THE ROLE OF NAMING GAME IN SOCIAL STRUCTURE

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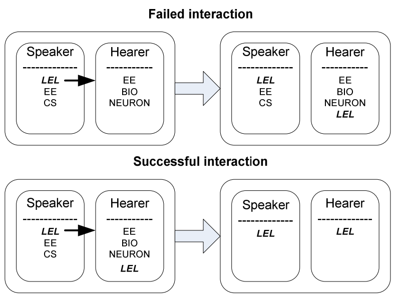
This paper presents a simulation study to explore the role of naming game in social structure, which is nearly neglected by contemporary studies from statistical physics that mainly discuss the dynamics of naming game in predefined mean-field or complex networks. Our foci include the dynamics of naming game under some simpler, distance restrictions, and the origin and evolution of primitive social clusters as well as their languages under these restrictions. This study extends the current work on the role of social structure in language games, and provides better understanding on the self-organizing process of lexical conventionalization during cultural transmission.

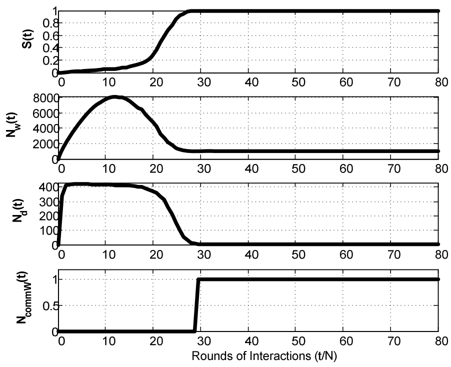
1. Introduction

The origin and evolution of language or general communication systems is a fascinating topic in the interdisciplinary scientific community. A number of approaches from biology, mathematics, physics, and computer science have been proposed to comprehend some specific aspects in this topic (Oller & Griebel, 2000; Christiansen & Kirby, 2003), among which the self-organizing emergence of a shared lexicon during cultural transmission has been extensively studied based on various forms of *language game* (Steels, 2001) models in the past few years.

Naming game (Steels, 1995) is one form of language games that simulates the emergence of a collective agreement on a shared mapping between words and meanings in a population of agents with pairwise local interactions. A minimal version of it was proposed by Baronchelli and Loreto (2006) to study the main features of semiotic dynamics. In this version of naming game, N homogeneous agents are describing a single object by inventing words during pairwise interactions. Each agent has an inventory (memory) that is initially empty and can store an unlimited number of words. As shown in Fig. 1(a), in a pairwise interaction, two agents are randomly chose, one as "speaker" and the other as "hearer". The speaker utters a word to the hearer. If its inventory is empty, the speaker randomly invents a word; otherwise, it randomly utters one of the available words in its inventory. If the hearer has the same uttered word in its inventory, the game is successful, and both agents delete all their words but the uttered one. If the hearer does not have the uttered word, the game is a failure, and the hearer adds (learns) the uttered word to its inventory. In a mean-field system, the dynamics of naming game can be traced in Fig. 1(b), in which $N_w(t)$ records the vocabulary explosion in the population, $N_d(t)$ records the lexical conventionalization, and $S(t)$ indicates the average successful rate of interactions among agents.



(a)



(b)

Figure 1. (a) An example of naming game, the italic words are the uttered ones in interactions; b) The dynamics of naming game (N = 1000, *No. interactions* = 8000, 1 round of interactions = 1000. $S(t)$ records the average successful rate at round t, $N_w(t)$ the total number of words in the population, $N_d(t)$ the number of different words, and $N_{commW}(t)$ the number of common words.

Besides the mean-field system, statistical physicists (e.g., Baronchelli & Loreto, 2006; Dall'Asta et al., 2006) have further explored the dynamics of naming game in 1D or 2D lattices, small-world, and scale-free networks. Although these studies extensively discussed the role of social structures in convergence of shared lexicon, most of them neglected the reverse role of naming game in social structure; in these studies, a successful or failed naming game only affects individual's linguistic knowledge, but has nothing to do with the predefined social structures. However, in a cultural environment, successful or failed interactions among individuals can not only adjust their knowledge, attitudes or opinions, but also affect their social connections or political status in the community. Factors that operate on a local scale, such as interaction procedures and geographical or social distance restriction, can also adjust the possibilities of interactions among agents, thus affecting individual or group similarities on a global scale (Axelrod, 1997; Nettle, 1999; Gong et al., 2006). These simple factors may take place much earlier than the emergence of complex social structures, and cast their influences on formation of primitive social clusters and their communal languages. For instance, during language origin, a successful naming game towards a common object in their environment may form a social binding among the participants of this game, and share a common lexicon among them. These factors may take similar effect in modern societies during language change. For instance, a successful or failed naming game towards a salient concept may form a new binding or destroy an old one among the participants, and adjust their communal languages. Moreover, in order to establish a complex social network in a huge population in which not every two individuals could ever directly interact with, a certain degree of mutual understanding is necessary, and simple language games like naming game may play a role in achieving such mutual understanding through local interactions. Therefore, besides its dynamics in some predefined complex networks, the dynamics of naming game under simpler constraints and its role in social structure are worth exploring, too.

In this paper, we present a preliminary study in this respect. Instead of detailed constraints determined by complex networks, we only simulate a distance constraint, and discuss its influence on formation of social clusters and their communal languages. The simulation traces the coevolution of language and social structure based on naming game, and the formation of mutual understanding in the population via local interactions among its members, both of which will help us to better understand the self-organizing process of lexical conventionalization based on naming game.

The rest of the paper is organized as follows: Section 2 introduces the simple distance restriction; Section 3 discusses the simulation results of two experiments; and finally, Section 4 provides the conclusions and future work.

2. Naming Game with a Distance Constraint

The interaction scenario of our naming game is identical to its minimal version described in Section 1. To introduce distance restrictions, we situate all agents in a 2D square torus (X^2, X is the side length of the torus), and each of them can randomly move around to its 9 unoccupied, nearby locations, as shown in Fig. 2. This torus represents either a physical world, or an abstract world, such as the distributions of opinions or social status.

The distance restriction is defined as follows, which is inspired from our previous study (Gong et al., 2005) and applied on agent selection during pairwise interactions:

The distance restriction: interactions only take place between agents whose coordinates are within a limited block distance (D_x and D_y), as shown in Eq. (1), where x_i, y_i are agent i's coordinates in the 2D torus X^2:

$$|x_i - x_j| \leq D_x \text{ or } |x_i - x_j - 0.5X| \leq D_x \text{ ; } |y_i - y_j| \leq D_y \text{ or } |y_i - y_j - 0.5X| \leq D_y \quad (1)$$

This concept of distance can either represent geographical distance, such as the city-county distance, or social distance, such as the dissident opinions. Under this distance restriction, each agent in the torus can interact at most $(2D_x + 1) \times (2D_y + 1) - 1$(itself) nearby agents. When D_x and D_y equal to 1, each agent only interacts with those lying in its 9 nearby locations. This restriction provides a *binding* for the participants of naming games: a successful naming game can bind the speaker with the listener, and they tend to *move together* so that their block distance does not exceed D_x and D_y; however, a failed naming game may break down this binding.

This distance restriction is much simpler than those defined by complex networks. Based on it, some big social clusters containing agents who may not necessarily interact directly with each other, but still share a common lexicon may emerge and be maintained. These simple clusters and their shared words are the prototypes of complex social structures and their communal languages.

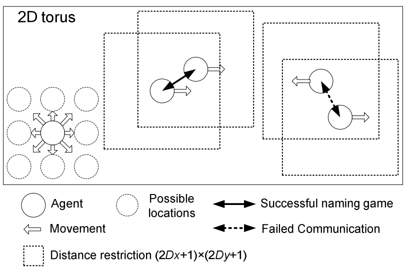


Figure 2. A 2D torus with moving agents.

We design two experiments to evaluate the influence of this simple restriction on formation of social clusters and conventionalization of shared lexicon. In Experiment 1, 100 agents are situated in a 10^2 torus (each location in the torus is occupied by an agent), and D_x and D_y range from 1 to 10. In

Experiment 2, 100 agents are put into tori whose side length X ranging from 10 to 55, but D_x and D_y are fixed. In each time step, all agents take part in at least one local interaction with others that are within its distance restriction (if possible), and at least one movement (if possible). The moving step is 1, and the total number of time step is 100. In each condition, the results of 20 simulations are collected for statistical analysis.

After a time step, S (the successful rate) and N_d (the number of different words) are evaluated. If all agents gradually share a common lexicon, S will gradually increase to 1.0 and N_d reduce to 1. In this situation, N_T (the number of time steps required to reach the highest S) indicates the effect of distance restriction on lexical conventionalization. On the contrary, if all agents cannot share a common lexicon, but form different clusters, S and N_d will not reach 1. In this situation, N_d indicates the number of isolated clusters, and N_T the effect of distance restriction on lexical conventionalization within clusters. In the following sections, the simulation results of these two experiments are discussed.

2.1. *Experiment 1: fixed torus size but various distance restriction*

In this experiment, all 100 agents lie in a 10^2 torus; D_x and D_y change from 1 to 10. In all simulations, after 100 time steps, a common lexicon is shared in the population; both S and N_d become 1 at the end of simulations. Fig. 3 illustrates the average and standard deviation values of N_T under different D_x and D_y.

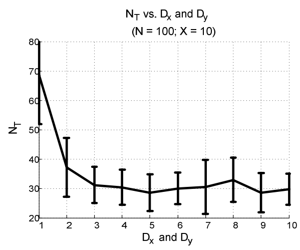
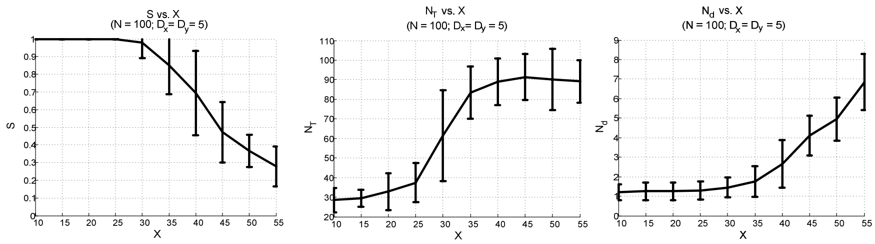


Figure 3. The statistical results of N_T in Experiment 1. The numbers outside brackets are average values, and those within brackets are standard deviations.

As shown in Fig. 3, with the increase in D_x and D_y, the process of lexical conventionalization follows two regimes: as D_x and D_y increase from 1 to 4, agents can interact with more nearby agents and adjust their words, then, the lexical convergence is accelerated and N_T drops; when D_x and D_y are greater than 5, each agent can already interact with all the others in the population, then, the lexical convergence is not further accelerated and N_T becomes stable. In addition, in a 10^2 torus, when D_x and D_y are small and each agent cannot directly interact with all the others, lexical conventionalization is still accomplished through intermediate agents, and a social cluster containing agents who cannot directly interact with each other but still share a common lexicon can be established.

2.2. *Experiment 2: various torus size but fixed distance restriction*

In this experiment, 100 agents are randomly situated in tori whose side lengths increase from 10 to 55 with a step of 5. D_x and D_y are fixed to 5. Fig. 4 illustrates the average and standard deviation values of *S*, N_T, and N_d in these situations.



(a) (b) (c)

Figure 4. The statistical results of *S* (a), N_T (b), and N_d (c) in Experiment 2. The numbers outside brackets are average values, and those within brackets are standard deviations.

The process of lexical conventionalization in these simulations also follows two regimes: when *X* is smaller than 30, all agents in the population can form a huge cluster and share a common lexicon; however, after *X* reaches a certain level (say, 30), *S* begins to drop, and both N_T and N_d begin to increase. In a relatively small torus (*X* is smaller than 30), although agents may not find many others within their distance restrictions, through moving around, they can encounter many agents and get their words converged to a shared lexicon. However, in a big torus (*X* is bigger than 30), this 1-step movement is insufficient for agents to meet others and the big torus size greatly restricts the local interactions among agents, then, isolated, smaller clusters gradually emerge, and each of which shares a common lexicon. Therefore, *S* of the population drops and N_d increases, both indicating the emergence of small clusters. Within a cluster *S* is high, but between clusters *S* is low, since different clusters may share different words. In addition, once such clusters are formed, it is difficult for agents within clusters to interact with others outside clusters, since the agents within clusters tend to maintain their distance among each other and not to freely move. The bindings within clusters are relatively strong, and these clusters and their shared words are relatively stable, which are indicated by the stable values of $S(t)$ and $N_d(t)$ for a number of time steps in specific simulations.

A "*local convergence, global polarization*" phenomenon (Axelrod, 1997) is shown in the simulations under a big torus: agents within clusters clearly understand each other via a shared lexicon, but those between clusters do not, since different clusters may share different words. This phenomenon partially reflects the coexistence of languages in the world, and it is solely caused by distance restriction and mutual understanding during local interactions. Besides, if we assume that agents are developing a basic vocabulary using naming game, these simulations may actually trace the concurrent emergence of different vocabularies, and later on, different languages in the early stage of language development in the world.

3. Conclusions and Future Work

The simple simulations in this paper demonstrate the role of a simple language game, naming game, in social structure: naming game under the assumption of distance restriction can adjust social binding among agents and form primitive clusters based on mutual understanding. This line of research is largely neglected in contemporary studies.

We present two experiments to vividly show the dynamics of naming game under different distance restrictions and world sizes. First, a big cluster sharing a common lexicon can be formed among individuals whose *local views* (distance restriction) might not allow them to overview all members in the population. In addition, there is a close relation between the local view and the world size: under a fixed world, the increase in the local view accelerates the conventionalization of individual knowledge among agents; under a fixed local view, the increase in the world size triggers the emergence of different clusters and *linguistic divergence*, i.e., common knowledge (shared lexicon) is developed within clusters; while heterogeneity (different shared words) occurs between clusters. Furthermore, the enlarging local view may be reminiscent of the growing mass media and the "global village" phenomenon in recent centuries. In contrast, the fixed local view with increasing world sizes may represent the reality that people do have such a constraint of a relatively limited view. Considering these, our model may address a scenario with these two competing conditions.

In the end, as shown in Fig. 3 and Fig. 4, the boundary values of distance restriction and torus size suggests a quantitative relation between the local view and the world size. Roughly speaking, the current results seem to show that given a certain number of time steps (100), once the local view $(2D_x + 1) \times (2D_y + 1)$ is smaller than 1/10 of the torus size, the whole population will not efficiently form a cluster and share a common lexicon. In order to clearly reveal this quantitative relation, we need further statistical analysis in simulations with bigger populations, and this will be the future work of the current study.

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