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Conformity-based cooperation in online social networks: The effect of heterogeneous social influence

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ABSTRACT

This paper extends the conformity model by introducing heterogeneous social influence into the analysis. We associate the influence of a player in the network with its degree centrality assuming that players of higher degree exhibit more social influence on its neighbors. The results show that the equilibrium level of cooperators can be dramatically enhanced if the conformity-driven players are preferentially influenced by neighbors of higher degree. We attribute this finding to two elementary mechanisms in the evolutionary process: (1) degree-based social influence facilitates the formation of strategic clusters around hubs; and (2) payoff-heterogeneity between cooperative clusters and defective clusters contributes to the promotion of cooperation. This research reveals the important role of heterogeneous social influence on the emergence of cooperation in social networks.

1. Introduction

The existence of social influence has been widely demonstrated not only among animal species but also within human societies [1–7]. The rapid advancement of internet technology and the subsequent booming of online social network services (OSNS) have further amplified this effect by accelerating information exchanges among individuals in online communities. OSNS users are more likely to be influenced by peers and the so called “herding effects” are observed by many previous studies [8]. Social influence theory asserts that individuals of the group tend to imitate the behavioral patterns of the majority despite that sometimes such behaviors do not represent the personal interest of the individual. Therefore, social influence enables the decision making process of the individual to deviate from the rational track and thus the observed behavioral patterns are usually different from the theoretically predicted ones. Most recently, Szolnoki and Perc proposed a conformity model to illustrate how this interesting phenomenon impacts the emergence of cooperation in social dilemma [9]. In their seminal work, the whole population is categorized into two groups: conformity-driven players and payoff-driven players. The conformity driven players prefer to adopt the strategy that is the most common within its neighborhood, while the payoff driven players tend to imitate the strategy that produces more payoffs according to Fermi’s rule. Their study shows that a moderate level of conformity-driven players significantly enhances cooperation in prisoner’s dilemma games on artificial networks like lattice grid and Barabasi–Albert (BA) network.

In this paper, we plan to further extend their research by introducing real online social network structures into the model. We not only show that the conformity model is also valid in real social network context, but also propose a simple but effective mechanism to further promote network reciprocity. Based on the conformity model, we introduce degree-based heterogeneous social influence for conformists, where players with higher degree are considered more influential. It turns out that this revised

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mechanism significantly enhances the equilibrium level of cooperators in conformity models. Many previous literatures have demonstrated the heterogeneous individual effects on promoting cooperation in evolutionary games [10–13]. In this paper, we will focus on the heterogeneous social influence on conformists, which are the most significant features of real-world networks. This research shows that degree-based social influence can significantly strengthen the effect of payoff heterogeneity around hubs and therefore elevate the level of cooperators in equilibrium.

The remainder of the paper is organized as follows: In Section 2, we give a detailed description of the network dataset and the revised conformity model. Simulation results are presented in Section 3. In Section 4, we summarize the results and outline the practical implications of our findings.

2. The model

Initially, equal percentage of cooperators (C) and defectors (D) are randomly distributed in the whole population. The game interactions of each pair follow the prisoner's dilemma game (PDG) rule: both players get R (reward) for mutual cooperation and P (punishment) for mutual defection. A defector exploiting a cooperator gets T (the temptation to defect) and the exploited cooperator gets S (the sucker's payoff). R, P, T, and S satisfy following conditions: $T > R > P > S$ and $2R > T + S$. Without losing generality, we predominantly consider the rescaled PDG where $T = b > 1$, $R = 1$, $P = S = 0$. According to random sequential update rule, a randomly selected player x accumulates its payoff Π_x by playing with all neighbors in each round. Then, player x randomly chooses a neighbor y, who also acquires its payoff via the same mechanism as x. Then, player x will adopt y's strategy with a probability determined by Fermi's function:

$$\Gamma(\Pi_x - \Pi_y) = \frac{1}{1 + \exp\left((\Pi_x - \Pi_y)/\omega_1\right)} \tag{1}$$

where ω_1 denotes the noise parameter in the strategy shifting process. We set $\omega_1 = 0.1$ here in the model to make sure that most players readily adopt the strategies of the better-performing opponents, despite that some may learn from the worse opponents with a small probability due to error and mistake.

Moreover, according to the conformity model, a fraction of the whole population is considered as conformity-driven players, who are totally indifferent to payoffs and are only influenced by the strategy of neighbors. As Szolnoki and Perc proposed, a conformity-driven player simply adopts the strategy that is the most common within its neighborhood. Similar to Eq. (1), a player adopts strategy s_x with a probability defined by Eq. (2):

$$\Gamma(N_{s_x} - k_h) = \frac{1}{1 + \exp\left((N_{s_x} - k_h)/\omega_2\right)} \tag{2}$$

where N_{s_x} denotes the number of players adopting s_x within x's neighborhood, ω_2 is the noise parameter and k_h is one half of the degree of player x. This function enables most conformists adopt the most prevalent strategy within their interaction range while maintains a very small possibility that some may learn from the minority.

Table 1
Primary parameters of the two networks.

	Dataset 1	Dataset 2
Connected vertices	769	6596
Connected edges	11,656	293,320
Diameter	6	9
Average connectivity	15.15	44.47
Density	0.0564	0.0135
Average path length	2.3378	2.6761
Clustering coefficient	0.2912	0.1639

It is worth mentioning here that this conformity model assumes that each neighbor poses equal social influence to the conformist when he decides which strategy to follow. However, if we extend the background of the research into the online social network context, this assumption can hardly hold. As demonstrated by numerous studies, heterogeneous influence does exist in online communities [14–18]. Several super stars, politicians and commercial figures compose opinion leaders of the community, whose social influence is apparently higher than ordinary users. To account for this observation, many studies associate the degree of social influence or social status of a user with its degree centrality in the network. In this paper, we also plan to adopt this assumption by rescaling N_{s_x} in Eq. (2) with degree-based weight. Let d_i denote the degree of play i, then the rescaled N_{s_x} can be expressed by R_{s_x} as follows:

$$R_{s_x} = \frac{\sum_{i \in \Omega_{s_x}} {d_i}^{\alpha}}{\sum_{j \in \Omega x} {d_j}^{\alpha}} \tag{3}$$

where Ω_x denotes the players within player x's interaction range and Ω_{s_x} represents those who adopt strategy s_x within x's neighborhood. α in the model is a tunable parameter that controls the extent of degree-based heterogeneity of social influence. Therefore, R_{s_x} represents the degree-normalized percentage of players adopting s_x in x's neighborhood and k_h should also be rescaled to 0.5. As a result, the probability that a player x adopting strategy s_x under heterogeneous social influence is redefined as follows:

$$\Gamma(R_{s_x} - 0.5) = \frac{1}{1 + \exp\left((R_{s_x} - 0.5)/\omega_2\right)} \tag{4}$$

It is worth noting here that the noise parameter ω_2 is set to be smaller (0.02) than ω_1 (0.1) here in the simulation since the scale of the payoff difference in Eq. (1) is significantly larger the the percentage of neighbors (R_{s_x}).The simulation is performed on two facebook datasets with different network sizes (from very small to very large) to test the robustness of the conclusion. The establishment of friendship in Facebook requires mutual authentication, thus we can infer an undirected graph of its network structure [19]. A comparison of primary parameters of the two networks is made in Table 1. It is obvious that the two networks are still heterogeneous networks despite that their degree distributions do not follow power-law form (Fig. 1).

The simulation procedures are as follows: in each iteration, the above described elementary steps are repeated for 1,000,000 times. The equilibrium fraction of cooperators is averaged over 100 independent runs.