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Cultural Evolution of Dynamic Signaling in an Interactive Game

Ghassen BEN HADJ LARBI[*1] Reiji SUZUKI[*1] Takaya ARITA[*1] Nana KANZAKI[*1]

[*1] Graduate School of Information Science, Nagoya University

Constructive approach toward the evolution of communication/language is an area of study that has received a lot of attention lately. We adopt a framework by Takano and Arita to make experiments with human participants. The goal is to validate theoretical results with participants and study the cultural evolution of dynamic signaling. We observed a variety of behaviors and the lower the degree of confrontation, the higher the success rate of the games, in accordance with Takano's results.

1. Introduction

The question of how language appeared and why we talk has always been one of mankind's greatest questions. There have been many theories hypotheses and theories on the subject [Tallerman 2011]. One particular theory became very popular due to its extraordinary explanatory power: the theory of evolution. In this case, language is seen as a complex adaptive system subject to the power of evolution and natural selection. By associating the theory of evolution and linguistics, the discipline of evolutionary linguistics was born [Barkow 1995].

One particular approach in this field was to use population dynamics describe language evolution models based on the payoff for individuals successfully communicating via "language" [Nowak 2006]. With the increasing computing power of computers, a new approach called "constructive approach" appeared. Basically, it utilizes computational models to simulate the evolution of language and focuses on the emergent properties of language dynamics [Kirby 2002].

Most of these studies made 3 basic assumptions:

- Symbols or signals exchanged are discrete expressions.
- Speakers and listeners are clearly separated.
- Both speaker and listener get the same benefit for communicating.

However these assumptions come from more basic counterparts:

- Discrete symbols originate from signals of continuous expressions such as vocalizations and gestures.
- A division of roles between the speaker and listener emerges from simultaneous two-way interactions.
- Symmetric property is just one of many relationships that can exist between the speaker and listener.

Furthermore, several studies have shown that communication evolves more easily when there is a low degree of confrontation, when both sides have a mutual interest. The opposite is also true, meaning that if there is a high degree of confrontation, communication evolves more difficultly owing to the greater losses that the yielding side suffers [Smith 1994, Smith 2003].

Takano and Arita developed a model that takes into account all three basic counterpart assumptions and investigated a variety of cases. In the case of degree of confrontation, their model evolves to have agents using two different types of signaling types and confirms the results of other studies in that they the lower the degree of confrontation, the easier communication evolves and vice-versa [Takano 2008]. However, the problem with such theoretical frameworks is that they are seldom verifiable and verified against actual data and tests with human participants.

In this study, we propose to adapt Takano's model to make experiments with human participants. We focus in particular on the case of the dynamic signaling under conditions of degree of confrontation. The goal is to verify and validate the theoretical results of the model with actual inputs from participants as well as study the cultural evolution of the signaling in different groups. For each group of participants, our goal is:

- To identify patterns of behavior and investigate whether a particular form of signaling emerges or not.
- To study the evolution of each player's behavior throughout the experiment.
- To study the effect of the degree of confrontation on the success rate of the games.

To do so, we develop an interactive game that will serve as the basis for evaluating human participants. The game allows two participants to engage in simultaneous 2-way interaction and choose a strategy the same way as in Takano's model.

2. Takano's model and results

Takano's model consists of a population of agents who engage in a two-way interaction, called negotiation, before choosing a strategy. Each agent has three attributes associated to it:

- A state a representing the strategy selected after the negotiation period.
- A signal ϕ that will be transmitted to the other agent.
- An internal state I used for preserving context when engaging in the dynamic negotiation.

These attributes were updated using a three-layer neural network and the neural network is evolved using as a fitness measure the average payoff obtained during the interactions with the other agents.

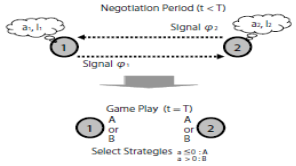

Figure 1: Interaction between 2 agents.

Contact: Reiji SUZUKI, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan, Tel/fax +81-52-789-4258, reiji@nagoya-u.jp

Figure 1 shows the interaction between two agents. During the first phase called negotiation phase (time t=0 to t=T-1), each agents transmits his own continuous-valued signal ϕ to the other agent and receives the other agent's signal ϕ in simultaneous two-way communication and they both update their attributes a, ϕ and I using the output of the neural network. Then at time t=T, based on the results of the negotiation period, the game-play phase consists in choosing a strategy and obtaining the payoff specified in Table 1. If the attribute $a \leq 0$, strategy A is chosen, while if $a > 0$ strategy B is chosen. The attributes are initialized with the value 0 and each agent competes 6 times with other agents, the mean payoff being the measure of fitness.

Table 1: Payoff matrix in the case of degree of confrontation.

	A	B
A	0, 0	1, α
B	α, 1	0, 0

In this study, we focus on the special case of degree of confrontation. As shown in table 1, in order to get a payoff, agents need to adopt different strategies. The confrontation is represented by the α value ($0 \leq \alpha \leq 1$). This situation can represent the fight of animals over resources : if both refuse to abandon, they suffer the cost and loose the resource while if one yields, the winner receives the resources while the looser suffers no cost. α represents the degree of confrontation, with big confrontation with a small α and low level of confrontation with higher values of α and confrontation at all when α = 1. A game is said to be successful when agents choose different strategies.

Evolutionary experiments of communication strategies based on recurrent neural networks were conducted with varying α from 0.1 to 1 with increments of 0.1. Two kinds of signaling were found.

In the first one, each state was convergent and was called convergent communication while in the second states keep oscillating and this was called oscillatory communication. In a typical case of convergent communication, both agents have their ϕ and a values at 0. They start by gradually decreasing their ϕ signal and increasing their a value, seemingly to choose strategy B. But after some time, one of them starts increasing the value of its ϕ signal indicating that it will choose strategy B. The other agent in response starts decreasing its $a(t)$ value in order to choose strategy A.

In a typical case of oscillatory communication, both agents keep oscillating their ϕ signal with the same frequency and phase, and after some time, one of them proceeds to invert his phase while keeping the same frequency. In this case, the change of state by an agent seems to indicate that this agent will choose strategy B.

Takano also found that the success rate is significantly higher for games with signaling than for ESS population when $\alpha \geq 0.5$, indicating that the signaling evolved to have a positive influence on the success of the game. Also, the success rate is very high for high values of α; probably owing to the low degree of confrontation that makes it easier for an agent to yield. On the opposite side, for low values of α, the success rate is much lower and so the signaling doesn't work as effectively because of the high degree of confrontation.

3. Experiment procedure

Takano's model offers a good framework for the study of the emergence of communication and signaling while satisfying the three basic viewpoints (a', b', c'). To further test this framework, we propose to adapt the model to perform experiments with human participants.

The basis of the experiment is the same as for Takano's model. The experiment consists of an interactive game played by pairs in groups of 4 people. The game uses software we developed and is played on computers. It is a simple game in which players keep exchanging a signal and have to choose a strategy. Depending on the strategy chosen, each player will receive a payoff, counting towards a monetary reward at the end of the experiment, the goal for each player being to maximize his own payoff. A variable monetary reward is also offered to the participants. The variable monetary reward is an incentive for participants, encouraging them to play the game with the goal of achieving the highest payoff. The goal of the experiment is to see whether some form of signaling emerges or not, and if so, to study its establishment and its phases. Furthermore, we want to study the role of cultural evolution in the establishment of a dynamic signaling. To do so, participants are divided in groups of 4 and are not allowed to play against a player from another group.

As mentioned previously, players are told that a variable monetary reward will be given to all the participants in the experiment. This reward is divided in 2 parts: a participation reward, which is 1000 yen, and a performance part depending on the performance in the game. However, it has been decided to award each participant 2000 yen regardless of his performance so as not to provoke tensions between the participants. Players are told the truth after the experiment is over and are paid immediately.

A total of 4 groups have been selected for participating in the experiment, meaning a total of 16 people. The participants in the experiment are all graduate students from different departments of Nagoya University, with the age ranging from 24 to 36.

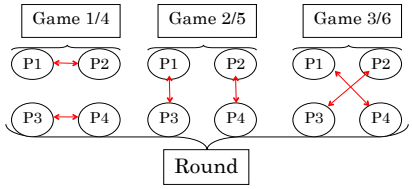

Figure 2: Progress of a round.

As shown in Figure 2, a round is when each player has played against the other 3 players of his group twice. The experiment comprises 5 rounds so each player plays a total of 30 games, for a total of 240 games across all groups. There are 5 different values of α, each corresponding to one round: 0, 0.25, 0.5, 0.75 and 1. This will allow us to study the role of α in the success rate of the games. The negotiation period is set to 60 seconds for all games. Before the experiment, participants are given explanatory

slides detailing the experiment procedure and also play 5 trial games in order to get accustomed to the software.

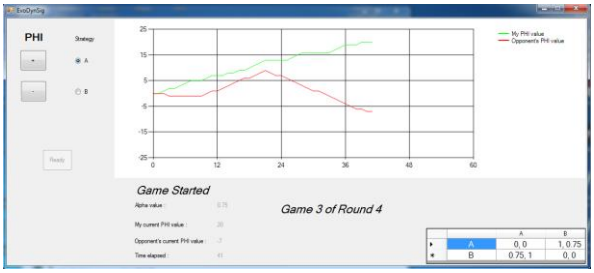

Figure 3: Screenshot of the software.

Figure 3 shows a screenshot of the software during the course of a game in the experiment. The different phases of a game are thus. First, the player has to choose an initial strategy. This is done so that players need to choose at least once a strategy and prevent the case where players do not choose a strategy during the game. Then the player presses the "Ready" button. When both the player and his opponent have pressed the button, a countdown of 5 seconds will start before the actual beginning of the game. When the countdown is over, players have then 60 seconds to change their strategy and PHI value. When the time is over, each player's payoff is calculated according to their choice of strategy and the payoff matrix described earlier. As in Takano's experiment, a game is deemed successful when players choose different strategies.

4. Experiment results

Four different patterns were observed:

- Correlation pattern: associating a high value of the signal ϕ to strategy A and a low value of ϕ to strategy B.
- Anti-correlation pattern: linking a low value of the signal ϕ to strategy A and a high value of ϕ to strategy B.
- Random pattern: randomly choosing a strategy and keeping the ϕ value close to the opponent's ϕ value.
- Greedy pattern: always choosing strategy A and increasing ϕ the maximum value.

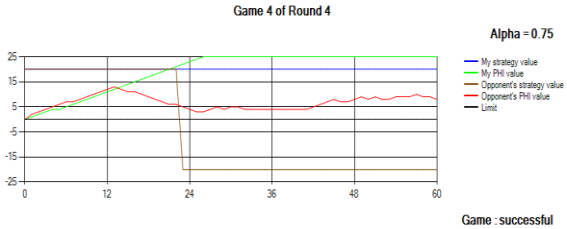

Figure 4: Typical game using the Correlation pattern.

Figure 4 shows a typical game where both players use the Correlation pattern. Player 1 uses the blue and green colors while Player 2 uses the brown and red colors. For ease of analysis, we have associated strategy A with the value 20 and strategy B with the value -20. During the experiment, players do not see the blue and brown lines indicating the strategy chosen. This particular game is the game 4 of round 4, with $\alpha = 0.75$.

As we can see, both players' initial strategy is strategy A. Both players start by increasing their PHI value, indicating that they are willing to choose strategy A. Then after 13 seconds, player 2 decides to yield. As thus, he starts decreasing his PHI value to signal his opponent his decision to choose strategy B and changes his current strategy to strategy B at 23 seconds. From there on, nothing of interest happens. This game is a successful game, and player 1 receives a payoff of 1 and player 2 receives a payoff of 0.75.

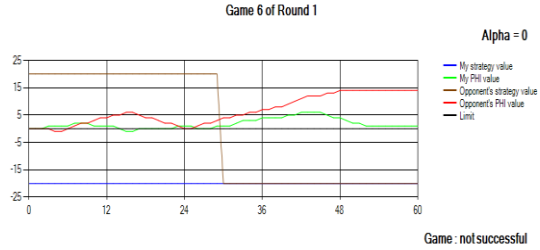

Figure 5: Typical game using the Correlation and Anti-correlation pattern.

Figure 5 shows a typical game where Player 1 uses the Correlation pattern and Player 2 uses the Anti-correlation pattern. As we can see, Player 1's initial strategy is B and Player 2's initial strategy is A. Both players seem hesitant at first, slowly changing their PHI value until the second 28 when Player 2 decides to increase sharply his PHI value and, following his behavior, changing his current strategy to strategy B. Player 2 does not seem to react and since he is using the Correlation pattern, it seems logical to him. Both players end up with strategy B at the end. This game is not a successful game, and both players' payoff is 0.

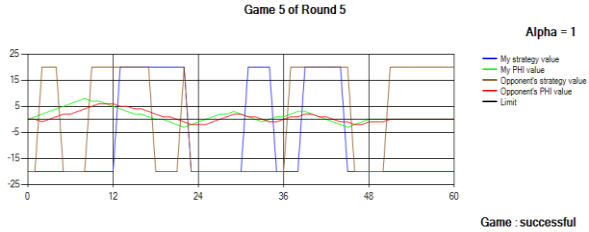

Figure 6: Typical game using the Random pattern.

Figure 6 shows a typical game where both players use the Random pattern. This particular game is the game 5 of round 5, with $\alpha = 1$. As we can see, the changes in the value of ϕ seem completely random, with the exception of keeping their value as close as possible and finally the same in the end. We also notice that strategies are changed constantly and seemingly in a random manner. In the end, Player 1 chooses strategy *A* while Player 2 chooses strategy *B*. The game is successful and both players receive a payoff of 1.

Correlation pattern was common to all groups and was the dominant pattern except in Group 4. The Anti-correlation pattern appeared in Group 2 but disappeared in the final games. The Random pattern was used in Group1 and 4, it disappeared in Group 1 but became dominant in Group 4. The Greedy pattern

only appeared in Group 3 but maintained until the end of the experiment.

To investigate the effect of α on the success rate of the games, that is the ratio of successful games, we combine the results of all the different groups together: α=0: 60%, α=0.25: 54%, α=0.5: 56%, α=0.75: 73%, α=1: 80%. Except for the case of α = 0, we see a gradual increase in the success rate of the games with each higher value of α. This confirms the results of Takano's model in that a higher value of α is positively correlated to a higher success rate of the games and a positive influence of the signals on the success rate. There is however a difference in that there is a sharp difference in success rates when $\alpha \leq 0.5$ for Takano whereas this difference does not exist in our results. This might express the human psychology in that humans are more inclined to cooperate than artificial selfish agents.

Table 2: Patterns of gameplay per player in group 2.

Round number	Game number	Player 1	Player 2	Player 3	Player 4
Round 1	1	1	1	3	3
	2	1	1	3	2
	3	3	1	3	1
	4	1	1	1	2
	5	3	3	3	3
	6	1	1	1	2
Round 2	7	2	1	1	2
	8	3	1	2	1
	9	2	1	2	1
	10	1	1	2	3
	11	1	1	1	1
	12	1	1	3	1
Round 3	13	2	1	1	1
	14	1	1	1	2
	15	1	1	1	1
	16	1	1	2	2
	17	1	1	1	1
	18	1	1	1	1
Round 4	19	1	1	1	2
	20	1	1	1	1
	21	1	1	1	1
	22	3	1	1	1
	23	1	1	1	2
	24	1	1	1	1
Round 5	25	1	1	1	1
	26	1	1	1	1
	27	1	1	1	1
	28	1	1	1	1
	29	3	1	3	1
	30	1	1	1	1

Table 2 shows the different patterns of behavior used by each player for each game, as well as the order and the participants of each game in group 2. Cells of the same color indicate that these 2 players were opponents for the particular game selected. The numbers indicate which pattern was used by each player for each game, in this case: the Correlation pattern is identified by the number '1' and the Anti-correlation pattern by the number '2'. When we fail to identify a pattern in a particular game, this is denoted by the number '3'. We can see clearly that Player 2 immediately adopted the Correlation pattern, while the other players were trying different strategies. The anti-correlation pattern was used mainly by Player 3 and Player 4, but by Round 3, the Correlation pattern became dominant in the group.

As outlined in the previous paragraphs, there has been more than one pattern of behavior identified in each group, with 4 distinct patterns in total. However, one of these patterns involved choosing the strategy randomly with ϕ random, and thus is not considered to be a meaningful signal. Also, in every group except Group 1, all the participants have converged to the use of only one pattern. The case of Group 3 is special in that technically, there were two patterns used, but the meaning of the signal of Greedy pattern was understood by players using the Correlation pattern. This shows that there was a pressure on each participant of the groups to conform to a single behavior. This effect and pressure to mimic an interlocutor is clearly established both linguistically and non-linguistically [Pickering 2004, Chartrand 1999]. This is also in accordance with the results of Takano's model, in that more than one type of signaling can emerge.

5. Conclusion

To investigate the cultural evolution of dynamic signaling and apply Takano's model to the real world in the case of degree of confrontation, we conducted experiments with participants who were asked to play a simple interactive game. The game mimics the mechanics and interaction between agents in Takano's model and provided a simple platform for testing the model. In each group, there has been more than one kind of behavior:

- In Group 1, the dominant pattern was the Correlation pattern, with the Random pattern being used in some games and by some players.
- In Group 2, players used both the Correlation and Anti-correlation pattern but the first pattern became dominant.
- In Group 3, the dominant pattern was the Correlation pattern, with a player adopting the Greedy pattern.
- In Group 4, the dominant pattern was the Random, with some players using the Correlation pattern in a few games.

The variety of behaviors seems to confirm Takano's results that more than one signal can appear. We have also seen that the higher the value of ϕ, the higher the success rate of the games, which is again in accordance with Takano's results. We also observed a relatively high success rate even when there is a high degree of confrontation. This could be an expression of human psychology.

References

Tallerman, M., Gibson, K., *The Oxford Handbook of Language Evolution*, Oxford: Oxford University Press, 2011.

Barkow, J. H., *The Adapted Mind: Evolutionary Psychology and the Generation of Culture*, Oxford University Press, USA, 1995.

Nowak, M. A., *Evolutionary Dynamics: Exploring the Equations of Life*, Belknap Press, 2006.

Kirby, S., Natural language from artificial life, *Artificial Life*, 8(2):185–215, 2002.

Smith, J. M., Must reliable signals always be costly?, *Animal Behaviour*, 47(5):1115–1120, 1994.

Smith, J. M., Harper, D., *Animal Signals*, Oxford University Press, 2003.

Takano, M., Arita T., Constructive Approach to the Evolutionary Foundation of Language: A Model for the Evolution of Dynamic Signaling, *IPSJ Journal*, 49(8):2890-2899, 2008.

Pickering, M. J., Garrod, S., Toward a mechanistic psychology of dialogue, *Behavioral and Brain Sciences*, 27, 1–22, 2004.

Chartrand, T. L., Bargh, J. A., The chameleon effect: The perception-behavior link and social interaction, *Journal of Personality and Social Psychology*, 76, 893-910, 1999.