Norm Emergence in Multi-Agent Systems After Network Integration

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1 INTRODUCTION

Norms, such as greeting manners and wedding customs, are kinds of “unwritten law” in human societies and generally exist as the form of customs. In practical terms, having social norms simplifies decision making process of the group of people in a society, and therefore to reach corporation efficiently.

Not only in sociology, the concept of social norms has been widely used by multi-agent system literatures to study how agents can reach coordination in multi-agent systems. There are basically two branches of approaches: the prescriptive one, in which central authorities will be declared to specify how agents should behave, and the emergent one, in which a social convention emerges as a natural result of agents’ local interactions. [1] The latter one is more similar to the emergence of the norms in human societies, and also more suitable for open and dynamic systems [2].

According to prior literatures, agents generally establish a globally accepted norm to achieve coordination under different types of networks [2]. This norm, in this paper, is defined as an action that is adopted by the majority (at least 90%) of the nodes in the network.

In this paper, we study the effects of integration with another network during norm emergence. In the integration, new links will be built to bring two networks together, so that the nodes previously in the different networks are able to communicate with each other. By doing so, the norms in these two networks will affect each other, and try to reach a norm as a whole after the integration. In real life, integration is also commonly seen in various scenarios: merging two departments into one unit, mergers and acquisitions between companies, combination of two countries, etc. Usually, the two original groups of people have different customs or habits, which means two different norms are emerging separately in these two groups, but finally, they should still reach a norm as a unified whole, to avoid separation.

In this process, several questions naturally arise: Will the norm necessarily emerge after integration? Will the norm emerged be one of the two norms accepted in the original disjoint networks? What is the key factor to determine which action is going to be the accepted as the final norm?

Inspired by these questions, the possible factors can be divided into two perspectives: the process of integration and the conditions of the two original networks. From the integration perspective, there are different level of togetherness, which means how tightly the two networks are combined [3, 4], and integration algorithms; from the perspective of conditions of the two original networks, there are sizes of these networks, the number of alternate actions, the diversity of agents actions at the point of integration, which is measured by "conformity" defined in [5].

The remainder of the report is organized as follows. Section 2 reviews the works related to this report. Section 3 introduces some concepts of norm emergence and network integration used in this paper. Section 4 presents our experimental study on norm emergence after network integration. Section 5 concludes the report with some directions for the future works.

2 RELATED WORKS

Social norms are regularities of behavior, which is a solution of a recurrent coordination problem, and turn normative with time [5]. In [6], a game-theoretic framework is defined. Also, it is showed that natural emergence of social norms from repeated interactions of pure coordination games by agents is possible. To evaluate the emergence of norms, [7] proposes a widely-adopted criterion: a norm has emerged in a system if at least 90% of agents have converged to choose one same action in the repeated game.

On the one hand, since real-life multi-agent system are systems in networked environments [1], a great amount of researches worked on how the network topology affect norm emergence. For instance, [2] shows that the achievement of norm emergence takes a longer time under a network with larger diameter. However, those works only reveal that agents under different types of networks can generally establish norm to achieve coordination. Making changes during the process of norm emergence seems to be a blank space.

On the other hand, there are also a lot of studies about network integration. [4] uses diameter of the integrated network as the criterion of integration, and discusses the best algorithm to reach the goal diameter with building least new links between the two networks. In [3], "togetherness" is defined from three perspectives, in order to mimic different scenarios in real life. Also, the optimal algorithms to reach different algorithms are also discussed. In this paper, due to the limit of the research period, we only consider the togetherness which is based on diameter of the network as the criterion of integration. Most of these works are concentrated on the integration itself, instead of combining integration with other studies.

Therefore, in this work, we try to integrate two networks during their processes of emerging norms, and investigate key factors that determine which norm will be more overwhelming after the integration.

3 METHODS

To let the norm emerge, we follow the game theoretic framework introduced by [7], where social norms can emerge naturally when agents are learning over the repeated pure coordination games (or precisely 2-player-m-action pure coordination games); to integrate networks, we follow the criterion and optimal algorithm given by [4], where we want to reach a certain diameter during the integration while build minimum new edges.

3.1 Pure Coordination Games

As it is explained in [5]: In the 2-player-m-action pure coordination games, there are multiple optimal joint actions among which agents select to reach coordination. If two agents playing these games choose the same action, they will be rewarded; otherwise, they will be punished. In total, there are m Nash equilibria which are equally good in these games, which denotes m possible ways to achieve coordination for agents.

3.2 Network Integration

The whole algorithmic approach to integrate two networks is from [4]. Therefore, in this paper, instead of providing all the detailed information, only a quick description will be introduced.

We use the definitions in [4]: define a *network* as an undirected unweighted connected graph $G = (V, E)$, where V is a set of nodes and E is a set of edges on V. We write an edge $\{u, v\}$ as uv. A *path* is a sequence of nodes $u_0, u_1, \ldots, u_k$ where $u_i u_{i+1} \in E$ for any $0 \leq i \leq k$. When $u_i =$

u_k, the path is a *circle*. The *distance* between u and v, denoted by $\mathrm{dist}(u, v)$, is the length of a shortest path from u to v. The *eccentricity* of u is $\mathrm{ecc}(u) = max_{v \in V}$ $\mathrm{dist}(u, v)$. The *diameter* $\mathrm{diam}(G)$ of G is $max_{v \in V}$ $\mathrm{ecc}(G)$. The *radius* $\mathrm{rad}(G)$ of G is $min_{v \in V}$ $\mathrm{ecc}(G)$. The *center* $C(G)$ of a graph G is the set of all nodes that have the least eccentricity.

We denote the diameter that we want to reach as Δ, the original networks to be integrated are G_1, G_2. According to [4], based on the required Δ, the algorithm deal with the two cases separately. Also, the changes inside the two original networks G_1, G_2 is not expected, we only build new edges between the networks, which means for all the newly built edges uv, $u \in G_i$ ($i \epsilon \{1, 2\}$), then $v \in G_{3-i}$.

Case 1: When $\Delta \geq \max\{diam(G_1), diam(G_2)\}$

In this case, firstly, we connect all the nodes in the center set of network G_1 with all the nodes in the center set of network G_2. We denote the merged network after this step as G_3.

Then, we keep building new edges between the two nodes that are in the end of the longest path, making the path become a circle until $diam(G_3) \leq \Delta$.

Case 2: When $2 \leq \Delta < \max\{diam(G_1), diam(G_2)\}$

In this case, we want to make not only the nodes between two networks, but also inside the networks become closer through this integration. Therefore, we find a node w in G_2, and by adding edges uw and vw(where $u, v \in G_1$), the distance between u and v becomes 2, which is smaller than Δ. We keep doing that until $diam(G_3) \leq \Delta$.

3.3 Problem Setup

As we integrate networks in the middle of their norm emergence process, a measure of the progress of emergence is needed. Therefore, similar to the definition in [5], we define *conformity* as follows:

Definition 1 (Conformity of a network $G = (V, E)$) *Given a network $G = (V, E)$, and a set of alternate actions A for each agent in G, the conformity γ of network G is*:

$$\gamma = 1 - \frac{1}{\log_2 |A|} H(a|G)$$

$$s.t.\ H(a|G) = -\sum_{a \in A} p(a|G)\log_2 p(a|G)$$

$where\ H(a|G)\ is\ the\ entropy\ of\ agents'actions\ in\ a\ network\ G, p(a|G)\ is\ the\ relative$

$freqency\ of\ agents\ choosing\ the\ acton\ a\ in\ network\ G, and\ \frac{1}{\log_2|A|}\ is\ a\ normalization$

$constant\ which\ normalizes\ \gamma\ to\ a\ scale\ of\ [0,1].$

By Definition 1, the more uniform agents' actions are, the larger value of the conformity is. When γ reaches the maximum value 1, it means that all the agents in the network choose the same action; while when γ reaches the minimum value 0, it means that all the actions have the same number of agents choosing it.

As the integration way is fixed in this work and the research time is limited, we especially investigate the influence of the number of alternate actions.

4 EXPERIMENTAL ANALYSIS

4.1 Basic Settings

We use two random networks with 500 nodes in each, and set the goal diameter of the new network $\Delta = \frac{\Delta_1 + \Delta_2}{2}$, $\gamma_1 = \gamma_2$, and stop the emerge process when either the conformity of the integrated network $\gamma = 0.9$, or the number of iterations reaches 5000. Generally, it only takes few hundreds of iterations to reach conformity 0.9. If the norm is still not emerged after running 5000 iterations, then the whole emerge process is a chaos, and a single norm will never appear.

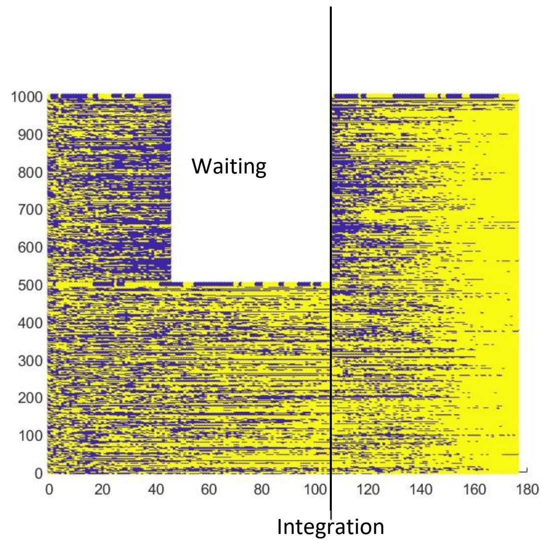
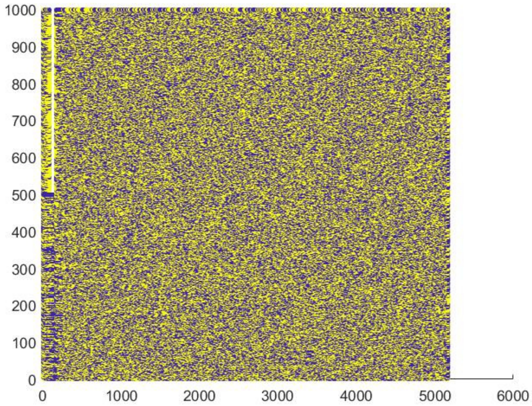


Figure 1(integrate when $\gamma_1 = \gamma_2 = 0.2$)

Figure 1 shows the general case of the experiment. The y axis means the agents ([0,499] is from a same original network, and [500, 1000] is from another), and the x axis means the number of iterations, and the colors of dots represnets the action that the agent chooses in this iteration. In this figure, every horizontal line shows the action choices history of an agent. After the integration, the yellow action overwhelms the blue one and become the final norm.

In all the experiments that integrate when the two networks reach a same conformity ($\gamma_1 = \gamma_2$) while there are only two available actions, the chance of successfully becoming final norm for each action is basically the same, as well as the percentage of not reaching any norm.



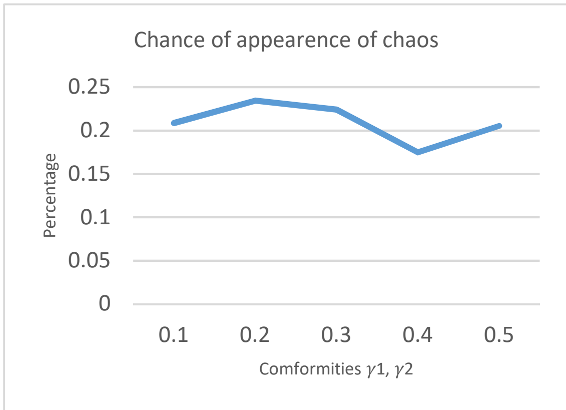


Figure 2(Cannot reach any norm)

4.2 increase number of alternate actions

Under this situation, we increase the number of available choices in the cooperation game. After increasing it to 3, the possibility that the final norm is not one of the two original norms which reach conformity γ_1, γ_2 in the two networks before integration arises.

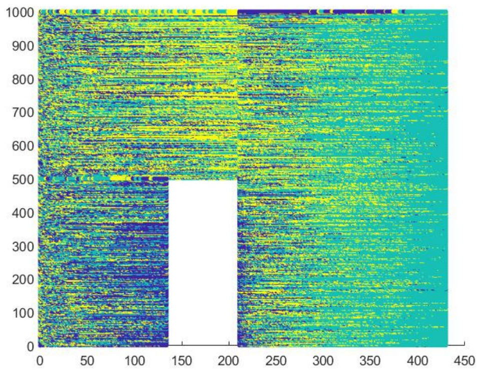


Figure 3($\gamma_1 = \gamma_2 = 0.2$, 3 actions)

Figure 3 shows the process of the third action becoming final norm. The chance of appearance of this situation is quite low, and it decreases with γ_1, γ_2 increases, which is easy to understand: the higher γ_1, γ_2 is, the fewer agents tend to choose the third action. When $\gamma_1 = \gamma_2 = 0.5$, this chance decreases to 0.

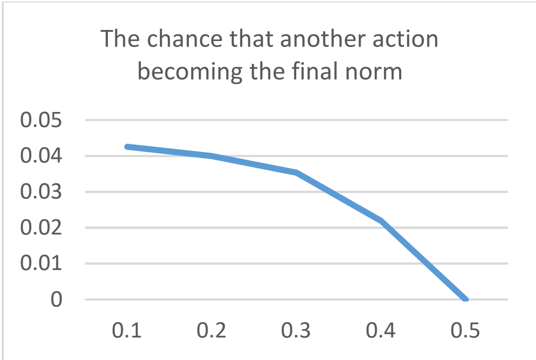


Figure 4

When there are more available action choices, the percentages of successfully becoming final norm for each action are still basically the same.

However, the rate of successfully achieving a norm decreases when the number of available actions increases. The reason of this phenomenon could possibly be that when there are more and more alternate choices, it is more difficult for any of them to gain significantly larger agents who tend to choose them through integration.

5 CONCLUSION AND FUTURE WORKS

In conclusion, increasing alternate actions can increase the chance of chaos in a certain level, and rise the problem of a third action becoming final norm. To solve these problems, integrating when the norms in the two original networks are more stable is helpful.

This work is just a shallow one, there are still a lot of factors to investigate how they affect the norm emergence after an integration of two networks. Also, from the perspective of integration, there are two more criteria and algorithms to mimic different scenarios in human societies could be implemented.

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