Communication Convention Formation in Large Multiagent Systems

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Research Summary: A fundamental challenge in large-scale multiagent systems (MAS) is to enhance network-related dynamical processes such as establishing social convention in a decentralized fashion by regulating the behavior of the artificial autonomous agents. In this research, we plan to study the specific problem of communication convention formation as a dynamic semiotic process over a large-scale MAS. In a semiotic process, a group of artificial agents collectively invent and negotiate about a shared language system that is used for communication. The landscape of the communication system will be captured through a hierarchy of interdependent networks where a semiotic network is built on top of an agent network. We propose a network theoretic investigation to determine its implications on the dynamic convention formation process and plan to develop a generalized theory of communication convention suitable for large-scale networked MAS. This theory will support predictions of system properties such as convergence dynamics across different temporal regions. Finally, an effective convention formation mechanism based on the generalized theory will be presented and evaluated for a real-world application domain.

1 Introduction

Coordination of agent activities in large multiagent systems (MAS) is central to cooperatively achieving goals. A social convention is considered to be a technique for increasing coordination [11]. It helps to reduce the overhead of coordination by simplifying agents' decision-making process through the determination of action choices. Therefore, establishing a social convention acts as a useful mechanism for deciding the dominant coordination strategy or building consensus in MAS. For example, the mechanism for predicting conventions in online communities (such as in Twitter) could be useful for understanding various socio-political phenomena [6].

In this research, we plan to study the problem of convention formation in the context of a dynamic semiotic process [10]. In this process a group of human or artificial agents collectively invent and negotiate a shared language system or a semiotic system to establish a *communication convention*. When the agents are situated in a networked society, it is important to ask how they self-organize a communication system or create a communication convention that enable them

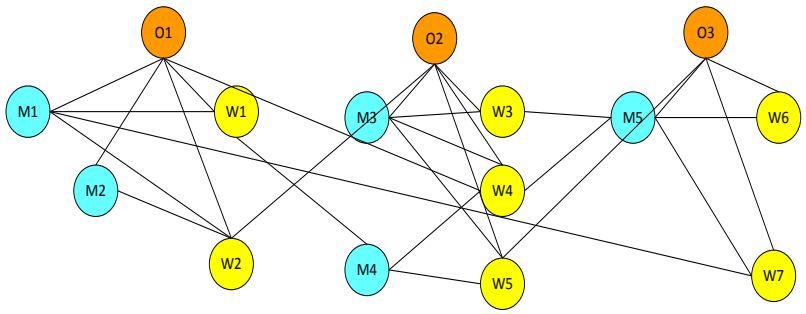
to share a common lexicon? Our research goal is to design a theoretical framework to investigate the process of convention formation carefully and to design mechanisms that ensure the emergence of an *effective* (each agent shares the same language), but also *efficient* (using less resource, e.g., small memory-size) communication convention.

2 Problem Formulation

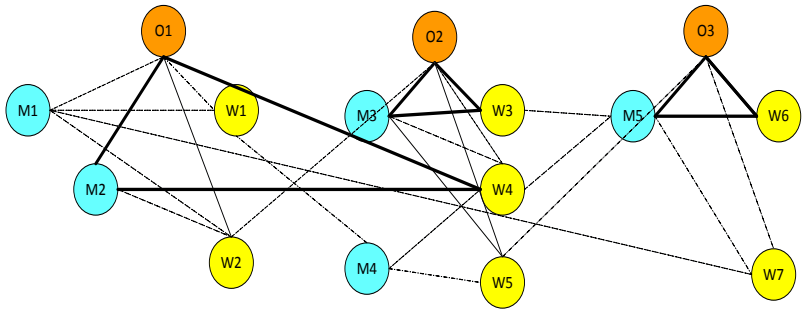
How agents invent symbols (words) and associate meaning in order to describe an object in their environment is an intriguing question. When the agents are situated in a networked society, it is more important to ask how they self-organize a communication system or create a communication convention that enable them to share a common lexicon? Traditionally the relationship between the objects, words and associated meanings are captured through a triadic model originally proposed by Pierce [9]. Agents in networked MAS form such triadic relationship for every object that they want to describe. However, due to un-coordinated language acquisition process, agents may use different words to describe the same object (synonymy). It is also possible that one word may refer to multiple meanings (ambiguity) or multiple objects (homonymy). The challenge, therefore, is to reduce or dampen synonymy, homonymy and ambiguity through a coordinated language learning process such that a communication convention emerge in the MAS.

A communication convention problem requires us to define (i) a semiotic landscape containing the relationship among the objects, words and associated meanings and (ii) an interaction network model for the agent society. The semiotic landscape is defined by semiotic networks that is described below and the agent network model is designed based on various complex network models.

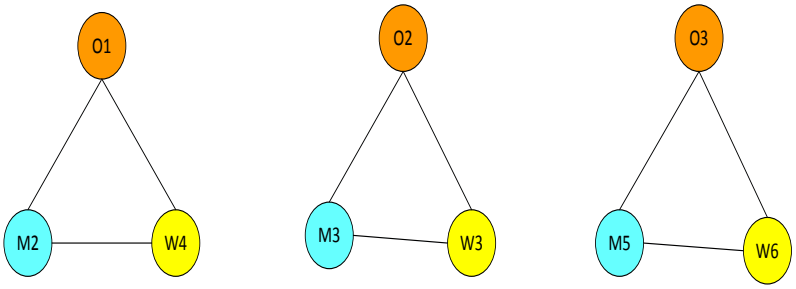
Semiotic Network: The relationship between the objects, words and the associated meanings can be represented by a connected graph topology or *semiotic network* [10]. In this type of network nodes are formed by the objects, words and meanings. Two nodes share a edge if the items associated with the nodes co-occur. Figure 1(a) provides an example of such semiotic network. In this figure, object 1 (referred as O1) is described by three words (W1, W2 and W4), an illustration of ambiguity. Word1 (W1) is associated with two meanings (M1 and M4) that illustrates the synonymy. Also, Word2 (W2) is referring to two objects (O1 and O2) showing homonymy. This network is dynamic because edges and nodes are dynamically created and removed as new objects are introduced and agents learn/invent new words, associate new meanings or converge into existing meanings. The edges can have weight and in course of time (through interaction) some edges may gain significantly more weight than other edges (Figure 1(b)). As a consequence the effect of synonymy, homonymy and ambiguity will be dampened. A perfectly coherent communication system or a communication convention emerges when this semiotic network disentangles into unconnected triangles as in Figure 1(c) and every agent shares these triangles. In such a case, each object would have a unique word and a unique meaning.



(a) Semiotic Network



(b) Weighted Semiotic Network



(c) Converged Semiotic Network

Fig. 1. Dynamics of Semiotic Landscape. Objects, words and meanings are referred by Ox, Wx and Mx respectively.

Approaching the dynamic semiotic process from a network theoretic perspective allows to use the tools of complex networks theory to study its properties. The semiotic network is built on top of the agent network forming an interdependent hierarchical relationship. This research will emphasize on the understanding of the properties of these hierarchical networks to predict the convergence time and scaling law of the convention process.

3 Approach

A population of agents are situated on the nodes of an undirected dynamic graph. Each agent has a limited computational power and limited memory. The interactions among the agents are captured through various games. At each time step, agents update their state (among a certain set of possible states) according to the state update rules through interactions with their neighbors. The dynamics at the agent state level influences the dynamics of the semiotic network. Tools of statistical physics will be used investigate how the agent network dynamics affects the dynamics of the semiotic network.

A **solution** to the communication convention problem will be composed of a set of state update rules and agent architecture. We will design the state update rules based on empirical investigation of the convention process over various agent network models. The results obtained from these investigations will also be used to design the agent architecture.

The intended generalized theory of communication convention would be developed based on a comprehensive experimentation of various network models, convention domains, agent architectures and state update rules. Following is a short list of the model parameters that will be used to perform the investigation:

Variation of the Agent Network Models: Previous studies on shared language problem have used standard models of complex networks such as Barabasi-Albert Scale-free and Watts-Strogatz Small-world network models [1]. These models assume that new nodes have access to information about the global state of the network. In many realistic scenarios this assumption does not hold. Therefore, we will use realistic complex network models such as local-world evolving network [7], fitness-based network [2] models and their variants.

Variation of the Agent Interaction Models: Typically agent interactions are modeled by using various games. We will augment the existing models and investigate their impact on the performance of our approach.

Variation of Agent Architecture: We will investigate the variation of the following components of the agent architecture: effect of memory size, neighbor selection strategy, negotiation models and agent learning.

4 Preliminary Results

We have designed a mechanism that is able to create a social convention within a large convention space for MAS operating on dynamic SF networks [5]. The

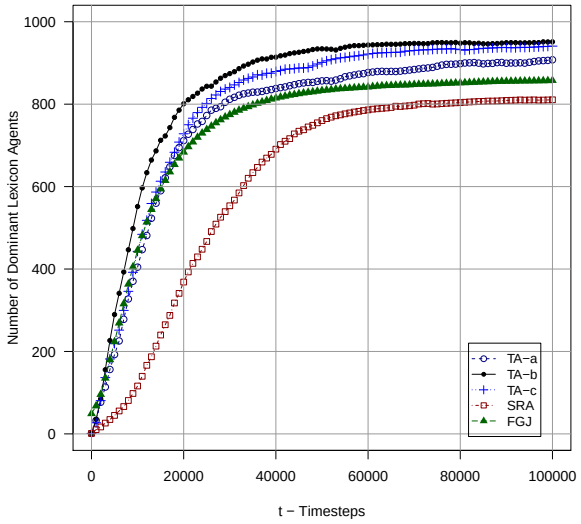


Fig. 2. Comparison of the number of dominant lexicon agents for three variants of the topology-aware (TA) approach with SRA and FGJ's approach.

language coordination problem from [3, 8] is used for investigation in which a society of agents construct a common lexicon in a decentralized fashion (these two approaches are referred as FGJ and SRA respectively). Agents' interactions are modeled using a language game in which agents send lexicons to their neighbors and update their lexicon based on the utility values of the received lexicons. We proposed a novel topology-aware (TA) utility computation mechanism and enable the agents to reorganize their neighborhood based on this utility estimate to expedite the convention formation process. Figure 2 compares how dominant convention agents evolve over time for three variants of TA with SRA and FGJ. Results indicate that the proposed mechanism is both **effective** (able to converge into a large majority convention state with more than 90% agents sharing a high-quality lexicon) and **efficient** (faster) as compared to the state-of-the-art SRA and FGJ.

Currently we are investigating this lexicon convention problem over various network topologies including small-world, local-world and random networks. The agents will be able to predict the topology of their local neighborhood and use an appropriate convention formation mechasim. Previoulsy we developed this type of topology-aware convention selection mechanism for a small convention space [4].

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