

## **DISCOVERING HIERARCHY IN AMBIGUOUS COMMUNICATIONS DURING AN EXPERIMENTAL SEMIOTICS TASK**

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How is it possible to detect the hierarchical communication that occurs in experimental semiotics? To answer this question, we collected data in an online experiment and developed a method of analyzing lexical and syntactic ambiguities. The results of this analysis indicated the syntactic structure in a case that shows a large gap of ambiguity between profiles that feature different chunking methods. From this, we conclude that our analytical method is useful for detecting hierarchical communication.

### **1. Introduction**

Human beings can utilize language to share their intentions, though it is not known how language evolved or how it came to represent the complexity of our thinking. The interdisciplinary field *Evolinguistics: Integrative Studies of Language Evolution for Co-creative Communication* investigates the mechanisms of language evolution using hierarchy and intention sharing as the two main conceptual grounds (Okanoya, 2022). These two concepts capture varying functions of human language. According to Hashimoto (2020), the former concept, which corresponds to linguistic syntax, enables the representation of complex knowledge, whereas the latter indicates an aspect of the semantics and pragmatics of language, leading to knowledge sharing in the language community.

The core question in the field at present regards the integration of the two concepts, in the form of the following question: “How did the hierarchical representation of our thought emerge in relation to the emergence of social collaboration in the history of humanity?” We consider that one possible link can be found in linguistic ambiguity. According to previous studies (Hashimoto, 2020), compound words such as ‘unthinkable’ have led to different interpretations, depending on an applied hierarchical structure such as [[un, think], able] or [un, [think, able]]. Linguistic ambiguity has also been investigated in the semantic and pragmatic domains. Pinker, Nowak, and Lee (2008) find that people may intentionally use ambiguous expressions (e.g., indirect speech) to maintain social relations.

Thus, linguistic ambiguity is involved in two main features of human language. Traditionally, ambiguity that relates to intention sharing and hierarchy has

been understood to be lexical and syntactic ambiguities (MacDonald, Pearlmuter, & Seidenberg, 1994). Lexical ambiguity is a reflection of the fact that a single word may have multiple meanings, and syntactic ambiguity relates to the fact that of the possibility of multiple hierarchy.

In this study, we experimentally examine these ambiguities by means of an approach called experimental semiotics, as proposed by Galantucci (2009). In a typical task relating to experimental semiotics, the participants play a collaborative game by exchanging symbols the meanings of which have not been established in advance. This approach allows us to observe language formation in a laboratory setting where the usual means of communication have been deliberately restricted.

As an initial step in exploring the role of ambiguity in hierarchical intention sharing, this study seeks to address the following research question: “How is it possible to detect the hierarchical communication that occurs in experimental semiotics?” To approach this question, this study has identified a novel method of analysis to quantify lexical and syntactic ambiguities using message logs obtained in an experimental semiotic task.

## 2. Method

### 2.1. Task

We adopt the task developed by Inoue and Morita (2021). It employs a cooperation and defection dilemma, similar to the social relations that Pinker et al. (2008) identify as a factor that induces linguistic ambiguity. Considerations of space limit this paper to only give an overview of the original task with a modification. As shown in Figure 1, the game consists of repetitive rounds including three independent phases: (i) allocation of objects (two players and one reward) in a  $3 \times 3$  grid space, (ii) exchanging messages between two players (only one message for each participant per round), and (iii) the movement of players. Through iterative rounds, players seek to obtain as many rewards as possible. Once a reward is obtained in a monopolized (only one player reaching it) or shared (two players simultaneously reaching it) manner, the next round begins with the objects randomly assigned to new locations. If the both players fail to reach the reward, the next round maintains the location of the objects from the previous one.

As the task belongs to experimental semiotics, the focus of the analysis falls on the second phase. To create a message, the players combine figures whose usage was not shared in advance. Assigning meanings to each combination of figures, players can collaboratively search for the rewards in the grid space. It is efficient for players to share their visibility to reach the reward as they can only make observations of horizontally or vertically adjacent objects (the other player or the reward) from their location.

The above setting, which uses novel communication media, is common in experimental semiotics (Galantucci, 2009). Inoue and Morita (2021) characteris-

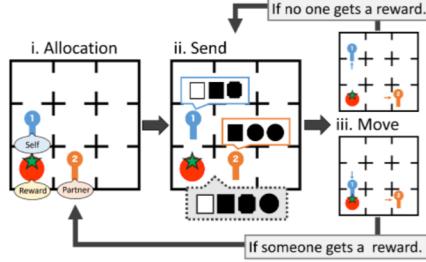


Figure 1. Flow of The Game

tically use discrete figures as message components to allow a simple count-based analysis. In this study, we modified the number of message components, allowing players to horizontally sequence three figures chosen from among four options. In the original task presented by Inoue and Morita (2021), players combine two figures from among ten options. Our modification was made to allow players to use a hierarchical structure when they create messages.

## 2.2. Participants

In all, 76 participants (43 men and 33 women) were recruited through a Japanese crowdsourcing site, lancers.jp. They were paid 800 Japanese yen (JPY) for their participation. They also could obtain extra payment depending on the number of rewards obtained in the task.

## 2.3. Procedure

The experiment was executed in an online environment developed by the authors. Participants who simultaneously accessed the crowd-sourcing site were paired and executed a collaboration and a dilemma game, in succession. Each game lasted for 20 mins. In the collaboration game, the reward was only obtained when both participants simultaneously reached the reward, whereas in the dilemma game, the participant could obtain the reward in a monopolized or a shared manner. The two manners were weighted in differently in the two conditions: 3:2 and 2:3.<sup>1</sup> After finishing the dilemma game, the participants completed a post-questionnaire (free description), including a prompt to “give your assigned meanings to the figures.”

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<sup>1</sup>Each number separated by colon indicates points obtained by the share and monopolize manner. These points were used to calculate extra payment for the participants (obtained points × 3 JPY).

Table 1. Dimensions of connotations.

Viewpoint	Object	Tense	Intention of the message	Label of axis
Absolute	Self	Present	I'm in the middle left now.	AbsSelfPre
		Post	I will go to the lower left next.	AbsSelfPost
	Partner	Present	The partner is in the middle right now.	AbsPartnerPre
		Post	I want my partner to come to the middle.	AbsPartnerPost
	Reward	-	The reward is in the bottom left.	AbsReward
	Relative	Post	I will move down next.	RelSelfPost
		Present	My Partner is not adjacent to me.	RelPartnerPre
		Post	I want my partner to come to my left.	RelPartnerPost
	Reward	-	The reward is below me.	RelReward

### 3. Analysis

This study analyzed messages sent during the dilemma game with no distinction between the two experimental conditions. The analysis was conducted to discover hierarchical structures by quantifying lexical and syntactic ambiguities in messages.

#### 3.1. Lexical Ambiguity

To grasp lexical ambiguity in this task, we made two assumptions. First, we assumed each combination of three figures was a chunk referring to a single location in grid space. Second, we assumed that there were connotations that specified the meanings attached to each denotation (location). Each row of Table 1 indicated an assumed connotation characterized by the three dimensions “viewpoint,” “object,” and “tense.”

The above assumptions indicate that lexical ambiguity can be further classified into two types, corresponding to denotation and connotation. The ambiguity of denotation indicates a weak one-to-one relationship between the locations and combination patterns of the figure. On the other hand, the ambiguity of the connotation represents the degree that one’s message presents multiple connotations.

To represent both types of lexical ambiguity, we created profiles of each participant using message logs. This profile consists of nine axes that corresponds to the rows in Table 1. Figure 2 shows how ambiguity of each axis was calculated. The steps taking in this calculation were as follows.

1. *Chose a connotation:* First, one axis from the nine axes in Table 1 is selected.
2. *Count rounds along with possible denotations:* This step counts the rounds that appear in the log data according to the object locations. If the viewpoint is absolute, nine states are defined [(0,0), (0,1), (0,2),... (1,0),... (2,2), where each represents x-y coordinates]. Otherwise, six states are assumed [upper, lower, left, right, same, invisible].

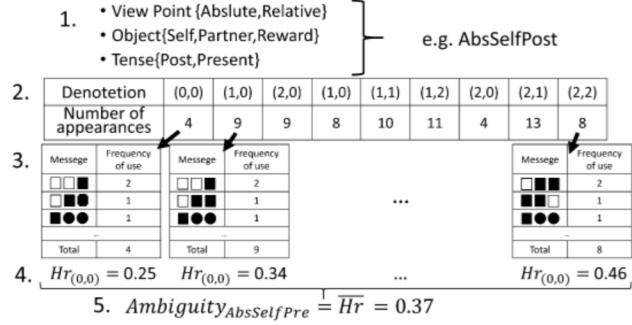


Figure 2. Diagrammatic Illustration of Calculation of Ambiguity

- Count figure chunks for each denotation:* This step counts the number of appearances in the log for each combination of figures.
- Calculate normalized information entropy for each denotation:* For each denotation (location), this step calculates the ambiguity as normalized information entropy  $Hr = \frac{n \log_2 n - \sum_i^k n_i \log_2 n_i}{n} \times \frac{1}{\log_2 k}$ , where  $n$ ,  $n_i$ , and  $k$  represent the number of appearances of each state, the number using the  $chunk_i$ , and the number of chunk patterns ( $4^3 = 64$ ), respectively. This index is also normalized through division by  $\log_2 k$ , which is the maximum value of this index.
- Aggregating the information entropy across denotations:* In the final step, information entropy is averaged by aggregating the denotation in the axis.

The above ambiguity score represents the ways in which the participant inconsistently uses the chunks of figures under an assumed connotation. We computed this score for each connotation and summarized the results in radar charts.

### 3.2. Syntactic Ambiguity

The analysis so far has treated three figures as one chunk. To investigate the structure inside the chunk, we calculated the truncated ambiguity by dividing three figures into two sub-parts: the front two and back two. In the case of there is no difference between the ambiguities calculated from the different sub-parts, we can assume that there is no hierarchical structure. On the contrary, if there is a difference between the two, we consider the possibility of utilizing a hierarchical structure inside the three figures provided by the participant.

## 4. Results and Discussion

To address the research question in the first section, we report representative cases that do not show statistical results.

### 4.1. Lexical Ambiguity

Table 2 presents five cases indicating how the profile of lexical ambiguities (the second column) presents the characteristics of the communication system in the task. These cases are chosen based on two indices, and the size and distortion are shown in the third and the fourth columns (the numbers in the parentheses indicate the rank among 76 participants). The size is the average ambiguity across nine axes ( $Mean = .271$ ,  $SD = .067$ ). The distortion marks the difference between the value of the minimum ambiguity and the average ambiguity ( $Mean = .081$ ,  $SD = .017$ ). These cases in the table are chosen to show high and low values of the indices according to the participants who provided interpretable free descriptions in the post-questionnaire (the fifth column).

As can be seen in the upper two cases (ID 1, 2), a large size profile indicates cases where participants conveyed several connotations. On the other hand, smaller profiles indicate a simple message without much consideration (ID 3) or sending mostly the same combinations of the figures (ID 4). The final case (ID 5) shows a highly distorted profile. In this case, ambiguity in the axis labeled AbsSelfPost indicates low values consistent with the free description that can be interpreted as mentioning moving locations.

### 4.2. Syntactic Ambiguity

Table 3 shows cases obtained by analyzing syntactic ambiguity. The three profiles, distinguished by the chunking method (three figures as a chunk, with the front two and back two figures as chunks) are overlain in the figure. To find representative cases showing syntactic ambiguity, we calculated the root-mean square difference between the front and the back two profiles (RMSDp) ( $Mean = .036$ ,  $SD = .002$ ). ID 6 is a typical case in this index, while ID 7 shows the third largest value in this index. Such differences in RMSDp seem consistent with the free descriptions. The description by ID 7 can be read as distinguishing the composition of the first two figures from the last to convey complex intentions.

## 5. Summary

This study addressed the question: “How is it possible to detect hierarchical communication occurring in experimental semiotics?” To answer this, we developed a method of analyzing lexical and syntactic ambiguities. This analysis successfully identified syntactic structures in cases involving large a gap of ambiguity between profiles adopting different chunking methods. We consider that our anal-

Table 2. Examples of profiles and free descriptions in the questionnaire

ID	Profile	Size	Distort	Free descriptions
1		0.409 (2)	0.064 (47)	A quadrangle is 1, a circle is 2, and an octagon is 3, representing the vertical and horizontal axes. Of the three input boxes of the message, if you enter it in the left two, it will show <i>my</i> coordinates, if <i>I</i> enter it in the center and right, it will show the coordinates of food, and so on.
2		0.379 (4)	0.062 (49)	It showed what was in the room I was in contact with. Each figure <i>means</i> a quadrangle: a blank room, a circle: the opponent's piece, an octagon: a reward, a blank: when I was in the four corners, there were two rooms in contact, so I expressed one place as a blank.
3		0.173 (71)	0.100 (17)	At first, I used it as the north, south, east, and west in the direction I was going (blank is north, square is east, circle is south, octagon is west), but it was agreed from the actions of the two that increasing the number of trials will earn points. From the point on, it didn't make any sense.
4		0.123 (75)	0.123 (9)	There are two types of messages: blank, blank, and blank <i>shows that I can't see tomatoes</i> , and blank, circle, and blank <i>shows that I can see tomatoes</i> .
5		0.329 (14)	0.254 (1)	From the <i>dilemma game</i> , I tried to show where <i>I am</i> . The circle is in the first row, the quadrangle in the second row, and the octagon in the third row, with a blank space. Also, if it is all blank, it means that <i>I am</i> not moving because it is close.

*Note:* The free descriptions were transliterated from Japanese using Google Translate. Before the translation, grammatical errors of the original text were corrected and several terms could not be successfully translated were manually corrected (italicized words).

ysis method is useful for detecting compositional communication, a precondition of hierarchical communication (Saldana, Kirby, Truswell, & Smith, 2019).

We consider that the study forms a contribution to the goal of evolinguistics, although the analytical method chosen is limited to a specific type of experimental semiotic task using discrete components of symbols. Using the method presented in this paper, we observe the process of evolving hierarchical communication. In

Table 3. Examples of profiles showing syntactic ambiguity

ID	Profile	RMSDp	Response to the questionnaire
6		0.028 (39)	The circle is yourself, the octagon is food, the square is nothing, and the blank is <i>meaningless</i> .
7		0.099 (3)	The X-axis 1 2 3 of where you are is circle, octagonal, four strokes, the Y-axis 1 2 3 is square, octagonal, circle, and the <i>case of staying is blank</i> . It was difficult to specify whether to proceed if there were two directions.



future work, we will explore the conditions emerging from hierarchical communications using the methods presented in this paper.

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