An interactive wall game as an evolution of proto language

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Abstract

A new interactive "wall game" is proposed in which two human players alternatively configure a pattern to communicate. A pattern consists of 3x3 sites, on which a player can place one of three symbols. The two major findings in this paper are i) the subjects mainly communicated in two modes. Either the subjects changed the pattern by watching the pattern as it is (dynamical mode) or by having narrative reflection (metaphorical mode). ii) Subjects switched between these two modes. Most of the experiments in evolutionary linguistics are based on "task-oriented communication" and they observe the emergence of lexical items. In contrast, our experiment explores whether "communication without purpose" leads to the emergence of complex rules such as linguistic grammar. We argue that the switching between the two modes observed in our experiment can be seen as a grammatical process in the sense that it is a procedure to take an internal state outside using the media (i.e., patterns in the wall game). Under this hypothesis, the players' exploration of the media becomes a crucial step in the emergence of language and grammar.

1. Introduction

Artificial life studies provide a test bed for exploring how symbols and grammars emerge in minimally interacting systems through computer simulation. For the last 10-15 years, artificial life studies have contributed greatly to this direction, and the origin and evolution of language has become a target of many scientific studies (see e.g. Steels, 1996, 2005; Hashimoto and Ikegami, 1996; Rizzolatti and Arbib, 1998; Vogt, 1998; Cangelosi and Harnad, 2000; Sugita and Tani, 2005 etc.). For example, Steels and Kaplan (2001) have developed a platform for studying the interaction between two artificial agents acting as speaker or hearer. In this approach, a population of robots develops a shared vocabulary and a corresponding ontology while playing language games (i.e., ritualized social interactions that follow a specific script).

More recently, there are many researches based on experiments using human subjects (e.g., Steels, 2006; Selten and Warglein, 2007; Scott-Phillips and Kirby, 2010) as a new approach to the origin of language. Subjects communicate through a communication tool and some structured system emerges. Some of these studies testify to a hypothesis that is raised by computational simulation studies. For example, the "iterated learning model," which is a model of vertical and horizontal cultural transmission, was proposed by Kirby (2002). It was originally studied as a computational model and later the model has been adjusted to experiments using humans (Kirby, Cornish and Smith, 2008). .

Among many studies of "language evolution in the laboratory," Galantucci (2005) introduces one of the most influential experiments. In his experiment, two subjects who are staying in different rooms play a video game together over a monitor. They have to be cooperative to get a high score. They are allowed to communicate using a special communication tool. This tool allows the subjects to draw graphics but not letters. As the experiment proceeds, the difficulty of the video game increases. The pairs that ended the game with success shared many signs for rooms and enemy, which were drawn with the communication tool.

In most of the researches adopting an experimental approach, the final outcome often consists of lexical items. This comes from the fact that in most of the experiments, subjects are asked to perform a task together to make them communicate with each other.

Not only the lexicon but grammar is an integral part of a linguistic system. To get more variations in results, the communication observed in the experiments should not be limited to those that are task oriented. For example, we assume that "communication without purpose" can be important to trigger proto-language with both grammar and lexicon in experiments. This idea is supported by the research in developmental psychology: infants are known to be engaged in two types of proto-linguistic communication. The first is communication with an aim, such those that are task oriented. The second is a communication without an aim, in other words communication whose aim is communication itself (Bates, 1976). Gómez, Sarria and Tamarit. (1993) argue the importance of the second type of communication. It is pointed out that the ability to communicate without purpose is an indicator for the ability called "theory of mind." With "theory of mind," one can infer other people's minds, which are different from one's own. And this ability is known to be integral to the use of language grammar properly (Tager-Flusberg, 1993). Tomasello (2003) has also argued the

importance of shared attention in development and pointed out the role of communication just to share communication in acquiring language.

Actually, Uno, Marocco, Nolfi and Ikegami (in press) made an attempt to use the A-life approach to explore the relationship between communication without purpose and the emergence of grammar. The agents were supposed to stay together in the target area using signals. However, when agents were given uncertain information regarding the target area, they start staying together outside the target area using newly created signals, which was argued to be a proto-declarative sentence: a sentence used to share intentionality.

In this paper, we are going to take an experimental approach to see how communication gets structured when there is no purpose. We explore what are the characteristics of human communication (which might possibly be implemented in artificial systems) when individuals are just having fun. We asked subjects to communicate using our communication tool, which is called a "wall game." The results show that there are two modes of communication. What emerged from the subjects' communication is not a set of lexical items but the way an internal state of mind can be expressed as an external message. We argue that this can be seen as a proto-grammar.

Section 2 explains the basic design of our experiment. Section 3 and 4 show the results of the experiments. Finally, section 5 analyzes and discusses the results of the experiment.

2. Description of the Experiment

Twenty-six subjects (13 pairs) were asked to communicate using an artificial communication system, where the expressions were the spatial pattern of the triplet in a 3-by-3 bit square. They were allowed to rewrite the pattern alternatively. We call this pattern a "message."

For the first 9 pairs, each subject sent 8 messages in turn, which is 16 messages in sum. For the next 4 pairs, each subject sent 15 messages and 30 in all. After all messages were exchanged, we asked them to report their intentions behind the sent messages, and their interpretations of the received messages in natural language. (Henceforth we call this data the "intention report.")

We conducted the experiment mainly in Japanese. The reports shown in this paper are translated into English by the authors.

The two subjects stayed in different rooms. The messages were sent to each other over the Internet. Figure 1A shows a screen where one can compose messages. All the messages that are sent and received are shown to the subjects so that they can compose their messages based on their communication history. Figure 1B shows how the history of exchanged messages is displayed to the subjects.

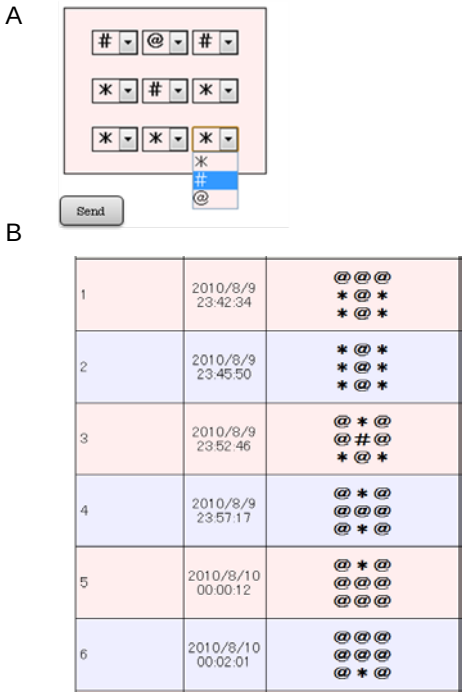

Figure 1: Two screen shots. A is a message composer. B is the timeline of exchanged messages.

Here are some examples of exchanged messages from our data. Player A sent (1) and Player B answered to it with (2). Then Player A replied to it with (3). Finally, (4) is an answer to (3) by Player B.

(1) From A to B	(2) From B to A	(3) From A to B	(4) From B to A
@@@	@@@	###	###
@*@	@*#	###	##@
@@@	@@@	###	#@@

Table1: Exchanged messages between Player A and Player B

We made a linguistic analysis of the intention report and mathematical analysis to the patterns. The results are given in the following sections, 3 and 4.

We performed the experiment under three conditions:

Condition 1
Messages are exchanged between two subjects. Subjects write intention reports after exchanging all the messages (Appears in Experiment 1, 2, and 3).

Condition 2
Messages are exchanged between two subjects. Subjects write intention reports in every round and players exchange messages (Appears mainly in Experiment 2).

Condition 3
Each subject plays with the game on his/her own. Subjects write intention reports after writing all the messages (Appears in Experiment 3).

The basic game is condition 1. In condition 2, the timing of writing the report differs from that in condition 1. In condition 3, the game is played by a single player.

3. Experiment 1: Two modes of communication

3.1 Linguistic analysis

To begin with, we analyzed the intention report from a linguistic point of view. We categorized the reports as three types: dynamical report, metaphorical report, and others.

What we call a "dynamical report" is a literal description of the patterns in the messages. For example:

(D1) All kinds of symbols are used.
(D2) The pattern is scrolled from left to right.

In these reports, patterns are described just as they are. The messages that these reports are made for are shown in Table 2 below.

On the other hand, in what we call a "metaphorical report," the subjects create a story based on the symbols inside the pattern. They are not describing the pattern as it is. Instead, they are using metaphors (in the sense of Lakoff [1987]). They describe symbols or a string of symbols as something else. Here are some examples:

(M1) A rabbit is in a cage.
(M2) The rabbit made a hole in a cage to escape.

Here the player sees the symbol "*" as a rabbit and a sequence of"@" as a cage, and "#" is a hole.

In this system, there is no way for one player to transmit her story to the other player. For example, while Player A intended to express a rabbit using the message shown as (M1) in Table 2, Player B made the following intention report for the same pattern:

(D3) * is surrounded by @.

In the category called "others," the reports are not strongly connected to the patterns. For example, we have emphatic expressions such as (O1) or feelings of the players, which are irrelevant with the patterns such as (O2):

(O1) Hello. Nice to meet you.
(O2) This experiment is difficult.

(D1)	(D2)	(M1)	(M2)	(O1)	(O2)
∗ # @	@ # ∗	@ @ @	@ @ @	@ ∗ @	@ # #
∗ # @	@ # ∗	@ ∗ @	@ ∗ #	∗ @ ∗	# ∗ #
∗ # @	@ # ∗	@ @ @	@ @ @	# # #	∗ ∗ ∗

Table 2: Examples of messages three types of reports are made for

The ratio of reports in each category used by each pair is given in Figure 2. It is shown that most of the reports are either dynamical or metaphorical.

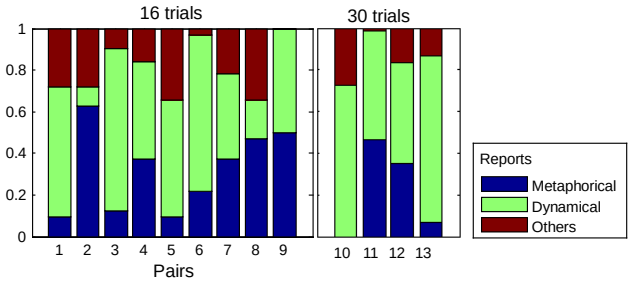

Figure 2: Ratio of report types in Experiment 1. It is calculated from the accumulated reports of two players who exchanged messages. The ratio between metaphorical and dynamical reports varies over pairs.

3.2 Mathematical analysis 1

In order to see the characteristics of the wall patterns in the two different report categories, we calculated the correlation between the Hamming distance of adjacent patterns and the frequency of each type of the reports. Hamming distance is defined as the number of changes required to match one character string with another string. Therefore, we regarded the wall patterns as linear character strings (e.g., (D1) in Table 2 is regarded as "*#@*#@*#@") to calculate it. The larger the Hamming distance of a couple of patterns, the less they are similar. In order to treat the report under mathematical analysis, the two categories of the report are indexed by counting the number of them in each turn (i.e., the metaphorical index is scored 2 for when both subjects interpret metaphorically, 1 for when one subject does, and 0 for when neither do). We calculated the correlation coefficient between Hamming distances and both the metaphorical indexes, and the dynamical indexes in each turn.

The results are shown in Figure 3. We found that when the Hamming distance between successive patterns gets smaller, the human subjects tend to use metaphorical reports. On the other hand, the Hamming distance between successive patterns gets larger when subjects use dynamical reports.

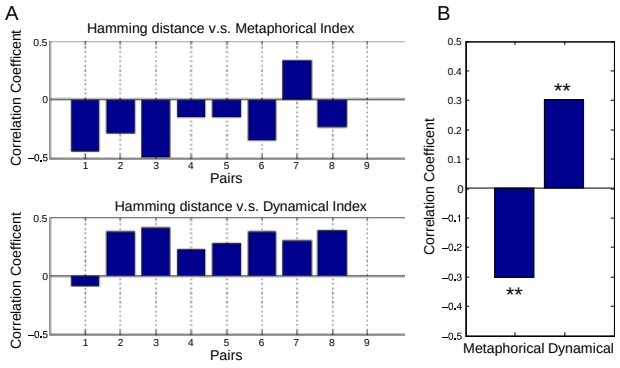

Figure 3: A: Correlation coefficient between Hamming distance and the number of two categories in reports for each pair. B: The same evaluation across all the pairs. Hamming distance has significant ($p < 0.01$) positive correlation with the dynamical report, and significant ($p<0.01$) negative correlation with the metaphorical report.

3.3 Mathematical analysis 2

We also drew a state transition graph between successive patterns. To analyze the transition state of the patterns, 16 messages were not enough to have statistically valid results. We therefore focused on pairs 10 to 13 who exchanged 30 messages (15 each) in one trial. They performed two trials under two different conditions (i.e., conditions 1 and 2. See Section 2 for an explanation). We are going to discuss the contrast between conditions 1 and 2 in detail in Section 4. The point is that under condition 2, more metaphoric reports were tended to be used compared to condition 1.

In order to create the transition graph, we grouped the patterns used in a game by the numbers of symbols the pair used. We first separated the patterns into three rows, and grouped each row using only the constituent ratio of the symbols (e.g., "*@*" is grouped into "210", "###" is grouped into "003", etc.). Thus, each line represents 1 of 10 groups (0 for "012" ... 9 for "210"). We then assigned the groups a triple-digit number (e.g., 091 for "#@#/*@*/@#@"). Finally, we grouped all the patterns used in the game from the number, and calculated the transition between them.

Figure 4A shows the state transition graph calculated for the pair 11. The linearity of the transition graphs is defined as follows: "the number of nodes divided by the number of edges of a graph." A linearity of the pair 11 under condition 1, whose main communication mode is dynamic, is calculated as 0.89. And the linearity of Pair 11 under condition 2, whose main communication mode is metaphoric, is as 0.97. The analysis of this pair suggests that the metaphoric mode has a tendency of having a lower linearity than the dynamic mode.

Figure 4B shows the correlation coefficient between the linearity and the number of the two report modes in all the trials by 4 pairs. The result shows that same types of transition are used repetitively in the dynamic mode but not in the metaphoric mode.

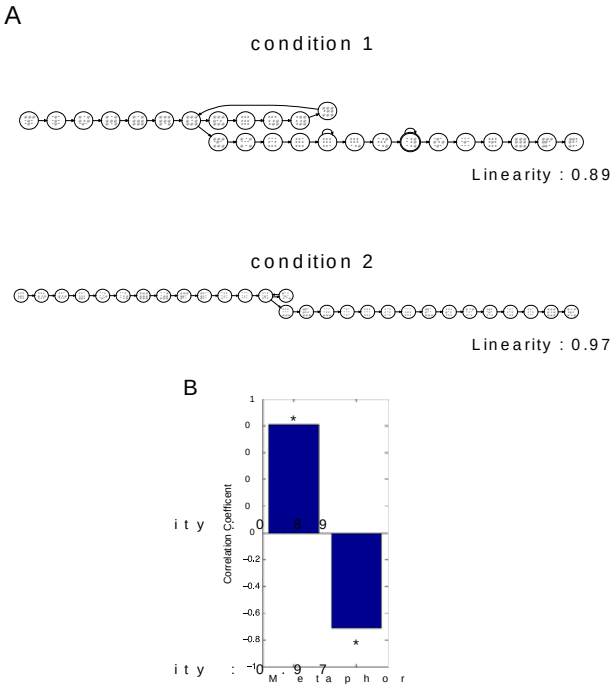

Figure 4:
A: Examples of state transition graphs obtained from results of the pair 11. Here, the linearity is defined as the ratio between the number of nodes and the number of edges. A higher Linearity is observed in condition 2, compared with condition 1.
B: The correlation coefficient between the linearity and the number of the two report modes in the 8 games. A positive correlation can be seen between the linearity and the metaphoric mode, and a negative correlation between the linearity and the dynamic mode.

Here we point out that there are two major modes in communicating with the system introduced in Section 2., metaphorical mode and dynamical mode. During the game, the subjects enjoyed processing patterns and trying to assign meanings to them. In a report, the former shows up as a literal description of dynamic patterns and the latter story is told using metaphors. This difference is correlated with the difference in changing the patterns, which can be partly calculated with the Hamming distance and linearity of the transition states.

4. Experiments 2 and 3

To know further about the two modes of communication pointed out in the last section, we made two additional experiments. Below we briefly review each experiment.

4.1 Experiment 2: Message-by-message report

We asked 4 pairs who exchanged 30 messages in Experiment 1 (which we call condition 1) to exchange an additional 30 messages in the new trial (which we call condition 2). This experiment is to make the intentions behind the messages clear and to see the effects on subjects' behavior. In the new experiment, in every round players exchanged the messages they had in order to to compile reports of their intentions.

Compare the ratios of the metaphoric and dynamic reports of conditions 1 and 2 shown in Figure 5. This result suggests that when subjects are more conscious of the intention of the message, they tend to be engaged in the metaphoric mode rather than the dynamic mode.

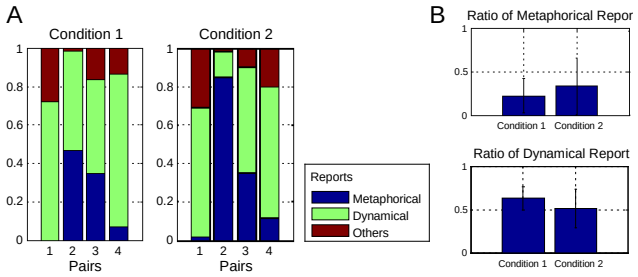

Figure 5:

A: Ratio of reports in each category in condition 1 and 2. In condition 1, the players did not have to make "intention reports" during the game. In condition 2 the players had to make "intention reports" every time they sent or received messages. It is calculated in the same manner as in Figure 1.

B: The ratios of the metaphoric reports and dynamic reports are averaged across all the pairs. There seems to be a tendency for dynamic reports to be more ascendant than metaphoric reports in condition 1, while the opposite tendency can be seen in condition 2.

4.2 Experiment 3: Solitary play

In the third experiment, we asked each subject to play with the game by him/herself (we call this condition 3). We asked one of the subjects who experienced Experiment 1 to make 30 messages by him/herself without having another player "behind the wall" asking him/her to report his/her intentions. Compare condition 1 in Fig. 5 and condition 3 in Figure 6. The result reveals that subjects tend to use either one of the modes, not both of them, when they have no one to communicate with.

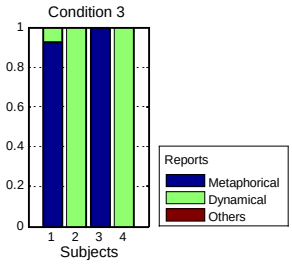

Figure 6: Ratio of reports in each category in condition 3. In this condition, subjects play the wall game alone. The reports are extremely biased into either metaphorical or dynamical.

At least the players get more varieties in behavior when they are together. Let's see an example that is congruent with the results in Experiment 2. Table 3 shows an exchange between two players.

(1) From A to B	(2) From B to A	(3) From A to B	(4) From B to A
# * *	# # #	* * *	* * @
# @ *	# @ #	* @ @	* * @
# # #	# # #	# # #	# # #

Table 3: Exchanged messages between Player A and Player B

Player A interprets the whole exchange in metaphorical mode. Below are the intention reports by player A for (1) to (4).

(A1) @ is me and * is a cherry blossom. Shall I go out by myself?
(A2) I am also alone.
(A3) It is more fun if we stay together.
(A4) Different scene. Here * and # are people. @ and @ joined them.

On the other hand, player B is communicating with dynamical mode form (1) to (3). At (4) he starts to use the metaphorical mode. Here are the intention reports by player B for (1) to (4) .

(B1) More #s.
(B2) I added more #s.
(B3) @ was added. * appeared again.
(B4) @ looks like an cute animal. # and * are environments. So I moved @.

Player B started to change the mode of communication after communicating with player A. As shown in this sample, an interaction between two players facilitates switching between two modes.

All of the experiments that show the characteristics of two modes of communication using our wall game are

summarized in the following table. We interpret the results in the next section.

	Experiment 1			2	3
	Intention Report	**Hamming Distance**	**Transition state**	**On-spot report**	**Alone**
Metaphorical mode	Metaphorical	Smaller	More linear	increase	**N/A**
Dynamical mode	Dynamical (literal)	Larger	Less linear	decrease	**N/A**

Table 4: Summary of the experimental results

5. Analysis and discussio

5.1 Interpretation of two modes

Different from previous evolutionary linguistic experiments, players of the wall game were asked to communicate without a purpose. The only motivation is to enjoy communicating with each other.

In this game, the easiest way to compose a message is to mimic what the other player did. However, this strategy has to be avoided because the communication becomes monotonous and predictable so that the players can easily get bored.

Accordingly, we assume that the behavior of the players is the one that tries to avoid mimicking each other and instead they need a strategy to make messages that has novelty for the other player. Two modes of communication can be understood from this point of view.

First of all, the dynamical mode is a mode in which the player pays attention to the patterns in the messages as they are. Therefore, the reports are literal descriptions of the patterns (dynamical report). To make an interesting change in messages only with patterns, there must be a distinct change. This explains why the Hamming distance calculated in Experiment 1 was relatively large. The frequently used patterns that can make interesting transitions are limited. For example, patterns with three lines are often used, as is shown in the transition from (D1) to (D2). This explains the result of Experiment 2, which shows that the transition state of the dynamical mode was less linear, which means that the same pattern was frequently used.

Turning to metaphorical mode, the players make their own stories based on the transition of the patterns. The story itself cannot be transmitted to the other player in this game. So for the Player B who does not share the story, the message by Player A in metaphorical mode is unpredictable and novel. It has been pointed out that metaphor helps people extend their understanding (Lakoff, 1987) and make inferences (Thibodeau and Boroditsky, 2011). In addition, we want to point out that metaphor helps people behave in a creative manner based on the observation in our experiment.

In metaphorical mode, as shown in Experiment 1, the Hamming distance is small. This is understandable when we realize that even small changes can be meaningful in a story. Compare (M1) and (M2). As shown in Experiment 2, the linearity of the transition pattern is big, that is, the same patterns are rarely used. This can be explained by the fact that in metaphorical mode what is meaningful is the difference between the current diagram and the last one. This means that there is no particular pattern that has to be used in metaphorical mode.

In Experiment 2, we tried to capture the relationship between two modes and “attention”.

The subjects enjoyed processing patterns and trying to assign meanings to them. In a metaphorical mode, subjects conveyed a message more consciously, by paying more attention to the messages. In contrast, in the former process, that is, in dynamical mode, the subjects explored the texture of the 3x3 bits until they became so familiar with the game itself that it became consciously transparent

Let’s move to the result of Experiment 3. It shows that when the players are alone, they tend to use either one of the modes. When two players are together, both modes occur in communication. This suggests that coexistence of the two modes is enhanced by communication.

5.2 Proto-linguistic grammar

The outcome of the wall game experiment is two modes and the player’s switching behavior between the two modes. These two modes together form a procedure of taking our inner thoughts and our feelings and then expressing them outside through the media, i.e., in this case, the wall game. What we got is apparently not lexical items but a process: a process that can be seen as a process of producing linguistic expression. It corresponds to grammatical rules, which are used to compose sentences in natural language. The interesting observation here is that the “grammatical process” observed includes the exploration of the media. In dynamical mode, players try to find out the possibility of the pattern, and what kind of patterns can be used to make a distinctive message.

Our hypothesis is that the exploration of the nature of the media is an integral part of the emergence of grammar. Just by looking at natural language, whose media is already transparent to the users, it is difficult to see whether this is true or not. From this perspective, evolutionary linguistic approach seems to be promising. Since the results presented in this paper are still far from proving this hypothesis, currently, as shown in figure 7, we are making wall games with various textures so that how the player explores the media can be observed. This attempt might give us a way to look into all kinds of languages that would be theoretically possible.

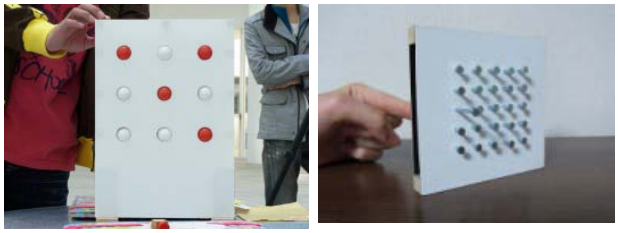

Figure 7: We are now making various types of wall games to analyze the exploratory behavior of players in playing with the wall. (Designed by Seara Ishiyama)

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