Local Norm Phenomena in Multi-Agent Systems under Community Networks

(Extended Abstract)

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ABSTRACT

This paper investigates how *local norm emergence*, other than conventional global norm emergence, helps to achieve coordination among agents in multi-agent systems. That is, when agents are partitioned into communities, different communities of agents establish different social norms. We provide a definition of local norms and propose two metrics, namely, conformity to local norms and diversity in agents' actions, to characterize the strength and diversity of local norms. The experimental results show that local norm emergence is more commonly found than global norm emergence under networks with significant community structure. In addition, it is also shown that community sizes and link density significantly affect how fast local norms emerge.

Keywords: Local Norm, Convention, Emergence, Community Networks.

1. INTRODUCTION

Social norms, such as driving on a particular side of a road and standing in line, dictate how people should behave and are effective measures to reduce conflicts in human society. To facilitate the coordination among agents, recently, the concept of social norms has been widely applied to various kinds of multi-agent systems where conflicts among agents usually occur.

Prior work [3, 4] has shown that it is possible for agents to achieve coordination via their own distributed interactions, as opposed to the high-cost centralized authority. Specifically, when agents are learning over the repeated pure coordination games, a globally conformed social norm (or a global norm hereafter) can naturally emerge as the result.

It is well recognized that the underlying network topology is a critical factor of social norm emergence in multi-agent systems. In this paper, we place agents on networks with community structure (or community networks) [2], such that agents are partitioned into several communities. The connections within each community are dense, however, the connections between different communities are sparse. It is unclear, a priori, if and how agents achieve coordination under such networks. We hypothesize that due to the sparse inter-community connections, a social norm is difficult to pervade the whole system and thus the conventional global norm emergence is unlikely to exist. In human society where a number of communities exist, different communities of people usually conform to different social norms. For example, on which particular side drivers of a country should drive may vary in different countries. We expect that such phenomena may extensively exist in multi-agent systems under community networks. That is to say, while agents of the same community conform to a social norm (which is referred as a local norm in this work) to achieve coordination, the local norms that different communities conform to are generally different.

To verify our hypothesis, we define a local norm to be a restriction on agents' behaviours within a community. We propose two metrics to measure the strength and diversity of local norms. Experiments are conducted on multi-agent systems under community networks. Our results confirm our hypothesis and show that with denser connections and smaller community sizes, it takes local norms fewer iterations to emerge.

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	action a_1	action a_2
action a_1	**1,1**	-1,-1
action a_2	-1,-1	**1,1**

Table 1: Payoff Matrix of a 2-player-2-action Pure Coordination Game

2. LOCAL NORMS AND MEASURES OF EMERGENCE

In a 2-player-m-action pure coordination game, both players have a set $A = \{a_1, a_2, \ldots, a_m\}$ of available actions and are rewarded for using a particular action $\hat{a} \in A$ out of the m actions. Therefore, there are m Nash equilibria which are equally good, which denotes m possible ways to achieve coordination in this game. An example of such a game where $m = 2$ is shown in Table 1.

2.1 Local Norms

Consider a system of agents, where agents are partitioned into a set C of communities, such that each agent belongs and only belongs to one community $c \in C$. We define a local norm of a community $c \in C$ under the scenario of pure coordination games to be a restriction on agents of the community c to choose a certain action $\hat{a} \in A$.

2.2 Conformity to Local Norms

We first measure the conformity to an individual local norm. Intuitively, to what degree a community of agents conforms to its local norm should concern how uniform agents' actions within this community is, since all Nash equilibria are equally good in a pure coordination game. We thus define the local norm conformity γ_c of any community $c \in C$, as follows.

$$\gamma_c = 1 - \frac{1}{\log_2 |A|} H(a|c) \tag{1}$$

where $\frac{1}{\log_2 |A|}$ normalizes γ_c to a scale of $[0, 1]$, and $H(a|c)$ is the entropy of agents' actions in community c, such that $H(a|c) = -\sum_{a \in A} p(a|c) \log_2 p(a|c)$ and $p(a|c)$ is the relative frequency of agents choosing the action a in community c.

Weighing the sizes of different communities, we then aggregate the local norm conformity γ_c of each community $c \in C$ to obtain the overall local norm conformity γ of a system, as follows.

$$\gamma = \sum_{c \in C} p(c)\gamma_c \tag{2}$$

where $p(c)$ is the size of community c and $\gamma \in [0, 1]$.

2.3 Diversity in Agents' Actions

We define the diversity δ in agents' actions of a multi-agent system, as follows.

$$\delta = \frac{1}{\log_2 |A|} H(a) \tag{3}$$

where $\frac{1}{\log_2 |A|}$ normalizes δ to a scale of $[0, 1]$, and $H(a)$ is the entropy of all of the agents' actions in the system, such that $H(a) = -\sum_{a \in A} p(a) \log_2 p(a)$ and $p(a)$ is the relative frequency of agents choosing the action a throughout the system.

By the above two metrics, we can have quantitative measures to distinguish between global norm emergence and local norm emergence. If a system's local norm conformity γ and its diversity δ are close to 1 and 0 respectively, then we can infer that a global norm emerges in this system. On the contrary, if γ is close to 1 but δ is significantly larger than 0, then we can expect that diverse local norms emerge in this system.

3. EXPERIMENTAL RESULTS

In this work, we adopt social learning model [3], so that agents in our experiments cannot observe others' interactions and independently learn their choices on actions by playing repeated pure coordination games (where m is set to 5) with their neighbours. We equip agents with Q-learning with ϵ-exploration and place them on various kinds of community networks which are generated by l-partition model [1]. These networks, more precisely, are random networks with community structure, such that each community corresponds to a dense Erdos-Renyi random graph, while different communities are connected randomly but sparsely. The significance or compactness of the community structure is determined by the average relative ratio of a node's intra-community neighbours to all of its neighbours, which is denoted by σ.

We first measure the social norm emergence under these networks by the traditional 90% convergence metric. According to this metric (which is a metric of global norm emergence indeed), a social norm is considered to emerge in a system if at least 90% of agents in the system use one same action. From our results, we observe that with the increase of the value of σ, the proportion of systems satisfying the 90% convergence metric significantly drops to about 0. This clearly confirms our hypothesis that global norms generally fail to emerge in systems under significant community networks (i.e., networks with large σ).

To find out if and how agents achieve coordination in these systems, we then measure the dynamics of these systems using the conformity γ and diversity δ. We find that, in the early stage, the values of conformity and diversity of these systems are around 0 and 1 respectively. Interestingly, when more iterations are experienced, the value of conformity gradually rises to around 1. In the meantime, the value of diversity has a noticeable decrease. The larger value of σ is, to a larger extent the decrease is. Both the values of conformity (which is close to 1) and diversity (which is significantly larger than 0) then remain stable in all the subsequent iterations. The above results in particular show that, diverse local norms emerge under networks with significant community structure, where the conventional global norm emergence is absent. In other words, in a system under such networks, although agents throughout the system do not conform to a global norm, each community of agents in this system actually conforms to a local norm and the local norms of different communities are generally different. Moreover, under networks with more significant community structure, more diverse local norms usually emerge. Therefore, we conclude that agents under networks with significant community structure can extensively achieve coordination via diverse local norm emergence. Compared with the conventional global norm emergence, diverse local norm emergence is a more commonly found and practical way to achieve coordination for agents under such networks.

We also investigate what network properties affect how fast local norms emerge in systems with significant community structure. We observe that with a larger average degree or a smaller average community size, the conformity and diversity of a system can reach stabilization within fewer iterations. That is to say, diverse local norms emerge faster in systems with denser connections among agents or in systems with fewer agents of each community. We also study the effect of the number of communities. However, the number of communities of a system turns out to have little influence on how fast diverse local norms emerge.

4. CONCLUSIONS

In this paper, we define a local norm in community network-based multi-agent systems to be a restriction of behaviours, which is imposed on a community of agents. We provide two quantitative metrics: local norm conformity and diversity in agents' actions, to measure the emergence of diverse local norms. Our experiments show that coordination is achieved via diverse local norm emergence under networks with significant community structure, where the conventional global norms fail to emerge. Moreover, we also find that agents spend fewer iterations in establishing diverse local norms under community networks with smaller community sizes or with denser connections among agents.

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