes in populations characterized by bidirectional commuting patterns. We consider n regions, the total population of the n regions is N. The connection of the n regions network follows the distribution $P(k)$. Specially, the initial population of a region with degree k is $n_k = \frac{k}{\langle k\rangle}\bar{N}$, where $\langle k\rangle$ is the average degree of the regions network, $\bar{N} = \sum_k P(k)n_k$ is the average population of the n regions. Noting that the region's degree reflects a specific region's connectivity. An example is presented in Fig. 2.

Considering the effect of homesickness but without the welfare on the human mobility, we have the following assumptions and instructions:

(1) People in region i with degree k_1 migrate to other neighbor region with probability α_{k_1}. In particular, they migrate to a neighbor region j with degree k_2 with probability $\alpha_{k_1k_2}$. Due to human migration, the number of people who migrate from region i with degree k_1 to a neighbor region j with degree k_2 is $n_{k_1k_2}$, and the number of native people who still stay in region i is $n_{k_1k_1}$.

(2) People in a region i with degree k_1 after migrate to other neighbor region, and then come back to the original region i with probability β_{k_1}. In particular, those people from a neighbor region j with degree k_2 return to the region i with probability $\beta_{k_1k_2}$.