3J3-OS-20b-3

Size Effect In Simulation of The Formation of Symbolic Communication System

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Coordination game has been used as an experiment paradigm to study the emergence of symbolic communication system. Efforts have been made to improve the experiment, so that quantitative analysis is possible. Whereas, the scalability problem has yet to be explored when adapting the experiment results to real world. In order to address this problem, we simulate the experiment with agent based modelling and reinforcement learning, and found that the number of selectable symbols is correlated with the performance of the formation of symbolic communication system. This size effect has been examined by referring to different message exchange styles.

1. Introduction

A scientific understanding of the mechanism of the formation of the social communication system is very important from both scientific and technological points of view ([Wagner et al., 2003]), while direct observation of the emergence of human communication system can hardly be made. As one of the effective experiment paradigms, [Galantucci, 2005] suggested a *coordination game* to study this issue in laboratories.

During this video game, two players would be separated into two different rooms in virtual environment (figure 1). Their initial position are decided randomly at the beginning of each round, and remain invisible to the other player until they meet each other in the same room. They are allowed to communicate with each other by graphic symbols only, before they had to decide where to move: horizontally, vertically, or stay still, while diagonal movements are prohibited. Every successful round earns them two points, while losing a round costs them one point. The goal of the game is to reach a certain score, so that the players need to win continuously as many times as they could. In order to do that, the participants need to act cooperatively to establish a symbolic communication system, i.e., *language*, during this game.

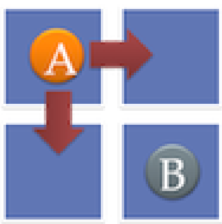

Figure 1: Setup of the four rooms coordination game.

Based on the four rooms coordination game, a more specific version of this experiment has been developed and conducted by [Konno et al., 2011]. In this experiment, the communication medium has been restricted further: the participants can choose two symbols from a pre-constructed symbols set to compose a message. Furthermore, all these symbols have no predefined meanings and message exchange can be made only once for each round. This enables a quantitative analysis over the formation of communication systems. However, we can actually choose *infinite* symbols to use in our daily life, including words and non-words, instead of only a limited number of symbols involved in the experiment. Therefore, the scalability problem of the symbols set becomes critical when adapting the experiment results to real world.

Moreover, there were two test conditions based on the differences of message exchange styles. Under the *asynchronous messaging* condition ($\mathrm{T_{AM}}$), messages are always sent immediately. Nevertheless, under the *synchronous messaging* condition ($\mathrm{T_{SM}}$), the messages can only be seen by the participants at the same time after both players sent their messages, so that no turn-taking could emerge. Meanwhile, it has been suggested that turn-taking plays an important role in forming pragmatic grounding, and thus also in developing communication system ([Konno et al., 2012]). Therefore, we expect that scalability of the symbols set may also be different under condition $\mathrm{T_{AM}}$ and $\mathrm{T_{SM}}$.

In this work, we built an agent-based model of the coordination game using reinforcement learning to explore the scalability problem of the symbols set under different message exchange conditions. The results could contribute to a better understanding of the role of turn-taking playing in the formation of symbolic communication system.

Besides, a computational model has been developed to explore the role of imitation during the formation of new communication systems ([Morita et al., 2012]). By comparing the simulation results to the human experiment, the authors suggest the importance of imitation during the process of forming a human communication system. This study provides good paradigm to examine the formation of communication systems with computer simulation.

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2. Modelling

The agent-based model used to simulate the coordination game involves two agents, each of which is capable to make movements, and to compose and send messages, by learning from the interactions with each other.

Behaviour strategies of the agents are dynamically emerged from the interactions using *Q learning*. To make any decisions, the agent use the current state as input, and then always choose the action with the biggest Q value. The Q value would then be updated later according to the formula:

$$Q(s,a) = Reward(s,a) + \gamma \cdot max_{a'} Q(s',a') \quad (1)$$

where s and a represent the input state and the corresponding actions, respectively. Likewise, s' and a' represent the resulting state and selected actions, respectively. The *Reward* would be either 2 or -1, depending on the game result, while γ is the discount factor and has been fixed to 0.5 during the simulation. The $max_{a'} Q(s',a')$ indicates the maximum Q value of the actions related to the resulting state. All the Q values are stored in tabular form as shown in table 1, while the initial values are generated randomly with a uniform distribution in range $[0.0, 1.0)$.

Action table	
Input	Initial position × received message
Output	One of the three movements
Message table	
Input	Initial position × received message
Output	Message composed of two symbols
Time threshold table	
Input	Initial position × internal time
Output	Threshold to send a message

Table 1: Three Q tables used in simulation.

The initial position can be one of the 4 possible values, though two agents can not have the same value at the same time. Accordingly, the output of the action table is one of the 3 possible movements: move clockwise, move anticlockwise, and stay still.

On the other hand, since any messages must be composed by two symbols, the number of possible outputs generated from message table is n^2, where n is the number of selectable symbols. However, the number of possible values for received message is n^2+1, which includes the additional state when no message has been received at all.

The time threshold table is specially designed for simulating condition T_{AM}, when the agents need to dynamically decide the timing to send messages. The input is one of the 15 possible values that represent the internal time points, while the output is an integral threshold value in range $[0, 10)$. A message will be generated and sent only if a randomly generated number is greater than the threshold, otherwise the agents have to wait for the other's message until the next time point.

The steps of the simulation is exactly the same as the human experiment. However, unlike human games, in which the players can learn from the revealed positions of the other one at the end of each round, the computer agents can not learn from the other's behaviour except the result of each round.

To examine the correlation between the number of selectable symbols and the performance of the learning process, we executed the simulation under condition T_{SM} and T_{AM}, which have different message exchange styles. The simulation results are presented and compared in the following section.

3. Results

3.1 Transition of concordance rate

The transition of concordance rate and score over time during a typical run under condition T_{AM} are presented in figure 2, where the concordance rates are calculated as the moving averages with a window size of 30. It can be found that to achieve a stable high concordance rate takes much more rounds to practice than in human case. Accordingly, the agents have already got a high score before reaching the final stable state.

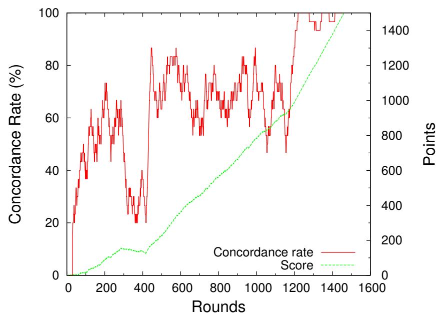

Figure 2: Transition of concordance rate of a typical run.

The "goal" point could be defined by either following the obtained score, which is the same as the original experiment, or following the concordance rate. According to the simulation results, we tested the model in both ways by defining the goal as: A) reaching 1500 points; B) winning the game 100 times successively. The game ends whenever the goal is achieved or after 30000 rounds running. The number of rounds took before the end of the game is then used as the index to evaluate the models.

3.2 Point based size effect

When setting the goal as reaching 1500 points, the correlation between the number of selectable symbols and rounds took before the end of the game is as shown in figure 3. As more symbols become selectable, the number of rounds took before goal also grows under condition T_{SM}, while it change little under other conditions.

By examining the transition of symbol usage under both conditions T_{AM} and T_{SM} (figure 4, the number of selectable symbols $n = 24$), we found that the number of used symbols always decreased alongside the growth of the concordance rate, though in very different patterns. The drop of the number of used symbols occurs gradually under condition

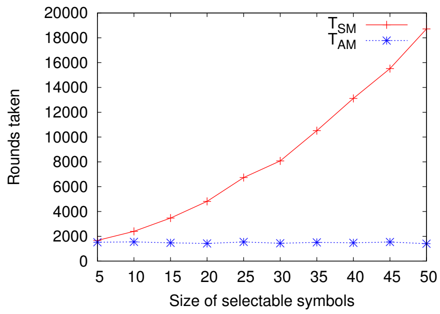

Figure 3: Size effect when setting goal A ($N = 50$).

$\mathrm{T_{AM}}$, and so is the growth of concordance rate, while all these changed dramatically under condition $\mathrm{T_{SM}}$. Meanwhile, the concordance rate of $\mathrm{T_{SM}}$ never reaches a stable state comparable to that of $\mathrm{T_{AM}}$, which may face difficulties in winning games successively.

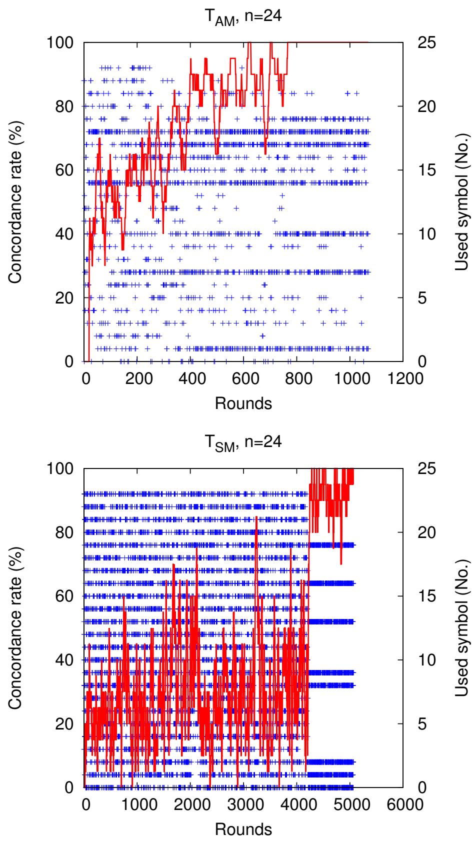

Figure 4: Symbol usage transition under $\mathrm{T_{AM}}$ and $\mathrm{T_{SM}}$.

3.3 Concordance rate based size effect

When setting the goal as winning the game 100 times successively, the correlation between the number of selectable symbols and rounds took before the end of the game is as presented in figure 5. Condition $\mathrm{T_{AM}}$ got better results when more symbols could be used, and changed little after reaching a certain level of performance; while condition $\mathrm{T_{SM}}$ kept taking very long time (failed in most cases) regardless the change of the number of selectable symbols, in concordance with the earlier results.

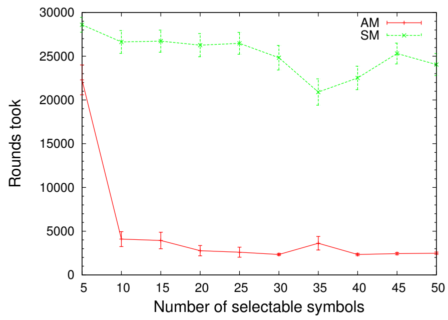

Figure 5: Size effect when setting goal B ($N = 50$).

4. Summary

In this work, we conducted computer simulation of coordination game with agent based modelling. We examined the scalability problem of selectable symbols under various conditions and compared the results with different goal settings. The results suggest that the dynamics of the formation of communication system are affected by the number of selectable symbols. When setting the goal as reaching a certain score, increasing selectable symbols lowered the chances to reach the state with higher concordance rate under condition $\mathrm{T_{SM}}$, which prevents the turn-taking to be emerged, and thus has a negative effect on the corresponding learning process, while has no effect under condition $\mathrm{T_{AM}}$, where turn-taking occurs.

On the other hand, when setting the goal as winning the game successively, decreasing the selectable symbols to a certain level cause the system more difficult to reach the stable state under condition $\mathrm{T_{AM}}$. Whereas the concordance rate under condition $\mathrm{T_{SM}}$ remains rather unstable across different tests, suggesting the turn-taking may play a role in stabilising the performances of the system.

Nevertheless, further investigation still needs to be conducted to reveal the nature of size effect, and to find out the implication of this effect for the real world.

5. Acknowledgement

This work was supported by a Grant-in-Aid for Scientific Research on Innovative Areas “The study on the neural dynamics for understanding communication in terms of complex hetero systems (No.4103)” (21120011) of The Ministry of Education, Culture, Sports, Science, and Technology, Japan.

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