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Communicating with sentences: A multi-word naming game model

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HIGHLIGHTS

- A new model "multi-word naming game (MWNG)" is proposed.
- MWNG extends single-word propagation to sentence propagation.
- Simulations are implemented on random-graph, small-world and scale-free networks.

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ABSTRACT

Naming game simulates the process of naming an object by a single word, in which a population of communicating agents can reach global consensus asymptotically through iteratively pair-wise conversations. We propose an extension of the single-word model to a multi-word naming game (MWNG), simulating the case of describing a complex object by a sentence (multiple words). Words are defined in categories, and then organized as sentences by combining them from different categories. We refer to a formatted combination of several words as a pattern. In such an MWNG, through a pair-wise conversation, it requires the hearer to achieve consensus with the speaker with respect to both every single word in the sentence as well as the sentence pattern, so as to guarantee the correct meaning of the saying; otherwise, they fail reaching consensus in the interaction. We validate the model in three typical topologies as the underlying communication network, and employ both conventional and man-designed patterns in performing the MWNG.

1. Introduction

Naming game (NG) is a simulation-based numerical study exploring the emergence of shared lexicon in a population of communicating agents about a same object which they observed [1–3]. The single object in NG can be an entity, idea, opinion, or a social or economic convention that can be described by a single word [4]. A population of self-organized agents is connected in a certain topology representing the relationships among them. The minimal NG is described as follows. Each time, one pair of connected speaker and hearer is randomly selected from the population. If the object is unknown to the speaker (who has no word to describe the object), he will invent a new name and then tell it to the hearer. When the object is known to the speaker, he will randomly pick a name from memory and utter it. When the hearer receives the name, he will search over his memory to see if he has the same name stored therein: if not, then he will store it into memory; but if yes, then they reach consensus, so both clear up all the names, while keeping the common one respectively. This pair-wise

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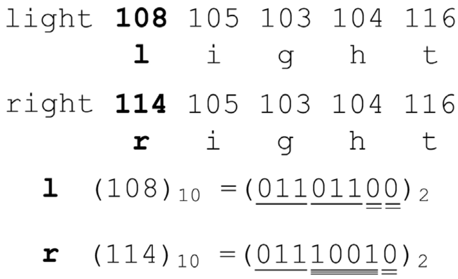

Fig. 1. An example of coding in naming game. Two atomic names, '*light*' and '*right*', can be decomposed into 5 independent letters respectively, where the integers are ASCII code for each letter. These two atomic names could be considered as '*l*' + '*ight*' and '*r*' + '*ight*', respectively. The difference between '*light*' and '*right*' are the initial words '*l*' and '*r*'. They can also be decomposed in other ways. When every letter in a name is coded in binary, the letters can be further decomposed into sequences of binary strings, e.g., '011', '0', and '1001'. As a result, '*l*' consists of two '011's and '0's in order, and '*r*' consists of one '011' followed by one '1001', with one '0' at the end.

success is referred to as *local consensus* hereafter. Such a pair-wise transmitting and receiving (or teaching and learning) process will eventually lead the entire population of agents to reach consensus, referred to as *global consensus*, meaning all the agents agree to describe the object by the same name. The convergence property of NG is not only observed by numerical simulations, but also proved theoretically [5] and verified empirically [4]. This conventional NG will be called the single-word naming game (SWNG) below.

Previous studies on naming game focus on mainly two aspects: the agent dynamics [2,6–12] and the information dynamics [13–16]. The former concerns about the topological relationships of agents, the roles of speaker and hearer, and the communication model among the agents, as well as their characteristics. For example, the minimal NG is investigated on random-graph and scale-free networks in [6,7], and on small-world networks in [8,9]. The speaker-only naming game (SO-NG) and hearer-only naming game (HO-NG) are proposed in [10]. In SO-NG, only the speaker will update his memory, while in HO-NG only the hearer will do so. Later, the NG with multiple hearers (NGMH) was proposed in [11], which is an HO-NG model with an additional rule: only when all hearers reached consensus with the same speaker, they reach local consensus together. The NG in groups (NGG) [12] allows every agent in a selected group from the population to play the dual role as a speaker and also as a hearer. All the aforementioned models have demonstrated that the convergence speed is faster when the number of participating agents increases. The finite-memory NG (FMNG), proposed in [2], studies the situation where the memory sizes of the agents are limited.

The study of information dynamics includes: The case when communications are influenced by learning errors is studied in [13], and the memory loss case is studied in [16]. The combinational NG [14] decomposes single words as atomic names and combinational names. An atomic name is unique and independent of other atomic names, e.g., '*blue*' and '*sky*'. In contrast, a combinational name is a permuted combination of atomic names, e.g., '*sky-blue*' and '*blue-sky*'. The blending game discussed in [15] uses similar combinational forms, but with different communication rules, thus a blending name will be composed only if a speaker-uttered name is not agreed by the hearer.

Whether a name for the object is atomic or combinational is determined based on the coding (mapping) method from the set of atomic words into the set of combinational words [14]. An illustrative example is shown in Fig. 1, where the integer coding could transform the atomic names to be combinational, and further, be decomposed into binary strings. This lacks a certain pattern to reflect the order and relationship between the components. Both atomic NG and combinational NG are SWNG, because the transmission information of each pair-wise interaction is a single word.

In this paper, we propose a multi-word NG (MWNG) to study the scenario where the names of objects are described by neither atomic nor combinational words, but more complicatedly, by sentences. We first classify the words into several categories, and then define some patterns as sentential structures, so that a sentence can be composed following a certain pattern. Here, the pattern employed in MWNG is simple, since the focus is on the converging process, rather than on the grammatical analysis of languages as in [17,18]. Note that due to the duality caused by coding, we can consider a specific sentence as a single atomic name, thus the MWNG is degenerated to the SWNG, or minimal NG. In this sense, the MWNG is a natural extension of the conventional SWNG.

2. Methods

The distinguished attribute of the MWNG model is that the speaker utters several words simultaneously (a simple sentence) rather than a single word to describe an object (e.g., an opinion, an event, etc.), which is more realistic and common in human conversations.

The pattern of sentences in MWNG is kept simple, as long as it is able to show some organizing structure of the words. Actually, patterns could also be considered as simple grammar. A simple implementation of pattern could be formed by combination of words from different categories. Categorization of words directly affects the resolution of patterns. Words of the same category are of equivalent importance. The term resolution concerns with the precision and correctness of a