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A physical pathway to understand individual's labeling behavior in signed social networks

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ABSTRACT

In this paper we propose a reshuffling approach to empirical analyze individual's labeling behavior in signed social networks. In our approach, each individual is assumed to have the ability to re-label his/her neighbors randomly with the parameters p_s and p_+. Many reshuffled networks, which have the same topological structure and different signs' configuration, are built through applying our approach to the given three signed social networks. The entropy S_{out} and the giant component ρ_G for each reshuffled networks are calculated and analyzed. We find that there exist two kinds of individual's labeling behavior according to the suppressed effect of S_{out} and the exponent α in the relationship of ρ_G and q_+. Additionally, the suppressed effect of S_{out} shows the non-randomness factor in individual's labeling behavior. These results offer new insights to understand human's behavior in online social networks.

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1. Introduction

Online social networks, such as the EBay, Epinions and Slashdot, provide the convenient platforms to manage social interactions. Social interaction can be better set out in the framework of the networked games [1,2], such as the Hawk–Dove game, prisoner's dilemma game and so on. For a given item, each individual has a tendency to express his/her attitude to improve his/her own payoff during the game process. Specially, the sign of a link is defined as "+" or "-" depending on whether it expresses a similar or opposite attitude from the generator of the link to the recipient [3]. For example, people can tag directed relations to items or others indicating trust or distrust in the trust network of Epinions, users can designate others as "friends" or "foes" in the social network of the technology blog Slashdot, and users can vote for or against another to be a admin in the vote network of Wikipedia [4]. Those social networks involving both positive and negative links can be represented in terms of signed social networks [5–8].

The primary interesting issue is to reveal signs' organization in real signed social networks. The social balance theory [9] and the status theory [3] are the two main social-psychological theories about signs' organization in social networks. The social balance theory was first articulated by Heider, based on the adages that "the friend of my friend is also my friend", "the enemy of my friend is my enemy" and so on [10,11]. The social balance theory has recently attracted more attention from sociologists and physicists, and is applied to the core questions of sign prediction [3], dynamical behavior [12,13] and the community detection [14]. The status theory was developed by Leskovec et al. [3] and applied in directed signed network. In the status theory, a positive link (u,v) means that u regards v as having higher status than himself/herself while a negative link (u,v) means that u regards v as having lower status than himself/herself. Both of those theories were considered from the local structure property in signed networks, for instance, triad types in the social balance theory and two-tuples types in the status theory. However, whether a link is labeled as a positive sign or negative one, i.e., how does individual label his/her neighbors (individual's labeling behavior), is seldom considered based on the subjective initiative of human in online social networks. Since human is an intelligent agent, whose social behavior is a complex process and not random completely.

To fill this gap, we propose a reshuffling approach to investigate individual's labeling behavior on the directed signed social networks of Epinions, Slashdot and Wikipedia. In our reshuffling approach, we assume that each individual has ability to relabel his/her neighbors randomly with a pair of parameters p_s and p_+, which can be regarded as a perturbation process in the real signs' configuration. Many reshuffled networks, which has the same topological structure and different signs' configuration, are built through operating our reshuffling approach on the three given signed social networks. We calculate the entropy S_{out} and the giant component ρ_G for each reshuffled network and analyze the relationships of S_{out} and ρ_G and the parameters p_s and p_+ respectively. We find that the values of S_{out}s and ρ_Gs for reshuf-

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fled networks are equal to the value of that for the real signed networks respectively at the fixed p_+^c, which is independent of p_s. What's surprise, p_+^cs of the networks of Epinions and Slashdot are the same and about equal to 0.9, which is different from that of the vote networks of Wikipedia. Furthermore, we found that the reason leading to the difference is the existence of the non-randomness in individual's labeling behavior, whose clear evidence is the suppressed effect of S_{out} in the relationship of S_{out} and q_+.

2. Description of signed social networks and our reshuffling approach

To begin with, we consider a directed signed social network $G = (V, L, A)$, where V is the set of vertices, L is the set of directed links, $A = \{A_{uv}\}$ is the signed adjacency matrix where $A_{uv} \neq 0$ if and only if $(u, v) \in L$, and A_{uv} is the sign of link (u, v). A positive sign $A_{uv}(= +1)$ represents that u tags v as a friend or u trusts v or u votes for v, while a negative sign $A_{uv}(= -1)$ reflects that u tags v as a foe or u distrusts v or u votes against v. Each directed signed social network has its own macroscopic parameters (N_v, N_l, q_+^0): the number of vertices N_v, the number of directed links N_l and the ratio of the positive links q_+^0. Generally, social networks are time-varying networks [15–18], where vertices and links are not always active simultaneously. Hence, in order to research the topology structure of the social network, we should reduce the time-varying network to a static one during a given time period.

We here focus on the individual's labeling behavior of the three famous signed social networks: the trust network of Epinions, the social network of Slashdot and the vote network of Wikipedia. Epinions is a product review Web site with a very active user community. The data of the trust network of Epinions with the macroscopic parameters $(131828, 841372, 0.853)$, where a signed link indicates that one users trust or distrust of the reviews of another, is obtained from the inception of the site in 1999 till in August 12, 2003 [3,4]. Slashdot is a technology-related news website, which provided the Slashdot Zoo to allow users to tag each other as "friends" or "foes" since 2002. The social network of the Slashdot with the macroscopic parameters $(77357, 516575, 0.767)$, where a signed link indicates that one user like or dislike the comments of another, is obtained in November 6, 2008 [3,4]. The vote network of Wikipedia (Wikielec) with the macroscopic parameters $(7118, 103675, 0.784)$ is the network of users from the English Wikipedia that voted for and against each candidate to be administrators in admin elections (the dataset is downloaded from http://konect.uni-koblenz.de/networks/elec) [19].

A given signed social network with two constant macroscopic parameters N_v and N_l can be regarded as an isolated system, which obeys the ergodic hypothesis from the viewpoint of statistical mechanics. According to the ensemble theory in statistical mechanics, each real signed social network has 2^{N_l} possible microstates, which is related to the signs' organization. Different signs' organization describes different microstate. However, there must exist one specific microstate which has the same signs' organization of the real signed social network. The main goal is to analyze individual's labeling behavior through analyzing the differences between the real signed network and it's reshuffled networks based on the information theory and the percolation theory.

Hence, we introduce a reshuffling approach to build the reshuffled networks through resetting links' signs in the given signed social network with the macroscopic parameters N_v and N_l fixed. The key idea is that each individual is assumed to have an ability to re-label his/her neighbors in our reshuffling approach. There are two operation steps during applying our reshuffling approach to the given signed social networks. Firstly, each link is chosen as

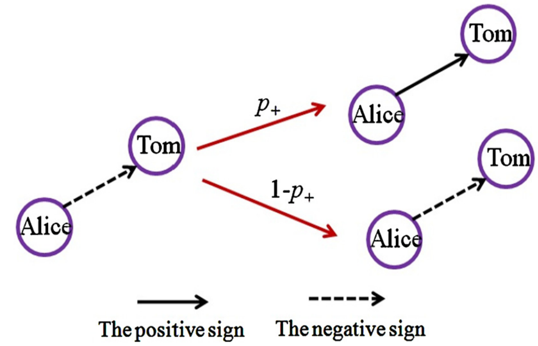

Fig. 1. (Color online.) The illustration of our reshuffling approach. In the reshuffling approach, each link, take the link from Alice to Tom for example, is chosen as the activity one with probability p_s. And then each activity link's sign is reset as the positive one with probability p_+, or as the negative one otherwise.

a activity one with probability p_s, which is called the reshuffling probability and describes the signs' resetting ability of individual. Secondly, each activity link is reset its sign as the positive one (sign "+") with probability p_+ or the negative one (sign "-") otherwise, see the illustration of our approach in Fig. 1. The reshuffled signed network is fixed when the reshuffling process finished, and so the ratio of the positive sign can be written as

$$q_+(p_+, p_s) = q_+^0 + (p_+ - q_+^0)p_s. \tag{1}$$

The reshuffled signed network returns to the real one when $p_s = 0$. While all signs will be reshuffled thorough randomly when $p_s = 1$, and the non-randomness factor of individual's labeling behavior disappears. The novel in our reshuffled approach is that the non-randomness reduces to null as p_s increasing from zero to one, and our present work provides a feasible approach to uncover the signal of non-randomness in society directly.

3. Results from information entropy

Analogously to an Ising model, a positive link is mapped as one with spin "↑" while a negative link as one with spin "↓". The presence of negative links introduce disorder (or frustration) in signed social network [5], where the sign of a link also describes the social property, such as friend and enemy, of the corresponding connection between individuals. Each individual has his/her self social status according to signs of his/her connections [20]. The self social status $p_{i(out)}^+$ of individual i is defined as the proportion of the positive links directing to his/her local neighbors due to the subjective initiative of human. The difference among individuals' social status, which is described as the distribution of individuals' social status, can reflect the disorder of signed social network. It is obvious that $0 \leq p_{i(out)}^+ \leq 1$ and the distribution of $p_{i(out)}^+$ with the bin width τ is defined as

$$\pi_j^{out} = \frac{\sum_{i=1}^{N_v} \delta(j\tau \leq p_{i(out)}^+ \leq (j+1)\tau)}{N_v} \tag{2}$$

where π_j^{out} is the probability that each vertex i with $p_{i(out)}^+$ falls in the bin of $(j\tau \leq p_{i(out)}^+ \leq (j+1)\tau)$, and $\delta(x)$ is the step function. $\delta(x) = 1$ when the condition x is true, and $\delta(x) = 0$ otherwise. When the reshuffling probability p_s is given (i.e., the microstate of the system is given), the probability distribution $\{\pi_j^{out} | j = 0, 1, 2, ..., (\lfloor \frac{1}{\tau} \rfloor - 1)\}$ is fixed.

The application of the entropy concept in complex networks is widely and deeply [21–25], since information entropy de-

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