A Context-aware Convention Formation Framework for Large-Scale Networks*

JAAMAS Track

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ABSTRACT

Conventions can serve as a useful mechanism for deciding the dominant coordination strategy and facilitating consensus in a multiagent system (MAS). In this paper, we present a decentralized convention formation framework that harnesses the structural properties and diversity of the network for creating social conventions within large and open multiagent convention spaces. We validate our convention formation framework using a language coordination problem in which agents in a MAS construct a common lexicon in a decentralized fashion on various networks. Experimentation results indicate that our approach 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 state-of-the-art approaches for social conventions in large convention spaces.

KEYWORDS

multiagent systems, large dynamic networks, contextual information, convention, diversity

1 INTRODUCTION

Establishing a social norm acts as a helpful mechanism for deciding the dominant coordination strategy and facilitating consensus in networks. Unlike human social systems in which the objective is to understand and predict the population level behavior based on empirically supported interaction rules (e.g., emergence and evolution of languages [8] or opinion formation [1]), artificial societies require participants to use mechanisms that give rise to fast and efficient convergence to a global norm. Often times these artificial societies are large in size and dynamic in nature. For example, online social networks and wireless sensor networks are dynamic in the sense that in these networks agents may join or leave the network as well as the connections among the agents may change over time. We view social norm emergence through the game theoretic lens of convention formation.

Online convention formation mechanisms are designed for large and open MAS [2, 5, 9, 13]. However, these mechanisms deal with a relatively simple convention space in which a global convention is chosen from two possible convention alternatives or *convention seeds*. In large and open MAS, other challenging issues need to be considered. First, multiple convention seeds may exist and hence the convention space could be complex. Second, it is possible that the existing convention seeds are not appropriate or good enough. Therefore, agents may need to create new convention seeds as well as form a higher-quality convention. Two significant mechanisms for solving this type of convention formation problem are described in [10] and in [3].[1] They model the MAS using complex small-world and scale-free networks. SRA uses a spreading based mechanism while FGJ augments this process by using a set of privileged agents with high-quality convention seeds. However, both approaches assume a static agent network and are unable to form a Large Majority Convention State (LMCS) in which 90% or more agents adopt a single convention in a reasonable amount of time.[2] Our definition of the LMCS is based on the 90% threshold standard used in the study of convention formation [2, 7, 11].

Our goal is to design a convention formation framework in a dynamic MAS suitable for a large convention space that is able to overcome the limitations of SRA and FGJ. This framework will enable us to investigate the convention formation problem for a broad range of networks and to determine the system level properties that could potentially influence the convention formation process. We intend to develop a convention formation approach that is **(i) effective** (able to converge into LMCS as well as the quality of the most common convention is high) and **(ii) efficient** (speed of reaching LMCS is fast). Similar to FGJ, in order to validate our approach, we investigate a **language coordination problem** that captures the challenges involved in creating high-quality conventions in large and open MAS.

The novelty of this work lies in the formulation of the norm emergence problem within the space of virtual societies. We perform a systematic and detailed investigation of the norm emergence problem in virtual societies by developing a framework that captures the core research challenges of the real-world applications and use a multiagent experiment based approach to investigate the various dimensions of the problem.

2 CONVENTION FORMATION IN LARGE CONVENTION SPACES

SRA and FGJ attempt to solve the convention problem for **a large convention space**. They use a language coordination problem for

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[1]Henceforth these two approaches are referred as SRA and FGJ respectively.
[2]In SRA as well as FGJ, the time-period for investigating the emergence of a lexicon convention is comprised of 100,000 time-steps of the experiment. We use this duration as a definition of *a reasonable amount of time* for convergence to occur.

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investigation in which a group of agents tries to create a lexicon convention through repeated interactions. As mentioned earlier, this problem was originally inspired by Luc Steels' *Naming Game* model. In [12], Luc Steels focused mainly on the formation of vocabularies, i.e., a set of mappings between words and meanings (for instance physical objects). In this context, each agent develops its own vocabulary in a random private fashion. However, agents are forced to align their vocabularies in order to obtain the benefit of cooperating through communication. Thus, a globally shared vocabulary emerges as a result of local adjustments of individual word-meaning association. The communication evolves through successive conversations, i.e., events that involve a certain number of agents (two, in practical implementations) and meanings.

SRA and FGJ are however limited in the size of the agent societies with about 1000 agents and they only consider a small subset of scale-free and small-world family of networks. Also in SRA, a sophisticated agent architecture design, characterized by the complex spreading mechanism, is used to create a high-quality language convention. On the other hand, in FGJ a set of privileged agents (influencer agents) equipped with high-quality lexicons is deployed to influence and expedite the convention formation process. However, these approaches do not consider the costs associated with the sophisticated agent architecture design or deployment and maintenance of the influencer agents. Moreover, the agent network is assumed to be static and does not converge into LMCS within a reasonable amount of time.

Our context-aware approach builds on SRA and FGJ as well as our previous work [6] to address the above mentioned limitations of the state-of-the-art approaches to the large convention space problem. We present a novel context-aware utility computation technique that enabled agents to expedite the convention formation process by reorganizing their neighborhood based on this utility estimate. A key idea here is that agents with the most influence (more connections) in the network are harnessed to adopt the best lexicons in the neighborhood. These influential agents, due to their large connectivity, have the capacity to quickly influence the agents in their network for adopting the high-quality lexicons. We also implement dynamic network topology through a *conditioned link diversity* mechanism. The network reorganization approach is a result of the intuition that agents are more likely to disassociate with a neighbor that is not beneficial and would like to make acquaintance with better quality neighbors.

3 ALGORITHM PSEUDOCODE FOR CONVENTION FORMATION MECHANISM

We consider MAS with a large number of agents organized in various types of network topologies including regular, random (RN), small-world (SW), scale-free (SF) and scale-free community (SFC) topologies.

Algorithm 1 describes the distributed **Context-Aware (CA)** convention formation mechanism. This algorithm is executed by individual agents. Initially mappings for the lexicons are randomly assigned among the agents. Then each agent sends one random mapping to a randomly chosen neighbor and computes both its communicative efficacy and lexicon specificity (Lines 1.2 - 1.4). Each agent then computes its topological factor and lexicon utility (Lines 1.5 - 1.6). Then each agent probabilistically spreads its partial lexicon and updates its lexicon (Lines 1.7 - 1.9). This process repeats (Lines 1.1 - 1.9) until a stopping criterion, e.g., a majority lexicon convention emerges or a maximum number of iterations. The stopping criterion should be determined by the designer of the system. In our experimentation, we used a large number of iterations as the stopping criterion.

Algorithm 1: Context-Aware (CA) Convention Formation Algorithm

```
1.1  for each agent i:= 1 to n do
1.2      randomLexiconAssignment()
1.3      sendOneMappingToRandomNeighbor()
1.4      computeEfficacyAndSpecificity(Equation ??)
1.5      computeContextFactor(Algorithm ??)
1.6      computeLexiconUtility(Equation ??)
1.7      probabilisticLexiconSpreadingtoNeighbors()
1.8      probabilisticLexiconUpdate()
1.9      networkReorganization()
1.10 end
1.11 iterate (Lines 1.1 - 1.9) until a majority lexicon convention
       emerges or for a maximum number of iterations
```

4 DISCUSSION

We conducted experiments on the five topologies described above. Each type of network consists of 1000 agents represented as nodes in the network. The following is a summary of the observations obtained from experimental results.

- Using the convention formation framework, we investigated the performance of CA, SRA and FGJ on five topologies. Our results show that CA outperforms both SRA and FGJ both in terms of the number of agents that reach LMCS and the speed of forming LMCS.
- The performance of the CA approach indicates that knowledge about local context is useful for forming conventions in a decentralized MAS.
- In addition to this, we observe that equipping the agents with the ability to rewire results into improved performance. We experiment with three rewiring techniques and determine the optimal one.
- We investigate the performance of CA on SF networks with various degrees and observe that sparse SF networks do not facilitate convention formation.

Open and dynamic MAS require a social norm framework that is distributed and evolves to adapt to changes in the environment. In this paper, we present a convention formation framework that supports mechanisms to create efficient social conventions in MAS. The framework allows us to deeply probe the relationship between the average degree of SF networks and the speed of convention formation. It also facilitates investigation of various diversity mechanisms and identifies the conditions for diversity that could harness maximum benefit in terms of both the quality of convention and speed of forming such conventions.

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