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Evolutionary of online social networks driven by pareto wealth distribution and bidirectional preferential attachment

Bin Zhou [a], Xiao-Yong Yan [b], Xiao-Ke Xu [c,*], Xiao-Ting Xu [a], Nianxin Wang [a]

[a] School of Economics and Management, Jiangsu University of Science and Technology, ZhenJiang, 212003, China
[b] Systems Science Institute, Beijing Jiaotong University, Beijing 100044, China
[c] College of Information and Communication Engineering, Dalian Minzu University, Dalian 116600, China

HIGHLIGHTS

- The origin of online social network evolution is analyzed and the evolution mechanisms are also explained.
- A model based on the Pareto Wealth Distribution and bidirectional preferential attachment is proposed.
- The evolutionary analysis of the proposed model is presented.
- The model can reproduce the essential evolution characteristics which are consistent with the ones of real-life online social networks.

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ABSTRACT

Understanding of the evolutionary mechanism of online social networks is greatly significant for the development of network science, but up to now most present researches on this topic have not enough insight. In this study, firstly we empirically showed the essential evolution characteristics of Renren online social network. The evolution mechanism of online social networks is explained by the perspective of Pareto wealth distribution and bidirectional preferential attachment. Then a novel model is proposed to reproduce the evolution characteristics which are consistent with the ones of Renren online social network, and the evolutionary analytical solution to the proposed model was presented. The results suggest that both Pareto wealth distribution and bidirectional preferential attachment play an important role in the evolution process of online social networks and can help us to understand the evolutionary origin of online social networks. The model has significant implications for dynamic simulation researches of social networks, especially in information diffusion through online communities and infection spreading in real societies.

With the rapid development of information technology, online social network platforms have appeared with a novel organizational form that differs from traditional social networks, in which the users maintain constant contacts and share the common interest, such as Facebook, Twitter, Renren, and Tecent QQ. Millions of people rely on online social networks to communicate with others, and their interactions generate new knowledge [1]. Thus the statistics and dynamics of online social networks are tremendously important to the researchers who are interested in human behaviors [2,3]. The systematic research on online social network data has created a new field of network sociology which integrates theories of traditional social networks and complex networks. Especially, network science has constituted a fundamental framework for analyzing and modeling online social networks [4].

* Corresponding author.
E-mail address: xuxiaoke@foxmail.com (X.-K. Xu).

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Traditionally, studies in the field of complex networks concentrated on the structural analysis of online social networks [5,6]. One of the most essential structural characteristic for online social networks is that the degree distribution follows a power-law instead of a normal distribution [7,8]. The degree of an individual is the number of friends that the individual has, and the degree distribution is the fraction for the individuals in the network who have exactly the number of friends. Among many different theories for generating a power-law distribution, the most prominent explanation is the Barabási and Albert model (BA model) of the preferential attachment [8]. The BA model is so well established that the preferential attachment is sometimes believed to be the origin of the power-law distribution. The community structure and the network connectivity are also important structure characteristics of online social networks, because they play an important role in information diffusion [9,10] and disease spread [11–15]. The community structure means that the nodes of the network can be easily grouped into sets of nodes such that each set of nodes is densely connected internally. A connected component is a set of individuals among which each pair of individuals are connected by at least one path through the network.

However, in this paper, our empirical analysis on Renren online social network indicates that the degree distribution is not a single power-law distribution but a two-region power-law distribution. The similar degree distributions of friend relationship have also been found in other online social networks [16]. The evolutionary characteristics of both the community structure and the network connectivity in Renren online social network are also not consistent with the ones in the simulation network generated by present models of social network [2,8,17,18]. Therefore, the state of art models cannot explain the essential structure characteristics of Renren online social network. A realistic online social network model needs to satisfy the essential structure characteristics of online social networks. Theoretical studies of dynamical processes and collective behavior taking place in online social networks would benefit from the realistic social network models [19].

The goal of this study is to analyze the evolutionary mechanisms of online social networks and propose a novel model to reproduce the essential multiple structure characteristics of Renren online social network. our results uncover that Pareto wealth distribution and bidirectional preferential attachment can play an important role in the evolution process of online social networks. This paper is structured as follows: firstly, we make the empirical demonstration of Renren online social network and show its essential structure characteristics. Secondly, we analyze the inherent features of online social networks and propose a novel social mechanism to explain the essential structure characteristics. Thirdly, a model is provided based on the proposed mechanism and the evolutionary analytical solution to the degree distribution is presented. Fourthly, our simulations reproduce the essential structure characteristics of Renren online social network. Furthermore, the model can also reproduce the rule of the common power-law degree distribution in complex networks. Finally, we discuss the significance of the work and conclude with a brief summary of our results.

1. Empirical demonstration

The evolution of complex systems in nature and society is from the initial unstable state to the final stable state. The mechanism of driving system evolving plays a dominant role in the evolution process from the initial unstable state to the final stable state. When the system reaches a stable state or dynamic equilibrium, the role of mechanism of driving system evolving will weaken or even disappear. Therefore, analyzing the evolution process from the initial unstable state to the final stable state will help us to explore deeply the mechanism of driving system evolution. The online social network is one of the most complex systems in nature and society. Although there are many online communications that form complex online social networks, detailed topological data is available for only a few, especially for the networks including the evolution process from the initial unstable state to the final stable state. The friend relationship graph of Renren Internet communication represents a well-documented example of the online social network, which is one of the largest online social networks in China. The website of Renren is http://www.renren.com. The online community is a dynamical evolving one with the new users joining in the community and new connections established between users. Each registered user of Renren has a profile, including his/her list of friends. If we view the users as nodes V and friend relationships as links E, an undirected friendship network $G(V, E)$ can be constructed from Renren. For privacy reasons, the data, logged from 21 November 2005 (the inception day for the Internet community) to 26 February 2006, include only each user's ID and list of friends, and the establishment time for each friend relationship.

Fig. 1(a)–(c) show chronologically the evolution process of degree distribution in Renren online community in the initial three months. The degree distribution changed from the initial single power-law distribution to the final two-region power-law distribution. The evolution characteristic indicates that some social mechanisms should play a leading role in the evolution process. Fig. 1(d) shows the evolution process of the average degree in the Renren online social network and the average number of friends for a user increases gradually. The community structure of Renren online social networks is detected using the Louvain method [20]. Fig. 1(e) shows the evolution process of community count and connected component count in the Renren online social network. The number of connected components first increases to the peak and then decreases. The evolution tendency of community count almost is consist with the one of the connected component count in the evolution process. We can further quantify this division using the modularity [21]. The modularity is the fraction of edges within communities minus the expected fraction of edges within communities in a randomized version of the network that preserves the degrees for each individual, but is otherwise random [22]. Fig. 1(f) shows that the evolution process of the modularity of the Renren online social network. The modularity decreases in the evolution process.

Take the prominent BA model as an example, Fig. 2(a)–(c) show the evolution process of the degree distribution of the simulation network generated by BA model. The degree distribution always follows the power-law. Due to the rules