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Ambiguity Advantage Under Meaning Activation

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Abstract
Traditional explanations for the presence of ambiguous words in natural language have focused on the cost of added complexity that would accompany unambiguous languages. In these theories, ambiguity arises because it represents the optimal trade-off between the informational benefits from precision and the costs for rich languages. In this paper, we suggest that ambiguity remains an inevitable feature of learning languages even without complexity costs. We show that ambiguous words occur more frequently and will therefore be learned more readily, thus triggering more semantic activations between senses of the ambiguous word. We illustrate this through a game-theoretical example.

Keywords Ambiguity advantage · Meaning activation · Signaling game · Reinforcement learning · Communication context

1 Introduction

Languages regularly feature words that have more than one interpretation, that is, lexical ambiguity. One type of lexical ambiguity called homonymy features words with radically distinctive meanings. For example, the word “mole” in English can be used to refer to “a dark spot on the skin,” to “a burrowing mammal,” or to “a spy.” The meanings are sufficiently distinct that there are rarely ambiguities in usage. Another type of ambiguity, polysemy, involves lexical senses that are more or less related to each other. For example, the word “mouth” can mean “the organ of the body” or “the entrance of a cave”, where these meanings are not contradictory in nature.[1]

Polysemy can be further divided into two types: metaphor and metonymy (see Apresjan 1974). In metaphorical polysemy, a relation of analogy is assumed to hold between senses, with the basic sense being literal and the secondary sense figurative.

[1] See Weinreich (1964), Cruse (1986) for a discussion of the different types of ambiguity.

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In the "mouth" example, the basic sense is "the organ of the body" and the figurative sense is "the entrance of a cave". In metonymic polysemy, both the basic and the secondary senses are literal. For example, the ambiguous word "rabbit" has the literal basic sense referring to "the animal", and the literal secondary sense of "the meat of that animal" (see Apresjan 1974). Therefore, according to Apresjan (1974), Klepousniotou and Baum (2007), Grindrod et al. (2014), there is no clearcut distinction between homonymy and polysemy, rather it seems a matter of continuum from pure homonymy to pure polysemy (metonymic polysemy). In contrast, metaphorical polysemy seems to lie somewhere in the middle of the two. In this paper, we use the concept of ambiguity in a broad way that covers both homonymous and polysemous ambiguity.

While not catastrophic, the presence of polysemy (and perhaps even homonymy) seems, at first glance, suboptimal.[2] Ambiguity of this form runs the risk of miscommunication: one might assume a speaker intends one meaning when they really intend another. We have not run out of possible words, so why not invent a new word for one of the many meanings of "mouth," "rabbit," or even "mole"? New words are invented regularly and meanings change, but why does ambiguity persist?

There are essentially two explanations. One suggests that when we expand our focus to include plausible constraints on language, ambiguity is an optimal solution to a difficult problem. The most common explanation is that the size of the lexicon is costly in some way (Jäger 2007; O'Connor 2014a, b; Santana 2014). Languages with more words entail some cost for the speaker or listener. Language, therefore, optimizes the balance of the benefits of precision with the costs of lexicon size. This argument suggests that, at a very general level, language will have ambiguity.

The second explanatory strategy suggests that ambiguity is not an optimal feature of language but is rather a result of constraints imposed by human psychology. In the domains of psycholinguistics and neurolinguistics, substantial research has been devoted to understanding the cognitive basis for using ambiguous words. The so-called "ambiguity advantage" appears to be a consistent effect, with ambiguous words recognized faster than unambiguous ones in a lexical decision task (see in Rubenstein et al. 1970; Kawamoto et al. 1994; Hino and Lupker 1996; Haro et al. 2017; Klepousniotou and Baum 2007). More specifically, empirical studies show that ambiguous words with more closely-related senses present more advantages because these words create greater semantic-to-orthography feedback (see Balota et al. 1991; McClelland and Rumelhart 1981; Klepousniotou and Baum 2007).

While these two levels of explanation are not directly contradictory, they seem to push in different directions. The general evolutionary explanation points to the importance of lexicon size constraints as making ambiguity optimal, while the more specific psychological explanation tends to point to structural features of human psychology that yield ambiguity even if not optimal. Of course, both may be correct in that the ambiguity in language is over-determined.

In this paper, we offer a constraint-based explanation (akin to the psychological literature) that is nonetheless general (akin to the evolutionary explanations). Our argument stems from a very general fact about learning in communicative contexts. As

[2] Wasow, Perfors, and Beaver provide a number of arguments for why this presents a critical problem for the understanding of language (Wasow et al. 2005).

in the psychological literature, we argue that ambiguous terms have wider applicability and are therefore used more frequently, triggering more semantic activation between multiple senses of ambiguous words. We show, however, that this feature is very general and does not depend on any particular features of human psychology. More importantly, our results show that even in the presence of the precise words, the more ambiguous ones are more likely to be chosen.

We illustrate the problem of ambiguity through a technical example based on a modified form of David Lewis' signaling game. The signaling game has been used to study language communication and features Skyrms (2010), Jäger (2014), Zollman (2005). We include discussion of communication context and learning for ambiguity. Through this model, we demonstrate that the senses-related nature of ambiguity leads ambiguous words to have advantages even in the presence of more precise words.

The rest of the paper is organized in the following way. Section 2 reviews the basic notions of Lewis's signaling game, including an introduction to reinforcement learning in signaling games. In Section 3, we modify the signaling game for discussion of communication context and meaning activation learning. Section 4 presents the simulation results. The paper ends with comparisons with other studies on this topic.

2 Lewis's Signaling and Learning

2.1 Lewis's Signaling Game

The traditional Lewis 's signaling game provides a baseline model to capture a rather simple communication scenario (Lewis 1969). In this model, there is a finite set of states. For each state, there is an action that matches with the state. There is a sender who observes the state information and sends a signal to the receiver. Because the receiver does not know the state information directly, they can only get information from the sender's signal. After receiving the signal, the receiver will take action. The payoff of the game is decided by the matching of the state and the action. Formally, the signaling game is defined as follows.

Definition 1 (Lewis's signaling game)
A Lewis's signaling game G consists of the following:

- two players: a sender S and a receiver R;
- a finite set of states indicated as $T = \{1, 2, \ldots, n\}$; Nature picks a state by a prior uniform distribution σ on T, σ is common knowledge;
- a set of signals $Sig = \{s_1, s_2, \ldots, s_m\}$;
- a set of acts $A = \{a_1, a_2, \ldots, a_n\}$;
- the sender's action is $s_i \in Sig$; the receiver's action is $a_i \in A$;
- the payoff is $U_S(i, a_j) = U_R(i, a_j) = \sum_{i \in T} \sigma_R(i \mid s_u)u(i, a_j), i \in T, a_j \in A, s_u \in Sig$, in which

$$u(i, a_j) = \begin{cases} 1, & \text{if } i = j; \\ 0, & \text{otherwise.} \end{cases}$$

We use $\sigma_R(i \mid s_u)$ to represent the receiver's conditional belief about the state after receiving the signal. Players share the same payoff. Thus, throughout the paper, we omit the subscript for utility.

In Game Theory (Osborne and Rubinstein 1994), Nash equilibrium is a profile of players' strategies such that no player can gain more benefits by only changing their own strategy. There are three types of equilibria in the signaling game: separating equilibrium, pooling equilibrium and partial pooling equilibrium. The following examples illustrate these concepts.

Example 1 The simplest Lewis's signaling game consists of two states: $\{1, 2\}$, two signals $\{s_1, s_2\}$ and two acts $\{a_1, a_2\}$.

An instance of "separating equilibrium" in this game has the following pattern

$$\begin{tikzcd} 1 \arrow[r] & s_1 \arrow[r] & a_1 \\ 2 \arrow[r] & s_2 \arrow[r] & a_2 \end{tikzcd}$$

When state 1 occurs, the sender sends s_1. By receiving s_1, the receiver takes a_1. Similarly, when state 2 occurs, the sender sends s_2. Under this equilibrium, all the information about the states is communicated successfully between sender and receiver and the players receive the highest payoff.

The signaling system here allows the sender to partition the state space into one of two singleton partition sets $\{1 \| 2\}$. Elements in this partition can be read as the possible meanings of signals. In this example, the descriptive meaning of s_1 is state 1 and the meaning of s_2 is state 2.

Meanwhile, the game has a "pooling equilibrium". The following is the pooling equilibrium of this example.

$$\begin{tikzcd} 1 \arrow[r] & s_1 \arrow[r] & a_1 \\ 2 \arrow[ur] & s_2 \arrow[ur] & a_2 \end{tikzcd}$$

In this equilibrium, the sender always sends the same signal and the receiver takes the same action by ignoring the signal. As a result, the information is not fully communicated. Pooling equilibria of this kind feature ambiguity because s_1 means both state 1 and state 2. Furthermore, these equilibria are Nash equilibria and are therefore stable in a certain sense. Neither the sender nor the receiver can unilaterally improve their situation by switching their strategies. Some variations on pooling equilibria are also the result of individual learning or cultural evolution (Huttegger and Zollman

2011; Huttegger et al. 2010). Seen as a partition on the state space, this equilibrium only allows the sender to say that one of the states is obtained and the state is in the set: $\{1, 2\}$.

Example 2 shows an instance of partial pooling equilibrium when there are more than two states and two acts.

Example 2 Consider a signaling game with three states: $\{1, 2, 3\}$, three signals $\{s_1, s_2, s_3\}$ and three acts $\{a_1, a_2, a_3\}$.

The following partial pooling equilibrium is possible for this example.

$$\begin{tikzcd}
1 \arrow[r] & s_1 \arrow[r] \arrow[dr] & a_1 \\
2 \arrow[ur] & s_2 \arrow[dr] & a_2 \\
3 \arrow[r] \arrow[ur] & s_3 \arrow[r] & a_3
\end{tikzcd}$$

In this equilibrium, signal s_1 is ambiguous between states 1 and 2. s_2 and s_3 are synonymous for state 3. The partition for this signaling pattern is $\{1, 2\|3\}$ representing that s_1 means either state 1 or state 2 while s_2 or s_3 carries the meaning of state 3.

Finally, when there are fewer signals than states, ambiguity is unavoidable. For example, if there are three states but only two signals $\{s_1, s_2\}$ in Example 2, then one possible equilibrium could be the following.

$$\begin{tikzcd}
1 \arrow[r] & s_1 \arrow[r] \arrow[dr] & a_1 \\
2 \arrow[ur] & & a_2 \\
 & & \\
3 \arrow[r] & s_2 \arrow[r] & a_2
\end{tikzcd}$$

In this equilibrium the states are partitioned in the same way as in the previous example: $\{1, 2\|3\}$. However, the cause of this outcome differs. In this case it is because the structure of the game prevents any further precision.

2.2 Learning in Signaling Game

Reinforcement learning in the signaling game has been used to study linguistic features including ambiguity (Skyrms 2010; Franke 2015; Santana 2014). The basic idea is the following: if the language feature in question gains more fitness (formally represented by payoff in the game) than the average of all the alternative features through the learning process, then this feature has the evolutionary advantage over the others.

Reinforcement learning can be described by a simple urn model with two colored balls. In each round, a ball is drawn from the urn randomly. Then, that ball and another same-colored ball are returned to the urn. As a result, the probability of the ball with that same color being drawn on the next occasion increases. When reinforcement learning is applied in the signaling game, players' strategies can be imagined as drawing colored balls from urns of signals and acts.

Reinforcement learning is a repeated play of the signaling game. The learning process can be defined by an updating rule and a response rule. For each signal s_i, we assign a number w_i to represent its fitness and this number updates recursively depending on how s_i worked in the previous round of play. Given any signaling game defined as in Definition 1, the updating rule for the fitness of a particular signal s_i is defined as follows.

Definition 2 Given a Lewis's signaling game G, and any signal s_j, the fitness w_j of s_j in the reinforcement learning follows this updating rule.

$$w_j(0) = 1;$$
$$w_j(t+1) = \begin{cases} w_j(t) + U & \text{if } U = \sum_{i \in T} \sigma_R(i \mid s_j) u(i, a_j) > 0 \\ w_j(t), & \text{otherwise.} \end{cases}$$

The response rule $q_j(t)$ for any signal s_j is defined as:

$$q_j(t) = \frac{w_j(t)}{\sum_{s_v \in Sig} w_v(t)}$$

The reinforcement learning rules for the receiver's actions can be defined in a similar way as in Definition 2.

The intuition behind these rules is that the signal that has more successful communication obtains more fitness. Then this signal is more likely to be used in the next round of the game.

For the purpose of this paper, we focus on the feature of ambiguity under meaning activation with communication context. Therefore, we need to modify both the basic signaling game model and the learning rules.

3 Signaling Game with Context and Meaning Activation

3.1 Signaling Game with Context

Communication context plays a critical role in language communication. At the same time, communication context shapes the features of language. Therefore, a signaling game with context is an important application of Lewis's signaling game. Signaling games with context have been well described in the literature (Santana 2014; Brochhagen 2020; Tang 2020).

To simplify the discussion, we fix the meaning of the signals in the form of a partition on the set of the states. Then we compare the partitions with respect to their ambiguity.

Considering these two factors, we redefine Lewis's signaling game as follows.

Definition 3 A Lewis's signaling game with context G^C consists of the following:

- two players: a sender S and a receiver R;
- a finite set of states indicated as $T = \{1, 2, \ldots, n\}$; Nature picks a state by a prior uniform distribution σ on T, σ is common knowledge;
- C is a partition on T representing the communication context. It is commonly known;
- a given set of partitions $\mathcal{P} = \{P_1, P_2, \ldots, P_v\}$ on the state T representing meaning partitions. For each $P_i \in \mathcal{P}$ and any element of the partition, there is a corresponding signal s^i_j carrying the meaning of the states within that element. We use $s^i_j \in P_i$ to indicate the signals defined for this partition;
- a set of acts $A = \{a_1, a_2, \ldots, a_n\}$;
- the sender's action is $s^v_u \in P_v$, $P_v \in \mathcal{P}$; the receiver's action is $a_i \in A$;
- the payoff is $U_S(i, a_j) = U_R(i, a_j) = \sum\limits_{i \in T} \sigma_R(i \mid s^v_u, C) u(i, a_j), i \in T, a_j \in A, s^v_u \in P_v$ and $P_v \in \mathcal{P}$, in which

$$u(i, a_j) = \begin{cases} 1, & \text{if } i = j; \\ 0, & \text{otherwise.} \end{cases}$$

$\sigma_R(i \mid s^v_u, C)$ represents the receiver's conditional belief of the state based on both the signal and the context C. The game is played in the following way. The sender observes the state and sends a message to the receiver. After receiving the message, the receiver combines the information from both the signal and the context, then takes an action. We use the following example to illustrate this.

Example 3 Consider a signaling game with the set of states $\{1, 2, 3, 4\}$, and the set of the signals $\{s_1, s_2\}$ with the meaning given by $P : \{1\|234\}$. The context is $C : \{12\|34\}$. The action set is $\{a_1, a_2, a_3, a_4\}$.

Supposing state 2 is the true state, and the sender sends the signal s_2. After receiving s_2 with the meaning $\{2, 3, 4\}$ and the contextual information $\{1, 2\}$, the receiver knows that state 2 is the true state and a_2 is the right action.

We use multiple meaning partitions P_i with different degrees of ambiguity to study the ambiguity advantage. For example, given the set of states $\{1, 2, 3, 4\}$, the meaning partition $P_1 : \{1\|2\|3\|4\}$ is the least ambiguous and $P_2 : \{1234\}$ is the most ambiguous. The ambiguity of $P_3 : \{1\|234\}$ lies midway between the other two. The learning process we consider is to select the meaning partitions instead of single signals.

3.2 Learning with Meaning Activation

Following discussions in psycholinguistics and linguistics (Cruse 1986; Klepousniotou et al. 2012; Apresjan 1974), lexical ambiguity can be divided into homonymy and polysemy. Polysemy can be further categorized into metaphor and metonymy. Homonymy means that the ambiguous word has radically distinctive meanings, as for the word "bank". In contrast, polysemy involves lexical senses that are more or less related to each other.

Moreover, in metaphorical polysemy, a relation of analogy is assumed to hold between senses, of which the basic sense is literal "mouth" and the figurative sense "the entrance of a cave". In metonymic polysemy, both the basic and the secondary senses are literal. For example, "rabbit" has the literal basic sense referring to "the animal", and the literal secondary sense of "the meat of that animal"(see in Apresjan 1974).

Hence, by considering the relations between different senses of the ambiguous words, the types of ambiguity can be defined. Psycholinguistic literature (Klepousniotou et al. 2012; Haro et al. 2017; Klepousniotou and Baum 2007; Klepousniotou 2002), suggests that an ambiguity advantage is observed in lexical decision tasks. The sense-relatedness and meaning activation trigger the ambiguity advantage, which results in shorter processing time in lexical decision experiments. Thus, the more the senses are related, the greater the ambiguity advantage is observed. Therefore, polysemy is shown to have a greater ambiguity advantage than homonymy, and metonymically polysemous words show a greater ambiguity advantage than metaphorically polysemous words.

Following the sense-relatedness and meaning activation in ambiguous words, we modify the current learning rule in the signaling game to the one accommodating the sense-relatedness and meaning activation for ambiguous words.

First, for an ambiguous signal s_u, we specify the senses of the signal and the relatedness between them. For instance, suppose s_u represents the state meaning $\{1, 2, 3\}$. Hence s_u has three senses indicated as s_{u1}, s_{u2}, s_{u3} for state 1,2 and 3 respectively. At the same time, the relatedness between s_{u1}, s_{u2}, s_{u3} depends on the distance between the senses. It is natural to define the distance for the senses from the distance of the state space and the similarity between the states.[3]

Definition 4 (Distance) Given a set of states $T = \{1, 2, \ldots, n\}$, the distance of states i and j indicated as D_{ij} is defined as $D_{ij} =\mid i - j \mid$. For any ambiguous signal s_u with the senses $s_{u1}, \ldots, s_{uv}$ carries the state meaning $\|s_{uj}\| \in T$,[4] the distance $D_{ij}^{s_u}$ between any two senses s_{ui} and s_{uj} is defined as $D_{ij}^{s_u} =\mid \|s_{ui}\| - \|s_{uj}\| \mid$.

In Example 3, the ambigious signal s_2 has three meanings $\{2, 3, 4\}$ indicated as s_{21}, s_{22}, s_{23}. Namely, $\|s_{21}\| = 2$,$\|s_{22}\| = 3$ and $\|s_{23}\| = 4$. Thus $D_{12}^{s_2} = 1$. $D_{13}^{s_2} = 2$.

Following the assumption in O'Connor (2014b), we assume that the meaning activation decreases as the distance between the senses increases. Applying the distance between senses, we can define the new reinforcement learning rules.

Definition 5 (Reinforcement learning under meaning activation) Given a Lewis's signaling game with context G^C, any meaning partition $P_i \in \mathcal{P}$, any signal $s_j \in P_i$ with senses $\{s_{j1}, \ldots, s_{ji}, \ldots, s_{jv}\}$, the fitness w_{ji} of s_{ji} in the reinforcement learning under meaning activation follows the following updating rule.

- $w_{ji}(0) = 1$;

[3] A similar idea appeared in Jäger (2007).

[4] We use $\|s_{ij}\|$ to indicate the corresponding state in T represented by one sense of ambiguous signal s_i.

- $$w_{ji}(t+1) = \begin{cases} w_{ji}(t) + U & \text{if } U = \sum_{\|s_{ji}\| \in T} \sigma_R(\|s_{ji}\| \mid s_j) u(\|s_{ji}\|, a_j) > 0; \\ w_{ji}(t) + U * \gamma * \frac{1}{D_{ik}^{s_j}} & \text{if } U = \sum_{\|s_{jk}\| \in T} \sigma_R(\|s_{jk}\| \mid s_j) u(\|s_{jk}\|, a_j) > 0, \\ & \text{in which } D_{ik}^{s_j} \leq d. \\ w_{ji}(t), & \text{otherwise.} \end{cases}$$
- $w_j(t+1) = \sum w_{ji}(t+1)$, w_j is the fitness of s_j;
- $w_{P_i}(t+1) = \sum_{s_j \in P_i} w_j(t+1)$.

The response rule $p(t)$ for any meaning partition P_i is defined as:

$$p_{P_i}(t) = \frac{w_{P_i}(t)}{\sum_{P_i \in \mathcal{P}} w_{P_j}(t)}$$

According to the updating rule, the fitness of a sense s_{ji} of an ambiguous signal s_j comes from two sources. One is from when the actual state is the meaning state of s_{ji}, namely, $\|s_{ji}\|$ and the communication is successful. The other is from the successful communication of its neighboring sense s_{jk} within a certain distance given by d. γ indicates the weight ratio between the neighboring sense and the actual sense. If the actual sense gets the weight U, then the neighboring sense gets the weight $U * \gamma$. We assume $\gamma \in [0, 1]$ in this paper. When $\gamma = 1$, then the neighboring sense gets the same weight as the actual state. Moreover, we assume that the further the distance between the senses, the less meaning activation is triggered. Therefore, the fitness for neighboring sense is multiplied by $\frac{1}{D_{ik}}$.

The response rule is defined on partitions instead of signals. As previously discussed, we compare partitions with different ambiguities rather than between signals. The signal containing more senses is considered more ambiguous. Among the partitions defined on the same set of states, the one that includes fewer signals is considered more ambiguous. For example, the meaning partition $P_1 : \{1\|2\|3\|4\}$ is the least ambiguous one and $P_2 : \{1234\}$ is the most ambiguous. The ambiguity of $P_3 : \{12\|34\}$ lies somewhere in the middle.

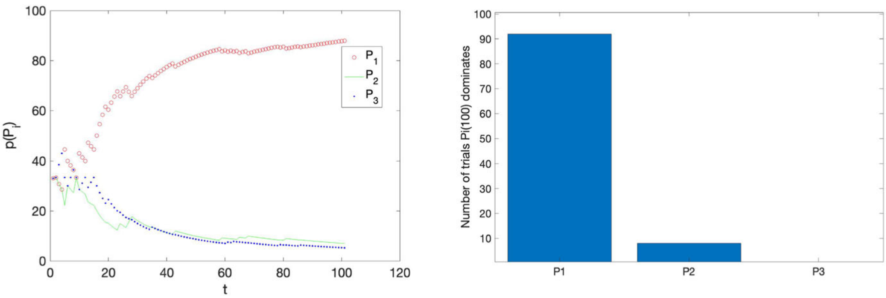
4 Simulation Results

In this section, we show the simulation results for ambiguity advantages using the following example with various parameter values.

Example 4 Given a signaling game with four states $\{1, 2, 3, 4\}$ occurring with the same probability, we considered three meaning partitions P_1, P_2, P_3 with different degrees of ambiguous signals as follows.

$$\begin{array}{ccc} P_1 : 1\|2\|3\|4 & P_2 : 12\|34 & P_3 : 1234 \\ s_1^1\|s_2^1\|s_3^1\|s_4^1 & s_{11}^2 s_{12}^2\|s_{21}^2 s_{22}^2 & s_{11}^3 s_{12}^3 s_{13}^3 s_{14}^3 \end{array}$$

Thus, P_1 is most precise, P_3 is most ambiguous and P_2 sits in the middle.



(a) One trial **(b)** 100 trials

Fig. 1 $(\gamma = 0)$

4.1 Reinforcement Learning Without Meaning Activation

First, for comparison, we considered the situation when the meaning activation is not included in the reinforcement learning, namely, $\gamma = 0$.

A simulation was conducted for 100 trials and in each trial the learning repeated for 100 iterations. The result is shown in Fig 1.

The left graph in Fig 1 shows the typical trajectory of evolution in one trial, where P_1 quickly dominates P_2 and P_3. In the right graph in Fig 1, we list the number of trials from 100 trials when each P_i is optimal at the end of 100 iterations. It shows that $P_1(100)$ is almost 100% optimal.

When the meaning activation between the senses of an ambiguous signal was not considered, ambiguous signals were inferior to the precise signals. Therefore, ambiguous advantage was not observed.

4.2 Reinforcement Learning with Meaning Activation

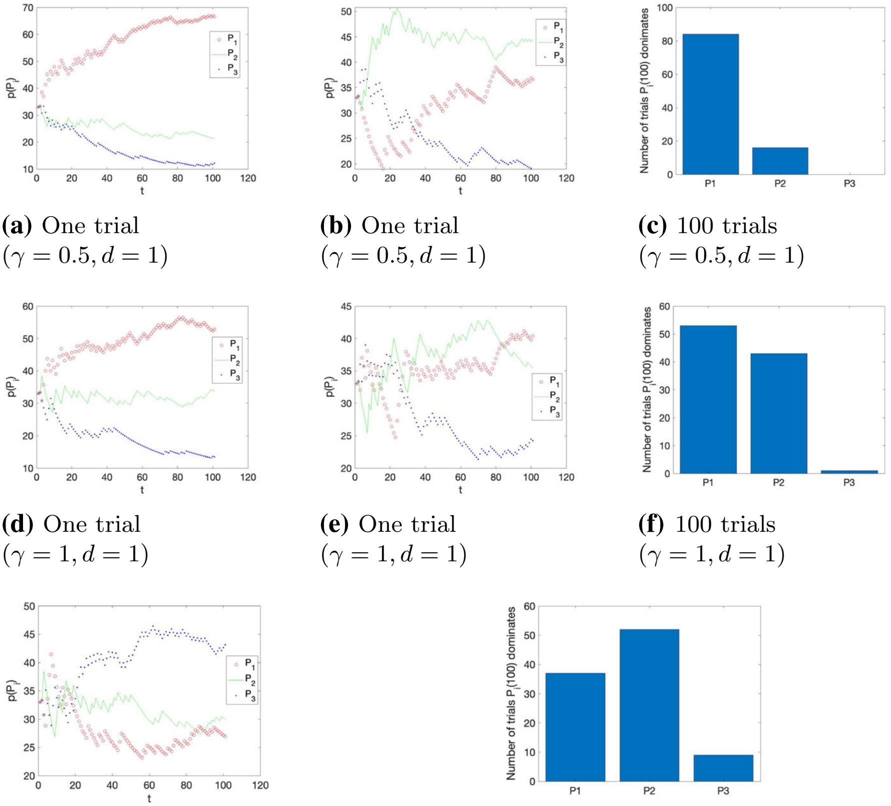
We considered three situations of reinforcement learning with meaning activation in Example 4:

(1) : $\gamma = 0.5$ and $d = 1$; (2) : $\gamma = 1$ and $d = 1$;(3) : $\gamma = 1$ and $d = 2$.

The same simulation (100 iterations in each trial with 100 trials) was performed under the learning rules with meaning activation. The result is the following.

As in Fig. 2, with meaning activation, the more ambiguous partitions (P_2 and P_3) started to dominate P_1 compared with the learning without meaning activation. The higher the activation ratio between the senses, the more ambiguous advantages were observed. For instance, when $\gamma = 0.5$, P_3 (most ambiguous) hardly dominated. When γ increased to 1, P_3 happened to dominate and P_2 has more chances to dominate within the 100 trials.

We also tested the effects of distance range d on the simulation results. When d increases, there was a wider meaning activation between the senses of ambiguous signals. Comparing (f) and (h) in Fig. 2, it shows that ambiguous advantage becomes more obvious when the range under consideration is increased.



(a) One trial ($\gamma = 0.5, d = 1$)

(b) One trial ($\gamma = 0.5, d = 1$)

(c) 100 trials ($\gamma = 0.5, d = 1$)

(d) One trial ($\gamma = 1, d = 1$)

(e) One trial ($\gamma = 1, d = 1$)

(f) 100 trials ($\gamma = 1, d = 1$)

(g) One trial ($\gamma = 1, d = 2$)

(h) 100 trials ($\gamma = 1,\ d = 2$)

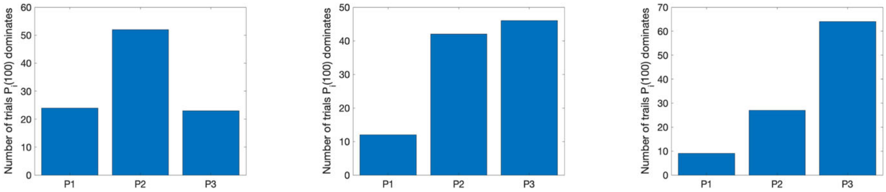
Fig. 2 Learning with meaning activation

4.3 Reinforcement Learning with Meaning Activation in Context

The last simulation considered the effect of communication context. As in the literature (Santana 2014; Brochhagen 2020; Tang 2020), context was expected to enhance the ambiguity advantage. Intuitively, the receiver in our signaling game combined the information from both the signals and the communication context (as defined in Definition 3). As a result, the ambiguous signals can express the same information as the precise signals under some communication contexts. Meanwhile, the ambiguity advantage is enhanced under learning with meaning activation. We show this result through the following simulation.

Consider a signaling game in Example 4 with the context C as follows:

$$C : 1\|234$$



(a) 100 trials ($\gamma = 0.5, d = 1$) **(b)** 100 trials ($\gamma = 1, d = 1$) **(c)** 100 trials ($\gamma = 1, d = 2$)

Fig. 3 *Example* 4 with Context

Applying the signaling game with context under learning with meaning activation, we undertook similar simulation for 100 trials, each trial with 100 iterations. We observed that the most ambiguous partition P_3 dominated the others more frequently as γ increased (as in Fig. 3), which means that in the communication context, the ambiguity advantage is enhanced because the imprecise signal can express precise information with the help of the context. At the same time, the meaning activation between senses of an ambiguous signal and the wider distance under consideration boost this advantage.

5 Comparison and Conclusion

Many studies have discussed ambiguity advantages using the signaling game. Here, we emphasize the similarity and differences between the current study and existing work.

Santana (2014) considers that communication is often ambiguous because signals take advantage of context sensitivity. Incorporating context and a signal cost into the Lewis-style signaling game leads to the predicted outcome of evolution favoring ambiguous signaling. In our model we accept the assumption of context but not the signal cost. Instead, we use the meaning activation for the ambiguous signals in the learning mechanism. Compared with precise signals, the disadvantage of ambiguity being imprecise can be compensated for by the context. Meanwhile, the meaning activation leads the ambiguous signals to gain more advantage.

Brochhagen (2020) and Tang (2020) focus on changes in communication context and ambiguity under context. The interlocutors are assumed to have different contextual beliefs at the beginning of communication and to update their beliefs through the process of communication. At the same time, the advantage of ambiguity is explored through consideration of context. Within Lewis's signaling game with context, the highest payoff the ambiguous signal can achieve is the same as the precise signals. Hence, ambiguity is favored only when complexity costs of precise signals are assumed. The main difference between the work described in this paper and previous models is that without assuming signal costs, we argue that the ambiguous advantage comes from the very nature of ambiguity. Ambiguous signals have multiple senses and there are meaning activations between senses during learning and when using ambiguous signals. As a result, evolution favors ambiguity.

We applied modified reinforcement learning in our model. We assumed that when one sense of the ambiguous signal gets reinforced, its neighboring senses within the same ambiguous signal can also be reinforced to some extent. A similar idea appears in O'Connor's discussion on vagueness O'Connor (2014b). However, O'Connor's work focuses on the boundary uncertainty between different signals rather than ambiguity, and there is no discussion about context in that work.

In conclusion, we offer a constraint-based explanation (akin to the psychological literature) that is nonetheless general (akin to the evolutionary explanations). We argue that ambiguity is not an optimal feature of language but is rather a result of constraints imposed by human psychology. Through a signaling game with context and modified reinforcement learning, we showed that the ambiguous signals gain more advantage even in the presence of precise signals.

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