Dynamic of behavior spread driven by information on weighted networks

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Abstract. In this paper, a new behavior-spread model is proposed, which incorporate the analysis the degree of closely connects, preference for things, and the reciprocal interaction and collaborative spreading of information and behavior on a weighted networks. Comprehensive consideration for the mutual influences of the timeliness, social reinforcement effect of information, and the degree of closely connect between individuals, individual preference on the behavior spread. The study found that, some properties of the information itself, such as timeless and social reinforcement, have impacts on the scope and speed in the information spreading on the network. And subjective factors, such as the degree of closely connect between individuals and individual preference, mainly affect the behavioral conversion rate and the number of individuals has received the information.

Introduction

Previous studies paid more attention to the spreading dynamics of disease, and established various epidemic model based on the mean field theory [1-4], the transmission threshold was theoretically induced on the Small-world networks and Scale-free Networks. Compared with the traditional disease study, disease research obtained some new conclusions are more close to the actual on complex networks. Recently, on the basis of studying of epidemic spreading, the propagation phenomenon of rumors, information spreading was studied. The rumors, information spreading are different from epidemic spreading, the epidemic spreading is a contact and passive process, and the rumors, information are a non-contact and initiative process[5-7], and the spreading have the memory effects, the social reinforcement and the non-redundancy of contacts. Not only that, whether people accept the information and broadcast information is selective, influenced by the people’s personality, hobbies and other subjective factors. With the rapid development of Internet, the global people’s distance become closer, people's social relationship network is expanding constantly, and the relationship among people are more and more frequent, the mutual influence of the thought and the behavior is more and more high. Recent studies showed, personal insomnia, smoking and drugs could spread on social networks based on friendship [8-10]. However, the existing research rarely study the behavior spread as the research object, and rarely consider the effect of subjective consciousness to the spreading. In this paper, we will study all kinds of behavior spreading phenomenon on the social network, propose a new behavior-spread model based on the weighted network, comprehensive consideration for the mutual influences of the degree of closely connect between individuals and individual preference on the behavior spread, and take an actual adolescent friendship network as the media network. Through simulation experiments to investigate the influences of various model factors in the behavior spread, getting some propagation laws on the social network.

Model Description

Suppose the information Q and action A is corresponding. Information Q can stimulate an individual to adopt the corresponding action A, correspondingly this action carry and spread this information. According to the spreading features of the information and action on the network, the node state can be divided into four kinds: (1) Unknown state, the individual has not known the information Q and action A; (2) Known state, the individual is aware of the information or action (i.e., received the information at least once). This individual can receive information repeatedly, but does not adopt the action A.; (3) Action state, the individual has adopted the action A, carry and spread the action, but this individual no longer receive the information. (4) Exhausted state, the individual has lose interest in the information, this individual is neither involve in information spreading, nor adopt the action.

It's known that, the weight of network has a significant effect on the spread [11-14]. Generally, we use edge weight to represent the contact frequency between individuals or the connection degree in the friend relation on social network. In this model, the edge weight w_{ij} defined as the number of individual i, j contact or communicates in a certain history period T, and denote $s_i = \sum_j^n w_{ij}$ as the strength of nodes. Actually, the information spreading rate between individuals and the connection degree between individuals are closely correlated each other, the more information exchange between individuals, which their connection degree is stronger, the greater the mutual action influence. Meanwhile, it has strong subjectivity to the acceptance and degree of recognition of individual for information and action, and it also has relation with individuality and preference of individual. For example, a sport-lover may be more easily to adopt a certain sport and not adopt the smoking action; it is difficult to resist the temptation of online games to mused children, but not read quietly. Therefore, in this model, we introduce preference coefficient $\alpha_i \in [0,1]$, representing the degree of preference of individual for the action A, the larger the preference coefficient α_i is, the more the individual may tend to adopt the action, the probability of adopting action A also is larger. As the individual preference is related to own individuality, and it is relatively stable, in below simulation experiment, each individual preference coefficient randomly take a constant value between 0 and 1.

At each time step, here coexist two dynamic processes, one is the information spread between individuals, and other is the state of individual transfer. They are as follows algorithm:

1. The information diffusion between individuals:

An individual i (in Unknown state or Known state) contact with the other individual j which is in Action-state, the probability of the individual i receives information from the individual j (call information spreading rate) is:

$$c_{ij} = \frac{w_{ij}}{T} \qquad , c_{ij} \in [0,1] \quad , w_{ij} \le T \tag{1.1}$$

At any time t, the cumulative number of the individual receiving information is : $\overline{m}_i(t) = \sum_{j \in \tilde{N}_i(t)} c_{ij}$, which $\tilde{N}_i(t)$ denote the set of its neighbors which in Action state at time t. From initial time to time t, the cumulative number of the individual i receiving the information is $m_i(t) = \sum_{s=1}^{t} \overline{m}_i(s)$.

2. An individual transfers from one state to another:

Denote m (t) as the cumulative number of an individual (in Unknown state or Known state) receiving the information Q at time t. If $1 \le m_i(t) \le M$, the probability of the individual turning into Action state is:

$$P_i(t) = \alpha_i(1-(1-b)^{m_i(t)}), \qquad \alpha \in [0,1] \tag{1.2}$$

Therefore, when $1 \le m_i(t) < M$, the probability of the individual still in K-state is:

$$\overline{P}_i(t) = 1 - P_i(t) = 1 - \alpha_i(1-(1-b)^{m_i(t)}) \quad , \quad \alpha \in [0,1] \tag{1.3}$$

When $m_i(t) = M$, the probability of the individual turning into E-state is:

$$\hat{P}_i(t) = 1 - P_i(t) = 1 - \alpha_i(1-(1-b)^{M}) \quad , \quad \alpha \in [0,1] \tag{1.4}$$

In (1.2) formula, the parameter $m_i(t)$ embodies the memory of the information and behavior spreading, the more the cumulative number of an individual receiving information, the larger the probability of an individual adopting action. In the context of each spreading is independent, it is different from the class of disease spreading which have no memory. The parameter M define as the maximum times of an individual receiving this information, called the information timeliness, which reflects the maximum times of the individual is stimulated by information. When an individual receives M times information, not adopt the corresponding action, which means that the individual has got immunity, be no longer affected by this information and action, and turned into an exhausted state. The parameter $b(0<b<1)$ called social reinforcement factor, which reflects social reinforcement, namely, multiple spreading gain beneficial effects. And it has popularity of society, that is to say, when b is larger, the public profile of information or action become larger, the probability of an individual adopting action also become larger. Obviously, $\frac{\partial P_i}{\partial b} = -\alpha_i(1-b)^{m_i(t)}\ln(1-b) \ge 0$, $\frac{\partial P_i}{\partial m_i} = \alpha_i m_i(t)(1-b)^{m_i(t)-1} \ge 0$, that is the state transition probability P_i increase with the increasing b and $m_i(t)$. Fig.1 displays the individual state transition process.

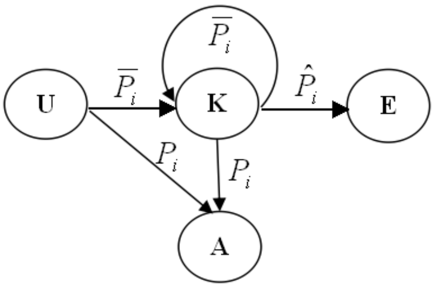
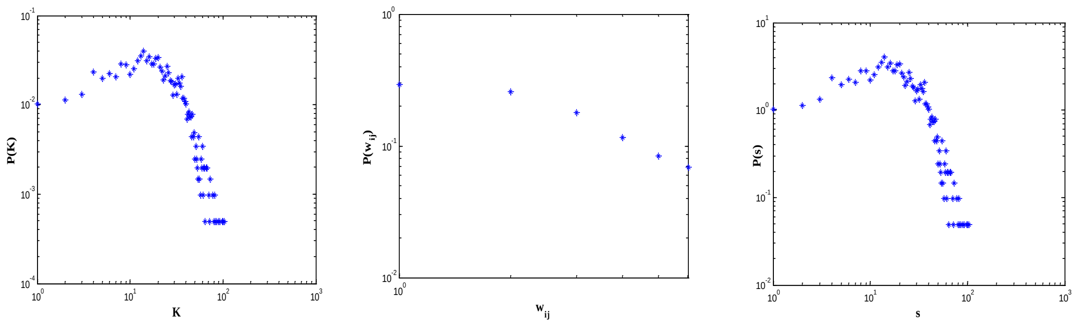


Fig.1. the individual state transition process diagrams.

Dataset

This research uses the Adolescent Friendship Networks [15], which composed of actual data, as the media network. This data from 1994 to 1995 J. Richard Udry, Peter S. Bearman, and Kathleen Mullan Harris do investigation report about the relationship between students. This project granted by the National Institute of Child Health and Human Development (NICHD). The weights represent the numbers of the kinds of participating activities with friends within a week (can be thought of the number of contacts), there are five kinds of activities, if the weight equal 1, it means that do not participate activity, in the same way, if weight equal 6, it means that participate all the activities. So, in the formula (1.1), the period T is 7. Fig.2 shows that the degree distribution, edge weight distribution and node's strength distribution of the network, they all possesses incline and tail approximates a power-law distribution. As the edge weight has narrow range, the edge weight distribution is few and sparse. Node's strength represents the value of the node on the network, the node's strength is larger, the communication is more widely, and the ability to spread is stronger.



a. The degree distribution. b. The edge weight distribution. c. The strength of nodes distribution

Fig.2. The degree, edge weight and node's strength distribution of the weighted network.

Simulation and Analysis

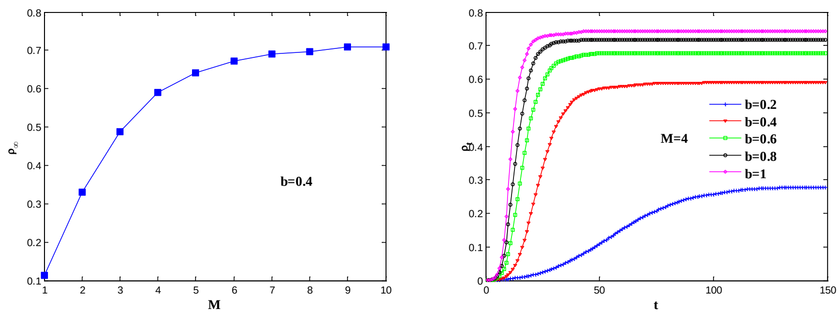
In this section, according to the model of behavior spreading rules do simulation experiments on the above adolescent friendship network. In order to eliminate the influence of random disturbance, all results are taken the average 50 independent realization.

Here, first presents the following notation: ρ_t denotes the density of Action state nodes at time t; ρ_∞ denotes the density of Action state nodes at the final steady state; f_s denotes the proportion of Action state nodes whose strength is s, called the relative density of Action state nodes.

Firstly, we examine the impacts of the information spreading characteristics, information timeliness M and the social reinforcement factor b.

The information timeliness M represent the effect range of the information, and represent the maximum times of an individual can receive information. Fig.3(a) shows the influence of the information timeliness on the behavior spreading. We see that the larger the timeliness, the broader the spreading range. This show that the time of individual interests in the information or action lasting long, the cumulative stimulate effect of information to individual is larger, the probability of adopting action is larger, and the dissemination range naturally become more widely.

Fig.3(b) displays the evolution of ρ_t with different parameters b. It shows that for different values of the parameter b, the time of ρ_t evolving into the stabilized state decrease with the increasing b, that is to say that the spreading speed increase with the increasing b. And its final value ρ_∞ increase with the increasing b, namely, the spreading range also increase with the increasing b. It's because the greater b means that the strength of once cumulative stimulates effect become larger. That also is to say that an individual adopt corresponding action as long as few information stimulus, and the action will be spread more quickly and widely.



(a). The evolution of ρ_∞ vs M with different value. (b). The evolution of ρ_t vs b with different value.

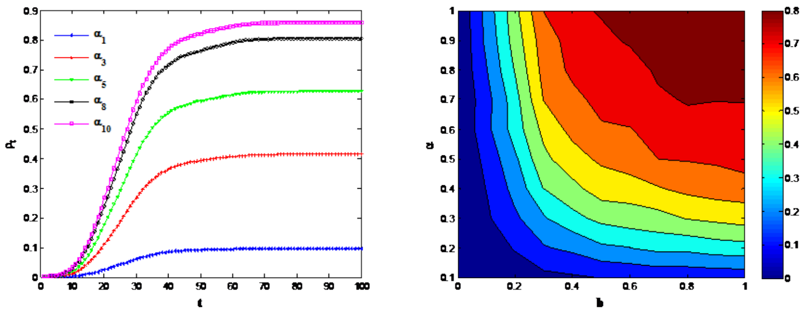
Fig.3. The changes of the information spreading characteristics.

Secondly, we investigate the impact of the individual preference.

As the world outlook, life outlook and value outlook of individual have the difference of personality, people's lovely degree for things is vary; different individual has different degree of interest to the action A. In this model, we use the preference coefficient α to show this difference.

In order to investigate the effect of the degree of preference, taking the $\alpha \in [0,1]$ is divided into 10 sub-intervals in step 0.1 : $\alpha_1 \in [0,0.1)$, $\alpha_2 \in [0.1,0.2)$, $\alpha_3 \in [0.2,0.3)$, $\alpha_4 \in [0.3,0.4)$, $\alpha_5 \in [0.4,0.5)$, $\alpha_6 \in [0.5,0.6)$, $\alpha_7 \in [0.6,0.7)$, $\alpha_8 \in [0.7,0.8)$, $\alpha_9 \in [0.8,0.9)$, $\alpha_{10} \in [0.9,1]$, calculating the density of Action state nodes with the time t in different sub-interval. Fig.4(a) shows that the evolution of ρ_t vs time t in 5 sub-intervals. We see that the final value ρ_∞ increase with the preference coefficient α, this indicates that the interest of an individual for action is bigger, this individual is easier to accept and adopt the corresponding action, and the actionable diffusion range is more widely. From the time to reach the stable state of the curve, we can see that the bigger the α is, short time to reach the stable state. The reason is that the smaller α, the proportion of individuals which are interest in the action is smaller in the group, and the small part individuals.

Furthermore, Fig.4(b) shows that the change of the density of Action state nodes ρ_∞ in the parameter space $R(\alpha,b)$, we can see that it's final value ρ_∞ increase with the increasing b and α, the impact of b and α, further to verify the conclusion of the Fig.3(b) and Fig.4. Simultaneous, whether it is from the horizontal or vertical observation, the change state of the color is similar, that indicates the social reinforcement factor and individual preference have the same force on the spreading on this network.

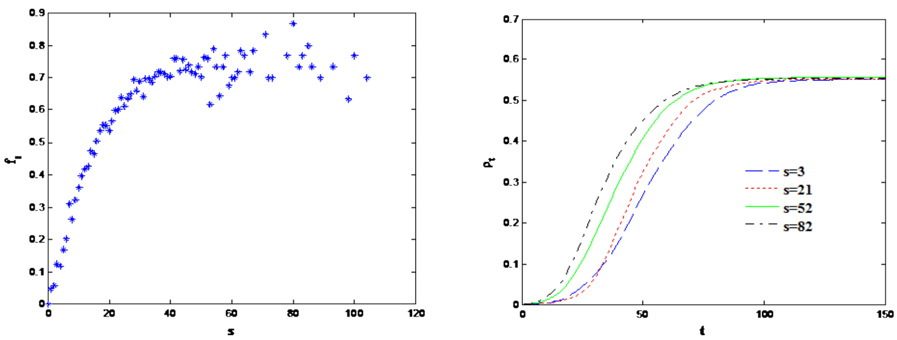


(a). The evolution of ρ_t vs α with different interval . (b)The changes of ρ_∞ in the parameter space $R(\alpha,b)$.

Fig.4. The changes of ρ_t and ρ_∞ in different conditions.

Finally, we investigate the impact of the strength of nodes and the strength of source nodes on the behavior spreading.

Fig.5(a) shows that the curve of the relative density f_s vs the strength of nodes s. f_s tends to increase with the increasing the strength of nodes s, the reason is that the greater the strength of nodes is, the more strong the individual contact with his neighbors, the larger probability and the number of this individual receiving action, that affect the probability of this individual adopting this action, which is similar to the law of disease or information spreading when the spreading rate is fixed value.



(a). The relative density f_s vs the strength of nodes. (b). The evolution of ρ_t vs the strength of source nodes.

Fig.5. The effects of edge weight.

Fig.5 (b) shows that the density of Action state ρ_t evolves with time when the strength of source nodes respectively takes 3,21,52,82. From the graph, in different the strength of nodes, the density of Action state ρ_t trends to the same value, that indicates the strength of source nodes had no significant effect on the final density of Action state nodes, namely, the strength of source nodes did not affect the behavior spreading range. From the time to reach the stable state of the curve, the smaller the strength of source nodes is, the shorter the time, the action spread out quickly. This is because the strength of source nodes is getting larger, this means that, the more consistent the link to its neighbors, the stronger the probability of spreading information, which makes the action can spread out quickly. The behavior spreading range is mainly related to the interest of the Net group for the action, and did not influenced by source node's surroundings. The propagation rules exhibit the properties of Markov, namely, in the spreading process, regardless of where is the source of information, only need to spread the action of message out, the action can be spread to a certain range, and did not affected by the source, the difference is the spread speed fast and slow. In the reality, some of the information and action dissemination has the same rules on the online social network. For instance, in the process of Micro message broadcast, whether the information spread by active user (which has larger strength) or non-active user, as long as the information is sent out, next broadcast action do not control by the source but the information content and the degree interest of people for the information and action, and not even going to ask where that came from, as far as it spread. Therefore, the strength of source nodes only affects the spreading speed and does not affect the spreading range.

Conclusion

In this paper, we have proposed a novel behavior spreading model on the weighted network, which reflects the reciprocal interaction and collaborative spreading of information and action. Focuses on the mutual influences of the timeliness, social reinforcement effect, the degree of closely connect between individuals, and individual preference on the behavior spreading. The results show that, on an inherent structure network, the time of individual interests in the information or action lasting long, more and more favorable to spread out, and the range also is getting more widely; the greater the social reinforcement factor, the more widely the spreading range and the more quickly the spreading speed; the more interested individuals are in information and action, the more easily the action diffusion on this system, but the larger the degree of preference, the longer the time to reach the stable in this system; the more strong the individual contact with his neighbors, the more easily this individual contact the information or action, thus increasing the probability of adopting action; therefor, the source node' s strength affects the spreading speed, the larger the strength of nodes, the faster the spreading speed for action on the network, but did not affect the spreading range. Moreover, we also found that the social reinforcement factor and individual preference have the same force on the spreading.

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References

[1] Pastor-Satorras R, Vespignani A.Epidemic dynamics and endemic states in complex networks [J].Physical Review E, 2001, 63(2):066117

[2] Pastor-Satorras R, Vespignani A.Epidemic spreading in scale-free network [J].Phys.Rev.Lett, 2001, 86(4):3200-3203

[3] Pastor-Satorras R, Vespignani A.Epidemics and immunization in scale-free networks

[J].Handbook of graphs and networks: from the genome to the internet, 2005, 111-130
[4] Castellano C, Pastor-Satorras R.Thresholds for epidemic spreading in networks[J].Physical review letters, 2010, 105(21):218701
[5] Damon Centola.The Spread of Behavior in an Online Social Network Experiment [J]. Science, 2010, 329(5996):1194-1197
[6] Lü L, Chen D B, Zhou T. The small world yields the most effective information spreading[J].New Journal of Physics, 2011,13(12):123005
[7] Zheng M, Lü L, Zhao M.Spreading in online social networks: The role of social reinforcement [J].PHYSICAL REVIEW E, 2013, 88(1):01281
[8] Christakis N A, Fowler J H. The collective dynamics of smoking in a large social network [J]. New England journal of medicine, 2008, 358(21): 2249-2258.
[9] Rosenquist J N, Murabito J, Fowler J H, et al. The spread of alcohol consumption behavior in a large social network [J]. Annals of Internal Medicine, 2010, 152(7): 426-433.
[10] Mednick S C, Christakis N A, Fowler J H. The spread of sleep loss influences drug use in adolescent social networks [J]. PloS one, 2010, 5(3): e9775.
[11]YAN Gang, ZHOU Tao, WANG Jie, et al. Epidemic spread in weighted scale-free networks [J]. Chin Phys Lett, 2005, 22(2): 510-513.
[12] KARSA M, ROBERT J, FERENC I. Non-equilibrium phase transitions and finite-size scaling in weighted scale-free networks [J]. Phys Rev E, 2006(73): 036116.
[13] CHU Xiang-wei, GUAN Ji-hong, ZHANG Zhong-zhi, et al. Epidemic spreading in weighted scale-free networks with community structure [J]. J Stat Mech, 2009(7): P07043.
[14] YANG Zi-mo, ZHOU Tao. Epidemic spreading in weighted networks: An edge-based mean-field solution [J]. Phys Rev E, 2012(85): 056106.
[15] Moody J. Peer influence groups: identifying dense clusters in large networks [J]. Social Networks, 2001, 23(4): 261-283.