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Influence analysis of information erupted on social networks based on *SIR* model

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In this paper, according to the similarity of chain reaction principle and the characteristics of information propagation on social network, we proposed a new word "information bomb". Based on the complex networks and *SIR* model, dynamical evolution equations were setup. Then methods used to evaluate the four indexes of bomb power were given, including influence breadth, influence strength, peak time and relaxation time. At last, the power of information was ascertained through these indexes. The process of information propagation is simulated to illustrate the spreading characteristics through the results. Then parameters which impact on the power of information bomb are analyzed and some methods which control the propagation of information are given.

Keywords: Social network; *SIR* model; influence analysis; control strategies of influence.

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1. Introduction

With the social network services like Facebook,[a] Sina[b] etc. which centered on "hobby, news, communication" integrating into people's daily life, they have more and more important roles. Information disseminated on social networks can bring staggering influence. However, "influence" as an abstract word is difficult to specify and information spreads quickly which cause governments to be unable to suppress bad information from spreading in advance until the outbreak. So, in this paper a new evaluation method is put forward which calculates the parameters of influence evaluation in the early days of dissemination. Then the power of information is predicted through those parameters and information spreading is stopped, before it creates an adverse impact.

The method which uses modeling to research network structure and behavioral dynamics is long-standing. In the early 1960s, Erdos and Renyi proposed ER model[1] of random network, then Watts and Strogatz proposed small world network (WS model)[2] which existed between regular and random network. As the connectivity of the network may be destroyed in the randomization process of WS model construction algorithm, Newman and Watts proposed NW model[3] which replaced the "random rewiring" of WS model construction by "randomized bordering". Barabasi and Albert proposed scale-free model (BA model)[4] after considering two important characteristics of actual network: growth and preferential connection. At present there are lots of researches on the dynamics of information spreading such as Refs. 5–9 which all refer to epidemic models like *SIR* model[10] or *SIS* model.[11] They are due to the similarities between the propagation process of information and infectious diseases. Reference 12 evaluated the influence of events through drawing up influence indexes in detail and setting proportion of them. References 13 and 14 researched on propagation forms, influence analysis and influence evaluation rules. We can see few articles associated model with analysis of information influence at present. This paper proposed a new method of influence evaluation based on *SIR* model and analyzed simulation results.

Atomic bomb[15] releases enormous energy and produces a nuclear explosion instantly through neutrons induce nuclear fission of uranium-235 (or plutonium-239) and formation of chain reaction. A message is like a neutron entering social network, more messages will form after one person forwards it and then more users will receive. A certain amount of social "energy" will release, when a user forwards the message. According to the similarity of chain reaction principle and the characteristics of information propagation on social network, we proposed a new word "information bomb". Based on the complex networks and *SIR* model, dynamical evolution equations were setup. Then methods using to evaluate the four indexes of bomb power were given, including influence breadth, influence strength, peak time and relaxation time. At last, the power of information was ascertained through these

[a] www.facebook.com.
[b] www.sina.com.

indexes. Parameters which impact on the power of information bomb are analyzed and some methods which control the propagation of information are given.

2. Information Spreading Model Based on *SIR* Model

2.1. *Mechanism and model*

In this paper, several key terms of infectious disease model are used to divide social network nodes into three classes: susceptible, infective and immune. Susceptible nodes (S) represent that nodes have not learnt the information but they have the ability to absorb and broadcast. Infective nodes (I) represent that nodes have accepted the information and were forwarding to adjacent nodes. After forwarding, they decayed to immune and release a certain amount of social energy. Immune nodes (R) represent that nodes are not interested in or trust the information.

Now the most widely used model is *SIR* model in researches of information propagation on social networks. However *SIR* model did not take into account that susceptible nodes might turn into immune directly, which did not need the course of infection. The spreading model proposed in Ref. 7 considered that infective nodes stopped transmitting by a certain amount of speed. However people on actual network will not forward the same message, if it has been forwarded. So in this paper, infective nodes will turn into immune with one probability. The propagation rules of model are as follows:

- At t time, we assume the average amount of susceptible nodes which adjacent to a infective node is proportional to total amount of the susceptible on network and the coefficient of proportionality is μ. Therefore, the amount of susceptible nodes which is adjacent to the infective at t time is $\mu I(t)S(t)$.
- Susceptible nodes which is adjacent to the infective receive information with a certain probability α.
- Susceptible nodes which have received information turn into infective with probability p or turn into immune with probability $1 - p$.
- Infective nodes turn into immune with one probability after forwarding the information.

The total amount of nodes $N = S(t) + I(t) + R(t)$, spreading model can be described by the following differential equations:

$$\begin{cases} dS(t)/dt = -\alpha\mu S(t)I(t), \\ dI(t)/dt = p\alpha\mu S(t)I(t) - I(t), \\ dR(t)/dt = (1-p)\alpha\mu S(t)I(t) + I(t). \end{cases} \tag{1}$$

Information added coefficient $A(t) = p\alpha\mu S(t)$, which means the average amount of new infective nodes generated after one infective node propagates information. When $dI(t)/dt = 0(A(t) = 1)$, infective nodes $I(t)$ reach the maximum. At this moment, the influence of information on network reach the maximum too. Therefore, the time t is assumed as the explosion point of information.

2.2. *Power of information bomb*

This paper refer to Refs. 12, 16 and 17 divides evaluation indexes of information influence into four terms: Influence breadth, influence strength, peak time and relaxation time. Then the power of information is evaluated from these four aspects.

2.2.1. *Influence breadth*

Influence breadth measure the scope and scale of network which information impact on. In this paper, we mainly refer to the proportion (W) which the sum of infective nodes during whole process is devoted to total number N. The more W approaches to 1, the more of an impact it can make.

$$W = \frac{\sum_{t=0}^{\infty} I(t)}{N}. \tag{2}$$

2.2.2. *Influence strength*

Influence strength measures the strength which information impact on. In this paper, we mainly refer to the proportion (M) which the number of infective nodes devoted to total number N when it reaches the maximum:

$$M = \frac{\max(I(t))}{N}. \tag{3}$$

In many cases, influence strength is more important than influence breadth. The explosion which is short-duration and high-intensity can bring stronger destruction of society.

2.2.3. *Peak time*

Peak time measures the sensitivity of network to the information. In this paper, we mainly refer to the time (t_p) from information entering the network to the number of infective nodes reach the maximum, in which $I(t_p) = M$.

2.2.4. *Relaxation time*

Relaxation time measures the influence degree of fast variables. In this paper, we mainly refer to the time (t_r) from information entering the network to the network tends to be stable, in which $I(t_r) = 0$.

2.3. *Calculation and analysis*

From Eq. (1) we can see that t_p, t_r is related to p, α, μ. Here is the solution process of parameter p when t_p reach the maximum, in which α, μ are constants:

$$\frac{dI}{dS} = \frac{1 - p\alpha\mu S}{\alpha\mu S}. \tag{4}$$

The integral is:

$$I(t) = \frac{1}{\alpha\mu}\ln(S(t)) - pS(t) + C, \quad C = I(0) + pS(0) - \frac{1}{\alpha\mu}\ln(S(0)), \tag{5}$$

$$\frac{dS(t)}{dt} = -\alpha\mu S(t)I(t) = -\alpha\mu S(t)\left(\frac{1}{\alpha\mu}In(S(t)) - pS(t) + C\right) \tag{6}$$

When

$$t = t_p, \quad k(t_p) = 1 : S(t_p) = \frac{1}{p\alpha\mu} \Rightarrow \tag{7}$$

$$\frac{dS(t_p)}{dp} = -\frac{1}{\alpha\mu p^2} \Rightarrow \frac{dS(t_p)}{dt_p}\frac{dt_p}{dp} = -\frac{1}{\alpha\mu p^2} \Rightarrow \frac{dt_p}{dp} = -\frac{1}{\alpha\mu p^2 \frac{dS(t_p)}{dt_p}}. \tag{8}$$

Taking (8) into (7), so:

$$\begin{aligned}\frac{dS(t_p)}{dt_p} &= -\frac{1}{p}\left(\frac{1}{\alpha\mu}\ln\left(\frac{1}{p\alpha\mu}\right) - \frac{1}{\alpha\mu} + C\right) \Rightarrow \frac{dt_p}{dp} \\ &= \frac{1}{\alpha\mu p\left(\frac{1}{\alpha\mu}\ln\left(\frac{1}{p\alpha\mu}\right) - \frac{1}{\alpha\mu} + C\right)},\end{aligned} \tag{9}$$

$$\frac{dt_p}{dp} = \frac{1}{p\left(\ln\left(\frac{1}{p\alpha\mu}\right) - 1 + \alpha\mu I(0) + p\alpha\mu S(0) - \ln(S(0))\right)} \tag{10}$$

When

$$\ln\left(\frac{1}{p\alpha\mu}\right) - 1 + \alpha\mu I(0) + p\alpha\mu S(0) - \ln(S(0)) = 0 \tag{11}$$

dt_p/dp tends to be infinite. So t_p reaches the maximum when p is the value which Eq. (11) works out. The above is also the solution process of parameter p when t_r reach the maximum, because $A(t_r)$ tends to 1 when the intensity of infective nodes tend to zero. We can also launch that if two of μ, α, p parameters are definitive, the third one exist a value that makes t_p, t_r reach the maximum.

In actual networks, the bigger influence breadth and influence strength are, the more influence they make. But the bigger peak time and relaxation time are, the less influence they make.

3. Simulation and Analysis

3.1. *Data description of network model*

Data of network model were extracted from 11 856 users of the most famous SNS site (sina weibo) in China at present, these users are looked as nodes and relations that

Table 1. Characteristic parameters of network model.

Nodes	Edges	Average degree	Max degree	Clustering coefficient	Correlation coefficient
11 856	30 828	5.21	134	0.289578	−2.379

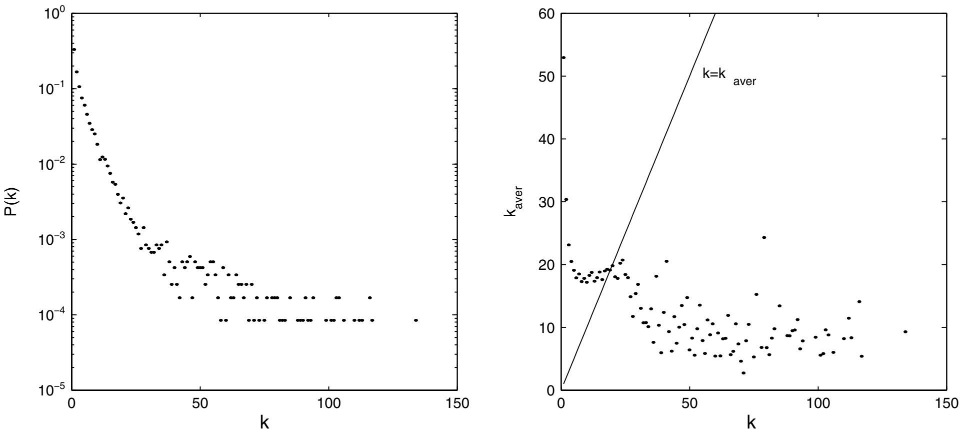

Fig. 1. Degree distribution and degree correlation of network model.

fans for each other are looked as connecting edges. The topological characteristic parameters of model are shown in Table 1. Degree distribution and degree correlation are shown in Fig. 1, in which k_{aver} means the average degree of nodes adjacent to those whose degree are k. From Table 1 and Fig. 1, these characteristics of network model can be seen: power-law degree distribution, big clustering coefficient, disassortative network. Therefore, this model conforms to the characteristics of real SNS network which can be regarded as the spreading base map.

3.2. *The analysis of information propagation process*

In this paper, the model which is made up with users data of sina weibo is regarded as base map. According to the information spreading model proposed above, the process of information spreading on real social network is simulated. In view of the average degree of model which is 5.21, we select one node ($k = 5$) as infective node in the initial state and others are susceptible, so $S(0) = N - 1, I(0) = 1, R(0) = 0$. The experiment is repeated 30 times.

(1) According to actual situation, we suppose the model parameters as follow: $\alpha = 0.8$, $p = 0.6$. Curves of $S(t)/N, I(t)/N, R(t)/N$ changing with time t during transmitting is shown in Fig. 2. $S(t)/N$ declines rapidly with $I(t)/N$ and $R(t)/N$ increasing and tends to be stable at last. $I(t)/N$ increases rapidly in initial stage, after reaching the maximum (the explosion point of information), it gradually reduces until being zero. $R(t)/N$ increases rapidly in initial stage with $I(t)/N$

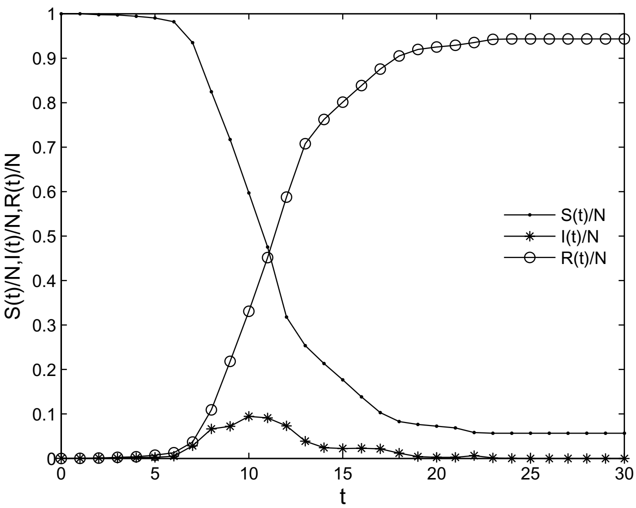

Fig. 2. Density curves of different nodes changing with time.

increasing and then gradually increases until being stable. $R(t)/N$ does not tend to 1, because $\alpha = 0.8$ that not all nodes receive this information. It conforms to characteristics that information spread on real network.

(2) Three kinds of node densities tend to be stable when t tends to infinity. Figure 3 shows curves of $S(\infty)$ and $R(\infty)$ changing with p when α take different values. We can find out the bigger p, α are, the wider information is spread. When p and α equal 1, $S(\infty) = 0$ and $R(\infty) = 1$. When $\alpha = 0.1$, $S(\infty)$ and $R(\infty)$ have barely budged, that is because the average degree of this model $k_v = 5.21$, α and p are so small that average added coefficient of information $A_v = \alpha p k_v < 1$, information

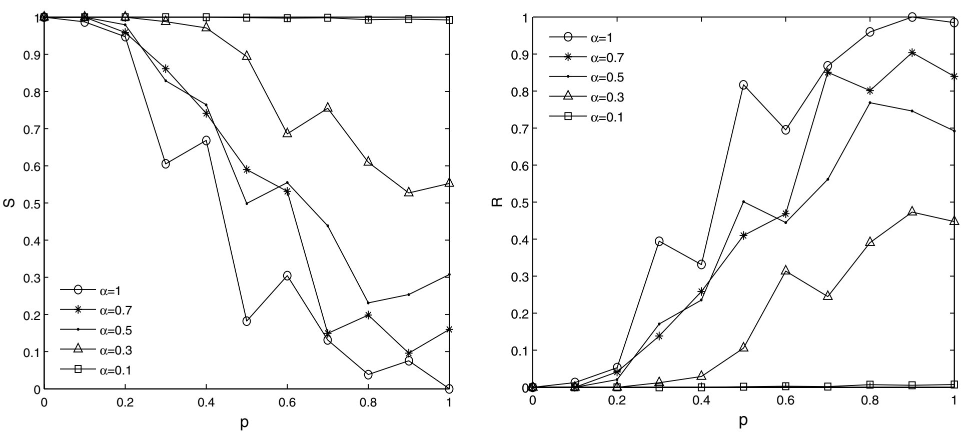

Fig. 3. Curves of $S(\infty)$ and $R(\infty)$ changing with p when α take different values.

cannot be spread out. Like *SIS* model have an epidemic threshold, this model also has a critical value that $A_v > 1$.

3.3. *The power analysis of information bomb*

(1) Figure 4 shows curves of influence breadth W and influence strength M changing with p, when α take different values. When $p = 1$ and $\alpha = 1$, influence breadth $W = 1$. If α and p are so small that $A_v < 1$, W and M will be very small and as α and p increasing that $A_v > 1$, W and M will rise rapidly.

(2) Figure 5 shows curves of peak time t_p and relaxation time t_r changing with p when α take different values. As shown, that peak time t_p and relaxation time t_r rise at first and then decrease with p increasing. The highest points of t_p, t_r (also called

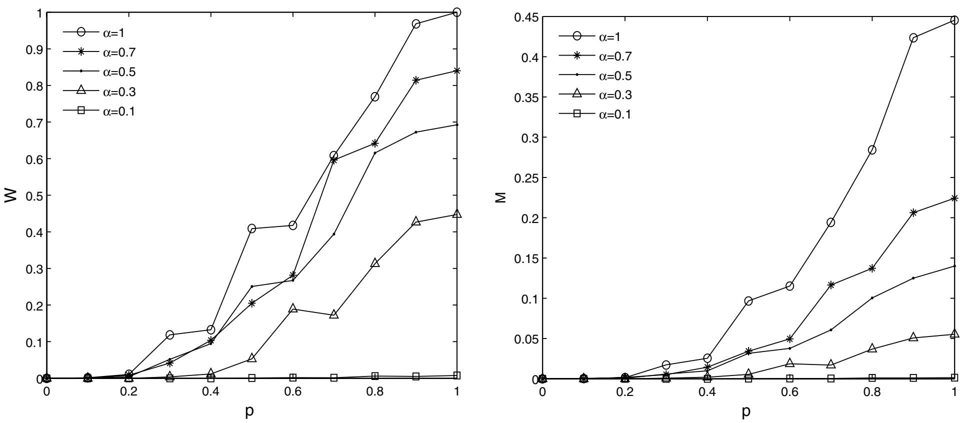

Fig. 4. Curves of influence breadth W and influence strength M changing with p when α take different values.

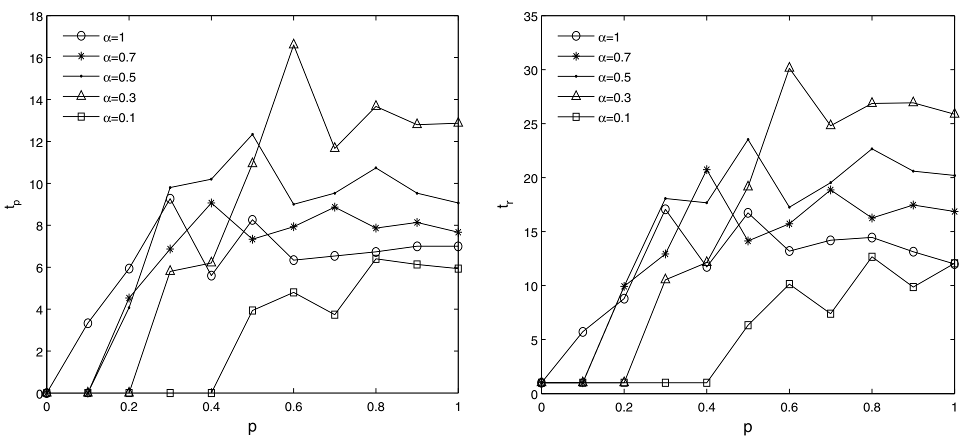

Fig. 5. Curves of peak time t_p and relaxation time t_r changing with p when α take different values.

transition point) are nearby $A_v = 1$, while the theoretical value which puts out from information spreading model, see Eq. (11). Before transition, the bigger α is, the bigger t_p, t_r will be. After transition, the bigger α is, the smaller t_p, t_r will be. When $\alpha = 0.1$, A_v has less than 1, so the curve has no transition.

From Figs. 4 and 5, we can see that transition point is crucial in evaluating information influence. Before transition, t_p, t_r are small, but so are W, M. Around transition point, W, M increase in size, but t_p, t_r also increase rapidly. On networks, if information spread over a long period of time which gives sufficient time to artificially suppress information spreading, influence will be a lot less. Only after transition, W, M are big enough and t_p, t_r are relatively small, information influence become enormous.

(3) The influence of information power that the degree of initial infective node makes is researched. When $k_0 = 1, k_0 = 5, k_0 = 134$, density curves of infective nodes changing with time are shown in Fig. 6.

As shown in Fig. 6 and Table 2, the bigger the degree of initial infective node is, the bigger W, M are, but the smaller t_p, t_r will be. Thus, the power of information

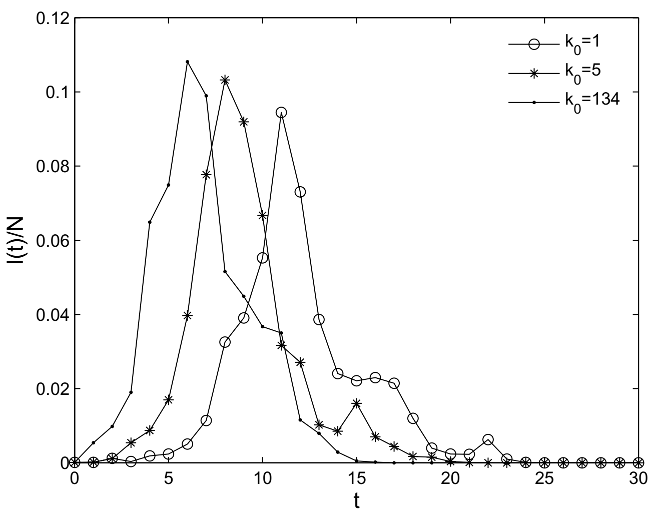

Fig. 6. Density curves of infective nodes changing with time when $k_0 = 1, k_0 = 5, k_0 = 134$.

Table 2. The values of evaluation indexes with different degree of initial infective node.

Evaluation indexes	$k_0 = 1$	$k_0 = 5$	$k_0 = 134$
W	0.47	0.52	0.57
M	0.094	0.103	0.108
t_p	11	8	6
t_r	25	21	17

which spread from central nodes is larger than normal ones. It fully illustrates celebrity firepower.

4. Control Strategies of Information Influence

Based on spreading model, information propagated on the network has the following characteristics:

- From Eq. (1) we can see, the power of information bomb which parameter μ impacts on is same as parameter α, but it is relatively stable and determined by the scale and structure of the network. The closer network structure is, the bigger μ will be.
- Parameter α is related to some uncertainties and the activity of nodes which is adjacent to the infective.
- Parameter p determined by the attractiveness and importance levels of information.

On normal social networks, the value of parameter p will be different as information is different, but parameter μ is relatively stable. If we want to control information influence, the only thing can be done is parameter α is forced to change artificially. This paper therefore proposed these control methods of information influence as follows:

- The shape part of information can be highlighted to raise p, or be blurred to reduce p during the process of information propagation.
- The time that information stay on the list or the space of the information is increased to raise α. Or information is filtered during propagation process to reduce α.

However, what we should pay attention to is, it may happen that peak time and relaxation time will increase with α and p increasing before transition. Thus α and p need to be ensured small or big enough, so that all evaluation indexes could meet the requirements.

5. Conclusion

According to the similarity of chain reaction principle and the characteristics of information propagation on social network, we proposed a new word "information bomb". Based on the complex networks and *SIR* model, dynamical evolution equations were setup and the moment of information explosion is pointed out. Then methods used to evaluate the four indexes of bomb power were given, including influence breadth, influence strength, peak time and relaxation time.

Simulation results show that spreading model conforms to the characteristics of information propagation process on actual social network. The power of information bomb is impacted by α, p parameters. If α, p are so small that average added coefficient of information $\text{Av} < 1$, information cannot be spread out. Transition point is crucial in evaluating information influence. The power of information which spread from central nodes is bigger than the normal ones. We can calculate α and p in early days of information dissemination and get N and A_v after understanding the scale and structure of networks to predict the power of information bomb, then take control measures before the explosion. In fact, information bombs are not necessarily negative. If they are positive energy information, they will take great contribution for the society. Especially if merchants understand the rules of it rationally and regularly, make adjustments after predicting the influence of advertising. It not only enhances efficiency but also reduces costs and is very beneficial to the promotion of products.

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