Ambiguity and Vagueness in Strategic Communication: An Evolutionary Approach

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Abstract: In this paper, the authors examine strategic communication including ambiguous utterances. Recently, game theoretical approaches are introduced in the study of pragmatics. Parikh’s paper is considered as one of the representative studies. He shows that there exist equilibria including an ambiguous utterance as a part of the equilibrium strategy in his model. However, his model has some limitations. First of all, in his model, interests between the sender and the receiver perfectly coincide, and secondly he analyzes with a static solution concept. In this paper, Parikh’s model of ambiguous utterances is extended by changing the degree of coincidence of interest between the sender and the receiver, and is analyzed by evolutionary dynamics. The authors found that ambiguous utterances can be a stable outcome with certain conditions. Agent-based simulation also confirmed this finding.

Key Words: pragmatics, ambiguity, vagueness, game theory, evolution, agent-based simulation.

1. Introduction

In this paper, the authors examine why people use an ambiguous utterance in their conversation by utilizing game theory.

In our communication, one frequently use an ambiguous utterance. For example, on an online auction, expressions “Good” and “Bad” are used to express the condition of an item for sale. One person’s judgment “Good” may be different from another person’s one (Hence, such expression has some vague or ambiguous meanings). Using such ambiguous utterances causes higher risks to make successful communication, hence it seems to be a lesser strategy from an evolutionary viewpoint. However, one still use ambiguous utterances in our conversation. This is a puzzle to be solved.

In the game theory, communication has been studied from a strategic viewpoint. A famous, earlier model is the signaling game that is a dynamic, Bayesian game with two players, the sender and the receiver. This model is firstly developed by Spence [1] that models job market signaling. Another important model is cheap talk game invented by Crawford and Sobel [2]. In this model, the sender’s message is payoff-irrelevant, that is, it does not affect both players’ payoff while sending a message is costly for the sender in signaling game mentioned above. As most of our daily conversation is costlessly made, cheap talk games are more appropriate to study the nature of communication.

Research in cheap talk games with incomplete information has been concerned with identifying conditions under which the sender’s private information can be conveyed to the receiver correctly. Crawford and Sobel [2] found that when interests between the sender and the receiver coincide, meaningful communication can be an equilibrium in cheap talk games with incomplete information. However, cheap talk games always have babbling equilibria where communication is totally uninformative. In babbling equilibria, the sender always sends the same message, hence the receiver cannot guess information that the sender really has. This seems to represent a kind of ambiguity in communication.

Farrell [3], Matthews et al. [4], and Rabin and Sobel [5] and others extended Crawford and Sobel [2]’s research by refining equilibrium concept. They focus on how to exclude unjustifiable belief off the equilibrium path and to justify informative, separating equilibria. In separating equilibria, the sender sends a message depending on the sender’s type, hence the receiver can get information about the sender’s true type. Their studies are called equilibrium refinement theories.

On the other hand, in pragmatics, a research field of linguistics, that was initiated by analytical philosopher Austin in 1960, intentional meanings of utterances are studied.

Among the researchers in pragmatics, Grice [6] regards his cooperative principle as the foundation of the pragmatic understandings of utterances. That principle states that the receiver interprets a utterance as if the sender truthfully made that utterance in order to convey her intention. Moreover, he goes on to say:

On the assumption that some such general principle as this is acceptable, one may perhaps distinguish four categories under one or another of which will fall certain more specific maxims and submaxims, the following of which will, in general, yield results in accordance with the Cooperative Principle. Echoing Kant, I call these categories Quantity, Quality, Relation, and Manner. The category of Quantity relates to the quantity of information to be provided, and under it fall the following maxims:

1 Make your contribution as informative as is required (for the current purposes of the exchange).
2. Do not make your contribution more informative than is required.

Under the category of Quality falls a supermaxim — “Try to make your contribution one that is true” — and two more specific maxims:

1. Do not say what you believe to be false.
2. Do not say that for which you lack adequate evidence.

Under the category of Relation I place a single maxim, namely, “Be relevant”. Finally, under the category of Manner, which I understand as relating not (like the previous categories) to what is said but, rather, to how what is said is to be said, I include the supermaxim — “Be perspicuous” — and various maxims such as:

1. Avoid obscurity of expression.
2. Avoid ambiguity.
3. Be brief (avoid unnecessary prolixity).
4. Be orderly.

Among several axioms consisting Grice’s cooperative principle, Sperber and Wilson [7] regards the axiom of relevance, defined as the best reference to get the maximum information with less effort, as most important in their relevance theory.

Anyway Grice assumes that interest between the sender and the receiver perfectly coincide. Later, Kawagoe and Takizawa [8] study cheap talk games in the laboratory experiment, especially the case where interests between the sender and the receiver does not necessarily coincide. They found that even though there is conflict between the sender and the receiver, the receiver tends to believe that the sender is willing to tell the truth in such cases. This is called “truth bias.” This way they show that Grice’s cooperative principle can be extended in the case where interests between the sender and the receiver does not necessarily coincide.

Recently, these game theoretical approaches have been introduced in the study of pragmatics. Parikh [9]–[12] addresses this subject. In his paper, he employed a type of signaling game involving ambiguous utterances, and showed that there exists an equilibrium involving an ambiguous utterance as a part of equilibrium strategy. Van Rooy [13] applies game theory to communication in a different way from Parikh to give an account for Horn’s division of pragmatic labor.

For modeling of ambiguity in game theoretic context, there are at least two possible ways. One is the way Parikh takes. While Parikh addresses qualitative ambiguity, Lipman [14] addresses a vagueness that can be regarded as quantitative ambiguity in language. An example of vagueness is the notion of “red” (imagine a sequence of colors of objects continuously from red to orange to yellow). This difference about notions of ambiguity is reflected in the sender’s type space of their model. That is, Lipman assumes that the sender’s type space is continuous, while Parikh assumes that it is discrete.

Now, Parikh’s model is considered as one of the representative studies in the field of game theoretic analysis of pragmatics. However, there are questions in Parikh’s model. Hence, in this paper the authors deal with two of them to modify his model. One of the problems is that he considered only the situation in which interests between the sender and the receiver perfectly coincides. Another is that he employed static solution concept for analyzing the game. Hence, for the former, the authors extend his model in the way Kawagoe and Takizawa’s paper [8] did, that is, the cases in which interests between the sender and the receiver does not necessarily coincide are considered. For the latter, the authors employ evolutionary dynamics, as van Rooy [13] did, to extend his model into a dynamic one, which enables us to see whether the equilibria including ambiguous utterances are evolutionary stable in the long run.

The organization of the paper is as follows. In the next section, Parikh’s model and its extension, its equilibria, and evolutionary dynamic model are presented. In section 3, agent-based simulation and its results are shown. The final section concludes.

2. Model

2.1 Parikh’s Model

Let’s consider a situation where the sender makes an utterance and the receiver tries to interpret it. Parikh [9] starts by examining a case where the sentence uttered has two possible meanings. This could be due to lexical or structural ambiguity to the need to assign reference or to a purely pragmatic availability of two readings for the sentence. Our definition of “ambiguity” is the same as Parikh used. That is, the authors use the term “ambiguous utterance” as an utterance has two possible qualitatively different meanings. Parikh gives an example in which the sender utters (ϕ):

ϕ : I’m going to the bank.

According to Parikh, this has the two possible meanings (p and p’):

p : I’m going to the financial bank.

p’ : I’m going to the river bank.

According to Parikh, successful communication depends on consideration of alternative utterances (μ and μ’). μ unambiguously means p, it could be, for example, “I’m going to the financial bank.” Similarly, μ’ unambiguously means p’, for example “I’m going to the river bank.” Extensive-form of the game is depicted in Fig. 1.

Nature chooses one of the two initial situations, s and s’, where s is the situation in which the information the sender in-
tends to convey is \( p; s' \) is the situation in which the information she intends to convey is \( p' \). The receiver does not know which is real situation, \( p \) and \( 1 - p \) are the probabilities for being situations \( s \) and \( s' \) respectively. \( t, t', e \) and \( e' \) are situations the receiver faces, which are induced by the respective utterances of the sender. \( t \) and \( t' \) are involved in the same information set because there is no way for the receiver to distinguish between them.

According to Parikh [9], the authors assign 20 units of payoff to the receiver getting the correct information. It may matter less to the sender, hence she may derive a smaller 15 units of conveying the correct information. Similarly, the respective cost to the sender and the receiver of uttering and interpreting \( \phi \) may be 5 units and 8 units respectively. And the costs of uttering and interpreting \( \mu \) and \( \mu' \) may be 8 units for each for the sender and 10 units for each for the receiver. Finally, the benefit of incorrect information is \(-5\) units and \(-7\) units for the sender and the receiver respectively.

For example, nature chooses the initial situation \( s \). Then, the sender knows that information set is \( s \) and chooses a message \( \mu \) or \( \phi \). If the sender sends a message \( \mu \), then the receiver's turn to move; the receiver is informed that the sender chose \( \mu \) and the sender's type is \( s \), and chooses \( p \). the sender and the receiver obtain 7 units and 10 units respectively. On the other hand, if the sender chooses a message \( \phi \), then the receiver is not informed whether the sender's type is \( s \) or \( s' \). Then, the receiver chooses \( p \) or \( p' \). If the receiver chooses \( p \), then the sender and the receiver obtain 10 units and 12 units respectively, otherwise \(-10\) units and \(-15\) units.

Parikh shows that pure strategy Bayesian Nash equilibria are \((\mu\phi, p') \) and \((\phi\mu', p) \) irrespective of the value of \( p \). Here, for example, \( \mu\phi \) means that the sender chooses \( \mu \) if her type is \( s \) and \( \phi \) otherwise. Moreover, these equilibria \((\mu\phi, p') \) and \((\phi\mu', p) \) are perfect Bayesian Nash equilibrium under \( 0 \leq p < 1/2 \), \( 1/2 < p \leq 1 \) respectively. Perfect Bayesian Nash equilibrium is a standard solution concept in game theory. The definition of perfect Bayesian Nash equilibrium is as follows [15].

**Definition 2.1.1 (Perfect Bayesian Nash equilibrium)**

Let \( T = \{s, s'\} \) be the sender's type set, \( M = \{\mu, \phi, \mu'\} \) be the sender’s message set, and \( A = \{p, p'\} \) be the receiver’s action set. For \( m^* \in M, t \in T \) and \( a^* \in A \), a pure-strategy perfect Bayesian equilibrium is a pair of strategies \( m^*(t) \) and \( a^*(m) \) and a belief \( \pi(t|m) \) satisfying four conditions.

1. After observing any message \( m \) from \( M \), the receiver must have a belief about which type of the sender could have sent \( m \). Denote this belief by the probability distribution \( \pi(t|m) \), where \( \pi(t|m) \geq 0 \) for each \( t \) in \( T \), and

\[
\sum_{t \in T} \pi(t|m) = 1.
\]

2. For each \( m \) in \( M \), the receiver’s action \( a^*(m) \) must maximize the receiver’s expected utility, given the belief \( \pi(t|m) \) about which type of the sender could have sent \( m \). That is, \( a^*(m) \) solves

\[
\max_{a \in A} \sum_{t \in T} \mu(t|m)U(t, m, a).
\]

3. For each \( t \) in \( T \), the sender’s message \( m^*(t) \) must maximize the sender’s utility, given the receiver’s strategy \( a^*(m) \). That is, \( m^*(t) \) solves

\[
\max_{m \in M} \sum_{t \in T} \pi(t|m)U_S(t, m, a^*(m)).
\]

4. For each \( m \) in \( M \), if there exists \( t \) in \( T \) such that \( m^*(t) = m \), then the receiver’s belief at the information set corresponding to \( m \) must follow from Bayes’ rule and the sender’s strategy:

\[
\pi(t|m) = \frac{p(t)}{\sum_{t' \in T} p(t')}
\]

For example, the authors will show whether \((\mu\phi, p') \) is perfect Bayesian Nash equilibrium. If the sender plays the strategy \( \mu\phi \), under the receiver’s belief given this choice, the receiver’s best response is \( p' \) and each type earns payoffs of \( 7 \) and \( 10 \) respectively. If \( s \) were to deviate by playing \( \phi \), then the receiver would react with \( p' \); \( s' \)’s payoff would then be \(-10\), hence there is no incentive for \( s \) to deviate from playing \( \mu \). Likewise, if \( s' \) were to deviate by playing \( \mu' \), then the receiver would react with \( p' \); \( s' \)’s payoff would then be \(7\), hence there is no incentive for \( s' \) to deviate from playing \( \phi \). Thus, \((\mu\phi, p') \) is a perfect Bayesian equilibrium.

These equilibria include an ambiguous utterance as part of an equilibrium strategy. From this, seemingly, Parikh’s model successfully gives an account for the reason why ambiguous utterances are common in our communication. However, as the authors have mentioned before, there are some questions about this model. The authors focus on two of them. First, Parikh only deals with a case where interests between the sender and the receiver clearly coincide. The question then arises about a case where interests between the sender and the receiver does not necessarily coincide. Next, it remains an unsettled question about what becomes equilibrium in another solution concept. Thus, the authors address these questions by extending Parikh’s model into more general or dynamic ones.

### 2.2 Crawford and Sobel’s Model

In this subsection, the authors extend Parikh [9]’s model in the previous subsection using Crawford and Sobel’s model [2]. Crawford and Sobel [2] study the following general payoff function in cheap talk games where various degree of coincidence of interests between the sender and the receiver can be considered.

\[
\begin{align*}
U_s &= a_s - \beta_1(a - (t - d))^2, \\
U_r &= a_r - \beta_2(a - t)^2,
\end{align*}
\]

where \( U_s \) and \( U_r \) are the sender and the receiver’s payoff functions respectively. \( a \) is a member of available the receiver’s action space \( A = [0, 1] \). \( a = 0 \) and \( a = 1 \) stand for that the receiver interprets \( p \) and \( p' \) respectively in our context. \( t \) is a member of available the sender’s type space \( T = [0, 1] \). \( t = 0 \) and \( t = 1 \) stand for that the sender’s type is \( s \) and \( s' \) respectively in our case. \( d \) is variable that stands for degree of coincidence between the sender’s and the receiver’s interests.

Substituting these payoff functions into the Parikh’s model, the resultant payoff table for type-action pairs is shown in Table 1. The authors assume that, \( d \), degree of coincidence between the sender’s and the receiver’s interests, is different between the sender’s type \( s \) and \( s' \). Denote \( d_s \) and \( d_{s'} \) as \( d \) for \( s \) and \( s' \) respectively.
sender’s and the receiver’s interests are perfectly conflicting, that is, $d_s = d_r = 1$. This is the case Parikh considered. Secondly, upper-right side (b) means that the sender’s and the receiver’s interests coincide, while type $s$ sender’s and the receiver’s interests coincide, that is, $d_s = -1$ and $d_r' = 1$. Thirdly, lower-left side (c) means that type $s'$ the sender’s and the receiver’s interests coincide, while type $s$ sender’s and the receiver’s interests are conflicting, that is, $d_s = -1$ and $d_r' = 0$. Finally, lower-right side (d) means that type $s'$ sender’s and the receiver’s interests coincide, while type $s$ sender’s and the receiver’s interests are conflicting, that is, $d_s = 0$ and $d_r' = 1$.

Then, the authors obtain the following extensive-form (Fig. 3).

![Fig. 3](image)

Fig. 3 Extensive-form of Parikh’s model in terms of Crawford and Sobel’s model.

Here $C_s$ and $C_r$ ($C_s, C_r > 0$) stand for the cost of sending a non-ambiguous utterances, $\mu$ and $\mu'$, for the sender and the cost of interpreting an ambiguous utterance, $\phi$, for the receiver respectively. Then, pure strategy Bayesian Nash equilibria, provided that $0 < \rho < 1$, $\beta_i > 0$ and $\beta_r > 0$, $C_s > 0$ and $C_r > 0$ is as follows (see, for example, [15] for details of calculating pure strategy Bayesian Nash equilibria).

Table 2 shows all pure strategy Bayesian Nash equilibria in case (a), (b), (c) and (d) respectively in Fig. 2. The authors focus on the condition $C_s \leq \beta_s$. In case (a), pure strategy Bayesian Nash equilibria are $(\mu \phi, p')$ and $(\phi \mu', p)$ as Parikh showed. And these are perfect Bayesian Nash equilibria. These equilibria include an ambiguous utterance as a part of equilibrium strategy. In case (b), pure strategy Bayesian Nash equilibria are $(\phi \mu, p')$ and $(\phi \mu', p)$. In these equilibria, the sender always uses an ambiguous utterance $\phi$ to dissimulate the true type. In case (c), pure strategy Bayesian Nash equilibria are $(\phi \phi, p')$ and $(\phi' \phi, p)$. In both equilibria, type $s$ sender always uses an ambiguous utterance $\phi$ to dissimulate the true type.

From this Table 2, the authors find that strategy profiles $(\mu \phi', p)$ and $(\mu' \phi, p)$ are never pure strategy Bayesian Nash equilibria. That is, unambiguous communication never happens in this model. On the other hand, Parikh’s results $(\mu \phi, p')$ and $(\phi \mu', p)$ are equilibria only in the case when interests between the sender and the receiver coincides.

3. Simulation

In this section, the authors further extend Parikh’s model by an evolutionary dynamics in order to verify whether the equilibria including an ambiguous utterance $\phi$ is dynamically stable [16]. Here, the authors shall confine our attention to an equilibrium $(\phi \mu', p)$ without loss of generality.

Evolutionary game theory was invented by Smith [17] and Smith and Price [18], and extensively studied in the last decades (see [19],[20]). Evolutionary game theory is basically based on Darwinian evolution model and is applied to strategic interaction between animals. Central solution concept is ESS (Evolutionary Stable Strategy), and it is a refinement of Nash equilibrium. Moreover, an ESS is an asymptotic stable point in replicator dynamics. Replicator dynamics is the most fundamental equation in evolutionary dynamics.

3.1 Evolutionary Game Theory

Consider that there exists infinite populations performing the role of the sender and the receiver respectively, and that randomly chosen individuals from each population are matched repeatedly. In the population performing the role of the sender, the ratios of individual playing $\phi \phi$, $\mu \phi$, $\phi' \mu'$ and $\mu' \phi$ are $x_{\phi \phi}$, $x_{\mu \phi}$, $x_{\phi' \mu'}$ and $1 - x_{\phi \phi} - x_{\mu \phi} - x_{\phi' \mu'}$ respectively. Similarly, in the population performing the role of the receiver, the ratios of individual playing $p$ and $p'$ are $y_p$ and $1 - y_p$ respectively.

In the population performing the role of the sender, the respective average fitness for the individuals playing $\phi \phi$, $\mu \phi$, $\phi' \mu'$ and $\mu' \phi$ are defined as $\pi_{\phi \phi}(y_p)$, $\pi_{\mu \phi}(y_p)$, $\pi_{\phi' \mu'}(y_p)$ and $\pi_{\mu' \phi}(y_p)$ respectively. $\pi_{\phi}(x_{\phi \phi}, x_{\mu \phi}, x_{\phi' \mu'})$ and $\pi_{p'}(x_{\phi \phi}, x_{\mu \phi}, x_{\phi' \mu'})$ are average fitness for $p$ and $p'$ in the population performing the role of the receiver. Finally, let $\pi_s$ and $\pi_h$ be average fitness of the pop-
whether Bayesian Nash equilibrium ($\pi_B$) is asymptotic stable point in replicator dynamics, the authors have to take the following steps (see [19]).

In order to verify whether Bayesian Nash equilibria are asymptotic stable point in replicator dynamics, the authors have to take the following steps (see [19]).

Step 1 Solve $dx_{ab}/dt = 0, dx_{ac}/dt = 0, dx_{bc}/dt = 0$ and $dy_p/dt = 0$ to verify whether $(\phi_1', \rho)$ is stationary point in the replicator dynamics.

Step 2 Construct the Jacobian matrix $J$ by the first-derivatives of the replicator dynamics where $J$ is as follows.

$$J = \begin{pmatrix}
\frac{\partial f_a}{\partial x_{ab}} & \frac{\partial f_a}{\partial x_{ac}} & \frac{\partial f_a}{\partial x_{bc}} & \frac{\partial f_a}{\partial y_p} \\
\frac{\partial f_b}{\partial x_{ab}} & \frac{\partial f_b}{\partial x_{ac}} & \frac{\partial f_b}{\partial x_{bc}} & \frac{\partial f_b}{\partial y_p} \\
\frac{\partial f_c}{\partial x_{ab}} & \frac{\partial f_c}{\partial x_{ac}} & \frac{\partial f_c}{\partial x_{bc}} & \frac{\partial f_c}{\partial y_p} \\
\frac{\partial f_p}{\partial x_{ab}} & \frac{\partial f_p}{\partial x_{ac}} & \frac{\partial f_p}{\partial x_{bc}} & \frac{\partial f_p}{\partial y_p}
\end{pmatrix}$$

(5)

Step 3 According to the putative equilibrium $(\phi_1', \rho)$, assign $x_{ab}$ to 0, $x_{ac}$ to 0, $x_{bc}$ to 1 and $y_p$ to 0 respectively.

Step 4 Solve the eigenpolynomial equation $|I - J|$ of $J$

If the real parts of the eigenvalues obtained in Step 4 are negative, respective stationary point is asymptotic stable. To verify whether Bayesian Nash equilibrium $(\phi_1', \rho')$ is asymptotic stable point in replicator dynamics, the Jacobian matrix $J$ of the equation (4), provided that $(x_{ab}, x_{ac}, x_{bc}, y_p)$ is $(0,0,1,1)$, is calculated as follows.

$$J = \begin{pmatrix}
-3\rho - 17 & 0 & 0 & 0 \\
0 & 14\rho - 17 & 0 & 0 \\
-20\rho + 17 & -23\rho - 20 & -3\rho & 0 \\
0 & 0 & 0 & -28\rho
\end{pmatrix}$$

(6)

For eigenvalues of Jacobian matrix $J$, the real parts of these are negative, provided that $0 < \rho < 1$. Thus this stationary point is asymptotic stable, that is, the fact that equilibrium $(\phi_1', \rho)$ is an ESS is confirmed. As for the other stationary points, the authors find that only $(\phi_2', \rho)$ and $(\mu_1, \mu_1')$ are asymptotic stable (ESS).

3.2 Agent-Based Simulation

We find that an utterance with definite meaning $\mu_1'$ is not asymptotic stable (ESS). However, it is possible that under a certain distribution of other player’s strategies, $\mu_1'$ can survive as it is Lyapunov stable. Additionally, it is difficult to handle analytically the case that a parameter $d$ has different values for different agents. Thus, the authors have implemented Parikh’s model in evolutionary dynamics as an agent-based simulation.

The simulation takes the following steps.

1. For each strategy $(\phi_1, \rho)$, $(\phi_2', \rho')$, $(\mu_1, \mu_1')$, $(\phi_1', \rho)$, $(\phi_1, \rho')$, $(\mu_1', \rho')$, equal number of agents are created.
2. Each agent is randomly matched and plays the game 10 times with the same opponent. Then each player’s fitness is determined by the cumulative payoff.
3. Players are selected proportionally to their relative fitness in the population for the next generation.
4. Repeat the steps 2 and 3 1,000 times.

The settings of the common parameters in the simulation are summarized in Table 3. The parameters are critical for the result. The authors calibrate these values from Fig. 1 and Table 1 in order to verify whether results of Parikh are robust. In each simulation, the authors change the value of $\rho$, $d$ and $d'$ as shown in Table 4. Please note that $(\rho, d, d') = (0.9, 0, 0)$ is the setting of Parikh’s model [21].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha, \beta, C_1, \alpha, \beta, C_2$</td>
<td>(15, 20, 3, 20, 27, 2)</td>
</tr>
<tr>
<td>Population size</td>
<td>100 individuals</td>
</tr>
<tr>
<td>Generations</td>
<td>1000</td>
</tr>
<tr>
<td>Iterations</td>
<td>10</td>
</tr>
</tbody>
</table>

We find that the results in our simulation basically coincide with models analyzed in previous sections. In addition, the authors find some interesting results. In the case $(\rho = 0.5, d_1 = 0, d_1' = 0)$, non-equilibrium outcomes, $(\mu_1', \rho)$ and $(\mu_2', \rho')$, survive in the long run, provided that $0 < \rho < 1$ and $C_1 > 0$. These outcomes are interpreted that the sender makes unambiguous utterances in both $s$ and $s'$. Figure 4 shows one of the results in this simulation with the parameter set $(0.5, 0.0, 0)$. On and after 22nd generation, only strategies that the sender always sends unambiguous utterances, $\mu$ and $\mu'$, survived. Finally, strategy $(\mu_1', \rho')$ survived. Thus, our simulation shows that unambiguous communication can survive in the long run under certain condition, unlike theoretical prediction. The authors run simulations 100 times with same parameter setting. Table 4 shows that the ratios of strategies survived in the end of simulation in each parameter settings. From this table, the authors find that $(\mu_1', \rho)$ and $(\mu_1', \rho')$’s ratios are approximately 20% and 28% respectively.
This will be the theme of our future research. As part of equilibrium strategy as in original Parikh’s model. It remains an unsettled question whether a model which deals with the vagueness as quantitative ambiguity where the sender’s type space is continuous as in Lipman [14]’s result, Parikh’s pessimistic result does not hold in some cases. Hence, the authors find via agent-based simulation that meaningful communication between the sender and the receiver can be a stable outcome with a certain condition. Agent-based simulation also confirmed this finding.

The results in our simulation basically coincided with stable point in replicator dynamics that was analytically obtained. However, there were some exceptions. Even strategies that are not asymptotic stable survived in the long run in our simulation. These outcomes only consist of unambiguous utterances. The authors found that ambiguous utterances between the sender and the receiver, and was analyzed by evolutionary dynamics. The authors found that ambiguous utterances can be a stable outcome with a certain condition. Agent-based simulation also confirmed this finding.

4. Conclusion

In this paper, Parikh’s model of ambiguous utterances was extended by changing the degree of coincidence of interest between the sender and the receiver, and was analyzed by evolutionary dynamics. The authors found that ambiguous utterances can be a stable outcome with a certain condition. Agent-based simulation also confirmed this finding. The results in our simulation basically coincided with stable point in replicator dynamics that was analytically obtained. However, there were some exceptions. Even strategies that are not asymptotic stable survived in the long run in our simulation. These outcomes only consist of unambiguous utterances. Hence, the authors find via agent-based simulation that meaningful communication between the sender and the receiver can be achieved with a certain condition. Hence, according to our result, Parikh’s pessimistic result does not hold in some cases. This explains the reason why human beings had developed verbal communication.

One of the problems which one must consider is the case where the sender’s type space is continuous as in Lipman [14]’s model which deals with the vagueness as quantitative ambiguity in communication. It remains an unsettled question whether this case has equilibria which includes an ambiguous utterance as part of equilibrium strategy as in original Parikh’s model. This will be the theme of our future research.

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