A game-theoretic approach to analyzing cross-linguistic pragmatic strategies, L1-L2 accommodation and pragmatic inference

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In this paper, I present a set of game-theoretic models towards the explanation of inter-linguistic accommodation using Van Rooy's (2004) formalization of Horn strategies (Horn, 1984). Incorporating Aoun and Li (1993) and Marden's (2004) observations of semantic licensing differences between Mandarin Chinese and English, I devise a novel model for the analysis of inter-linguistic accommodation. The results of this analysis point to a definite division of pragmatic labor in both English-to-Mandarin and Mandarin-to-English accommodation strategies, wherein (un)marked expressions received (un)marked interpretations. In addition to accommodation, this paper also explores how Bayesian updating strategies can account for pragmatic inference. Incorporating elements from both Parikh (1991, 2000) and Rasmusen (2007), I apply the Harsanyi (1967) transformation to Van Rooy's framework of strategic communication to create a model of pragmatic inference with incomplete information, asymmetric information and certainty. This model is in turn applied to describe situations where a sender and receiver must coordinate on the interpretation of semantically-ambiguous utterances. The results of the second analysis point to a necessity for considering focal points (Schelling 1960) in games of strategic communication.

Keywords: Horn strategies, Mandarin Chinese, English, signaling, semantics, conversational maxims

1. Introduction

Consider the following English utterances:

(1) Every student didn't pass the exam.
- a. $\neg\forall x\ [x\ [student] \rightarrow x\ [passed\ the\ exam]]$ (not>every)
- b. $\forall\ [x\ [student] \rightarrow\ \neg x\ [passed\ the\ exam]]$ (every>not)

(2) Not every student passed the exam.

(3) No student passed the exam.

The first utterance (1) has two possible readings, or pragmatic uses. In one reading (1a), referred to as a *not>every* interpretation, some student did not pass the exam; this reading may be paraphrased as (2). In another reading, the *every>not* interpretation, *not* is predicated over every member *x*; thus, the reading obtained may be paraphrased as (3) above.

The above example is an instance of a rule known as Horn's division of pragmatic labor (Horn 1984), which stipulates that "(un)marked expressions typically receive an (un)marked interpretation" (Van Rooy 2004: 289). This notion of a Horn strategy follows from neo-Gricean maxims of communication, which, as Grice (1975) suggests, should be derivable from general principles of rationality and economy. The notion that economy considerations are present in how speakers use language follows a pedigree tracing back to Zipf (1949). Speakers obey Horn's division of pragmatic labor because they "use a conventional language that, perhaps due to evolutionary forces, is designed to minimize the average effort of speakers and hearers" (Van Rooy 2004: 289). That certain linguistic features are conventionalized via public "language-games" is a notion derived from Wittgenstein's (1953) treatise, *Philosophical Investigations*. Horn's (1984) neo-Gricean maxims, namely the *Q* and *R* principles, have been applied not only to game-theoretic analyses of communication (e.g. Parikh 1991; Van Rooy 2004), but they also hold a fundamental position in Blutner's (2010) optimality-theoretic framework.

Beginning with a set of observations of semantic licensing differences between Mandarin Chinese and English, a particular construction is selected which yields both surface and inverse scope interpretations in English, while in Mandarin, only a surface scope interpretation is permitted. Blutner's (2010) classifications of the neo-Gricean *Q* and *R* principles (Horn 1984) are then reformulated to define a strictly-dominant Nash equilibrium (solution concept) for a game of strategic communication (Nash 1950). Adopting Parikh's (1991 2000) speaker-hearing signaling game framework and incorporating modifications by Van Rooy (2004), game-theoretic models operating under a cost-sensitive utility function are constructed. Mandarin- and English-based speaker-hearer strategies are then analyzed by the model in the context of cross-linguistic accommodation. The cost-sensitive model predicts one unique speaker-hearer strategy pair for English-to-Mandarin accommodation situations, and one unique strategy pair for Mandarin-to-English accommodation situations. Both strategy pairs form strictly-dominant Nash equilibria and are evolutionarily stable. Horn's division of pragmatic labor is found to hold for cross-linguistic pragmatic accommodation.

2. Overview of the Framework

Game theory, a branch of applied mathematics that models situations of strategic interaction among numerous agents, was initially formulated in the seminal works of von Neumann and Morgenstern (1944) and Nash (1950), among others. Aside from its original applications in economics, game theory has been widely used in evolutionary biology (Maynard-Smith and Price 1973; Maynard-Smith 1982), moral philosophy (Kuhn 2004) and linguistics (Clark 2011). Despite the breadth of its cross-disciplinary applications, the fundamental concepts of game theory are largely consistent across fields. Of particular interest to the present study is the application of game theory within linguistics, namely pragmatics. The literature on game theory contains some applications in both communication games and linguistic pragmatics, which I will review here.

Inspired by Horn's (1984) formalization of Zipf's (1949) *principle of least effort*, Blutner (2000, 2010) and Dekker and Rooy (2000), Parikh (1991, 2000) and Van Rooy (2004) offer separate accounts as to why (un)marked expressions typically receive (un)marked interpretations. Blutner proposes to account for the emergence of Horn's division of pragmatic labor via bidirectional optimality theory (OT). The idea behind OT in semantics and pragmatics is that conventional meaning "underspecifies" the actual interpretation of an expression, and that a combination of viable OT constraints determines what the optimal (and thus realized) interpretation is from among other candidate interpretations (290).

This account is bidirectional in that both the speaker and the hearer must determine the optimal expression and interpretation, respectively. Thus, what is optimal is not simply meanings with respect to forms, nor simply forms with respect to meanings, but rather sets of form-meaning pairs. Such a form-meaning pair is strongly optimal (following Jäger 2000; cf. Van Rooy 2004) if it satisfies both the speaker's principle (i) and the hearer's principle (ii), where *f* denotes 'form' and *m* denotes 'meaning'.

(i) $\neg\exists f': [f,\ m] < [f',\ m]$

(ii) $\neg\exists m': [f,\ m] < [f,\ m']$

This concept of a strongly optimal form-meaning pair serves as the basis for game-theoretic formulations of strategic communication via signaling games (e.g. Parikh 1991, 2000; Van Rooy 2004). Further, Blutner's (2000) notion serves as the basis for the solution concept espoused throughout the present investigation.

Blutner (2010), Blutner and Strigin (2011) and de Hoop, Hendricks and Blutner (2007) provide an optimality-theoretic formalization of Horn's (1984) *Q* and *R* principles, which is given in (4) and (5) below (Blutner 2010: 171-2).

(4) *Q* Principle: the production system can find no expression A' such that
[*sem*(A'), τ] > [*sem*(A), τ]

(5) *R* Principle: the interpreter can find no context τ' such that
[*sem*(A), τ'] > [*sem*(A), τ]

This formulation of the *Q* principle states that the production system can find no expression that will better fit the present context. Similarly, the *R* principle states that the interpreter can find no better context that fits the production system's expression. I suggest that Blutner's (2010) formulations of the neo-Gricean maxims of quality and economy can be reformulated as (6) and (7) below.

(6) Optimal Strategy for Speaker: The speaker (S) can find no signal σ' such that the expected payoff of σ' is greater than the incumbent signal, σ.

(7) Optimal Strategy for Hearer: The hearer (H) can find no interpretation ι' such that the expected payoff of ι' is greater than the incumbent interpretation, ι.

The formulations given in (6) and (7) are directly applicable to communication games of the pragmatic variety discussed in Wärneryd (1993), Jäger (2004, 2008), Potts (2008), and others.

Dekker and Van Rooy (2000) and Van Rooy (2004) provide a fundamentally different account of Horn's (1984) division of pragmatic labor. In this game-theoretic model, speaker-hearer communication constitutes a two-player strategic game in which each player, uninformed at the time of his/her decision, chooses an action from a set of actions available to that player. The game is simultaneous, and the availability of information is incomplete. The actions chosen by each player depend on their preferences, and are modeled in terms of a utility function (U), or lottery, over the available action profiles $(a_1, a_2, \ldots, a_n \in A_i)$. Reformulating Blutner's (2000, 2010) notion of a strongly optimal form-meaning pair, we may define a strictly dominant Nash equilibrium for a speaker-hearer strategy pair (Van Rooy, 2004: 291).

(iii) $\neg\exists a'_1 \in A_1 : U_1(a_1, a_2) < U_1(a'_1, a_2)$

(iv) $\neg\exists a'_2 \in A_2 : U_2(a_1, a_2) < U_2(a_1, a'_2)$

Essentially, (iii) and (iv) above stipulate that a profile of actions constitutes a strictly dominant Nash equilibrium if and only if neither player can profit by choosing a different action, given the actions of the other players.

In a series of publications, Parikh (1991, 2000) provides a game-theoretic analysis of when communication is possible, arguing that "[a] speaker (S) communicates something to a hearer (H) if and only if the discourse interaction can be described as a game of partial information with a unique solution" (Van Rooy 2004: 292). To summarize Parikh's framework for signaling games, I return again to the following series of utterances.

(8) Every student didn't pass the exam. (f_*)

(9) Not every (i.e. some) student passed the exam. (f_1)

(10) No student passed the exam. (f_2)

According to Parikh, a speaker uses an expression (f_*) that can be interpreted in a number of ways (cf.: 8 above). How f_* should be interpreted depends on the actual situation, or state of the world, that the speaker is in (denoted $t_1,\ t_2$). By using utterance f_* the speaker ideally intends to communicate that he/she is in state of the world t_1 when appropriate, and state of the world t_2 when appropriate.

Parikh (1991) assumes that there is a probability of 0.8 of the speaker being in t_1, and a probability of 0.2 of the speaker being in t_2. Under this probability distribution, which is common knowledge to both players, it would seem that both players should simply map f_* to t_1. However, Parikh argues that players must be aware of alternative expressions that are available. That is, in addition to f_*, f_1 and f_2 (9 and 10 above) also exist. While f_* may refer to either t_1 or t_2, f_1 refers exclusively to t_1, and f_2 refers only to t_2. In Parikh's cooperative game, the speaker has some information about an event, and his/her goal is to transmit this knowledge to the hearer successfully. To coordinate, S needs to choose one signal from a finite set of possible signals. Thus, S's strategy here is to map the information to some signal; after observing the signal, H's task is then to discern what information has been mapped to that signal. If H interprets S's signal according to the mapping S had envisaged, then both players (*S* and *H*) receive a positive payoff. If not, then the payoff is 0. Wärneryd (1993), Jäger (2008) and Jäger, Metzger and Riedel (2011) argue that such a coordination game has an evolutionarily stable state if and only if there is a one-to-one correspondence between signal and meaning, where the speaker's strategy is the inverse of the hearer's strategy.

Although Parikh's model is essentially adopted by Dekker and Van Rooy (2000) and Van Rooy (2004), these authors do modify a few aspects of the model. Most notably, that communication is modeled as a simultaneous game seems not to reflect actual (i.e. real-world) communication. Thus, Van Rooy's (2004) refinement of Parikh's (1991, 2000) original model will be considered. In addition to Van Rooy's reformulations, I add another substantial change to the conceptual format of the model by adding Nature, a pseudo-player who always moves first and in so doing choosing the probability of a particular state of the world. This will be described at length in the coming section.

In sum, Van Rooy then makes the argument, following Horn's (1984) division of pragmatic labor. Horn's division of pragmatic labor is reconstrued as a "Horn strategy"; in such strategies, marked expressions are typically paired with marked interpretations, whereas unmarked expressions are typically paired with unmarked interpretations (see Jäger, 2008: 418 and Van Rooy, 2004: 493 for discussion). Jäger (2008) notes that "a Horn strategy and its sub-optimal counterpart (pairing simple forms with complex meanings and vice versa) [are] evolutionarily stable" (418); under such circumstances, it is conceivable that both optimal and sub-optimal Horn strategies could coexist within a diverse population simultaneously.

3. Modeling Cross-Linguistic Pragmatic Accommodation

Based on insights from Aoun and Li (1993) and Huang (1982), Marsden (2004) observes a case in which English licenses two possible interpretations of ambiguous utterances containing a universally-quantified subject and an existentially quantified object, whereas Mandarin Chinese licenses only one interpretation (Marsden 2004: 20-1; Huang 1982: 112; Aoun and Li 1993: 14). The difference between the interpretations is one of quantifier scope, or the domain over which a quantifier has influence. In English, a statement such as (11) below has two possible readings, (11a) and (11b).

(11) *Every policeman saw a thief.*
  a. $\forall x \, [Px \rightarrow Tx]$
     'For every policeman, there is some thief that he/she saw.'
  b. $\exists x \, [Tx \, \& \, (\forall x \, [Px \rightarrow Tx])]$
     'There is a thief, such that every policeman saw him/her.'

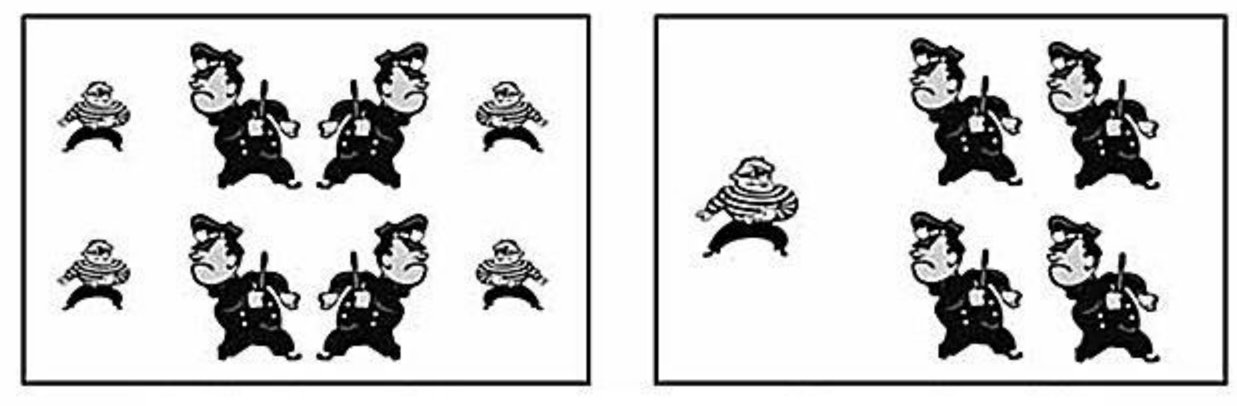

Figure 1 *Surface scope (left) and inverse scope (right) interpretations of (11)*

Whereas English licenses both a surface scope reading (11a) and an inverse scope reading (11b), Mandarin Chinese licenses only a surface scope interpretation in such canonical (subject-verb-object) forms. Cf.:

(12) 每个警察都看到一个小偷.

Mei-ge	jingcha	dou	kandao	yi-ge	xiaotou
Every-Q	policeman	all	saw	one-Q	thief

‘Every policeman saw a thief.’

a. For every policeman, there is some thief that he/she saw.

b. * There is a thief, such that every policeman saw him/her.

In sum, in canonical (SVO) utterances where there is a universally-quantified subject and an existentially quantified object, Mandarin permits only one interpretation while English permits two.

In light of the observations of Aoun and Li (1993) and Marsden (2004), I provide a game-theoretic analysis of strategic communication in an accommodation situation, first between an English speaker and a Mandarin hearer, and finally, between a Mandarin speaker and an English hearer. The following accommodation analysis operates under the general assumption that there are three possible signals: f_1, f_2, and f_* (notation adopted from Parikh 1991 and Van Rooy 2004, with changes for clarity). For the player constrained by English grammar, the mappings $\{t_1 \leftrightarrow f_1\}$ and $\{t_2 \leftrightarrow f_2\}$ are one-to-one; however f_* can map directly to either state t that is chosen by Nature, $\{t_1, t_2 \leftrightarrow f_*\}$. For the player constrained by Mandarin grammar, the one-to-one mappings, $\{t_1 \leftrightarrow f_1\}$ and $\{t_2 \leftrightarrow f_2\}$, hold. The discrepancy between Mandarin and English lies in the mapping of f_*. In Mandarin grammar, f_* can only map to t_1. This mapping scheme reflects the surface and inverse scope ambiguity that exists in English grammar, as well as the lack of inverse scope interpretation available in the Mandarin grammar (in this particular syntactic context).

3.1. *Analysis of English-to-Mandarin Accommodation Strategies*

Following the scheme outlined by Parikh (1991: 482) and Van Rooy (2004: 500), I begin by establishing the speaker-hearer strategy functions. By definition, a speaker's strategy, *S*, is a function from situations to forms [$\{t_1, t_2\} \rightarrow \{f_*, f_1, f_2\}$]. Similarly, a hearer's strategy, *H*, is a function from forms back to situations [$\{f_*, f_1, f_2\} \rightarrow \{t_1, t_2\}$]. In my accommodation model, I have modified Van Rooy's (2004: 500) hearer strategy to reflect the appropriate mappings available to the player constrained by Mandarin grammar in the scope context considered here. The strategies available to the English speaker and the Mandarin hearer are depicted below in Table 1.

	t_1	t_2
S_1	f_*	f_2
S_2	f_*	f_*
S_3	f_1	f_*
S_4	f_1	f_2

Speaker (English)

→

	f_*	f_1	f_2
H_1	t_1	t_1	t_2

Hearer (Mandarin)

Table 1 *Speaker (English) to Hearer (Mandarin) strategy mappings*

In searching for an optimal speaker-hearer strategy, I follow Parikh's (1991) practice of defining equilibria according to expected utility (EU). In order to calculate expected utility, I must first define both a probability function and a (marginal) utility function, provided below in (13) and (14).

(13) Probability Function

$$Prob(N(t_1)) = 0.5, Prob(N(t_2)) = 0.5$$

(14) Utility Function (Basic)

$$U\left(t, N(t), S(N(t)), H\left(S(N(t))\right)\right) = 1, iff\ H\left(S(N(t))\right) = 1$$

$$U\left(t, N(t), S(N(t)), H\left(S(N(t))\right)\right) = 0, otherwise$$

Given these functions, it is possible to calculate the expected utilities for each speaker-hearer strategy. In general, the expected value of a strategy is the payoff that a player anticipates as a lottery over all possible states of Nature. The formula provided in (5) will be used here and henceforth to calculate expected utility.

(15) Expected Utility Function

$$EU\ (S,H) = \sum_t Prob\big(N(t)\big) \times U\left(t, N(t), S\big(N(t)\big), H\left(S\big(N(t)\big)\right)\right)$$

Under the basic utilities model, the expected utilities for all available speaker-hearer strategies are shown below (Table 2).

t_1	H_1
S_1	1
S_2	1
S_3	1
S_4	1

t_2	H_1
S_1	1
S_2	0
S_3	0
S_4	1

→

EU	H_1
S_1	1
S_2	0.5
S_3	0.5
S_4	1

Table 2 *Expected utilities under the basic utilities model*

Following Van Rooy's (2004: 502) criterion, I accept only those strategy combinations that form strictly-dominant Nash equilibria as candidates evolutionarily stable strategy profiles. Since I have yet to formally define the criteria for a Nash equilibrium for this analysis, I provide an adapted version of the conditions used by Van Rooy (509).

(16) Strictly-dominant Nash equilibrium condition for Speaker

$$\neg\exists S' : EU\ (t, N, S, R) < EU(t, N, S', R)$$

(17) Strictly-dominant Nash equilibrium condition for Hearer

$$\neg\exists H' : EU\ (t, N, S, R) < EU(t, N, S, R')$$

Returning to Table 3, it seems that there are two candidates, neither of which is a strictly-dominant Nash equilibrium strategy. For a strategy to be evolutionarily stable, it must be a best response. That two strategy combinations offer equal expected utilities is problematic to successful communication. To remedy this, I appeal to Van Rooy's proposal of a cost-sensitive utilities model (503-4).

Under a cost-sensitive utilities model, the probability function is identical to the one given in (13); now, however, complexity has been added to the utility function given in (14), which now takes the form provided in (18) below.

(18) Utility Function (Cost-Sensitive)

$$U\ \left(t, N(t), S\big(N(t)\big), H\left(S\big(N(t)\big)\right)\right) = \frac{1}{Complexity(S\big(N(t)\big))}, iff\ H\left(S\big(N(t)\big)\right) = 1$$

$$U\ \left(t, N(t), S\big(N(t)\big), H\left(S\big(N(t)\big)\right)\right) = 0, otherwise$$

While successful communication is most important to every model considered here, success with a simple expression is preferred to success with a complex expression. Following Van Rooy (502), I assign cost values to every available form *f*, as given in (19).

(19) Cost Function

$$Complexity\ (f_*) = 1, \qquad Complexity\ (f_1) = Complexity\ (f_2) = 2$$

Espousing the same probability and utility functions employed in the previous (basic utilities) model, I carry out a similar calculation of expected utilities for speaker-hearer strategy pairs under the revised cost-sensitive utilities model (Table 3).

t_1	H_1
S_1	1
S_2	1
S_3	0.5
S_4	0.5

t_2	H_1
S_1	0.5
S_2	0
S_3	0
S_4	0.5

→

EU	H_1
S_1	0.75
S_2	0.5
S_3	0.25
S_4	0.5

Table 3 *Expected utilities under a cost-sensitive utilities model*

With this modified utility/cost function, the game has one distinct Nash equilibrium, {S_1, H_1}. In this strategy combination, state t_1 is expressed by the simple form f_*, while the latter state t_2 is expressed by the more complex form f_2. In light of Horn's (1984) division of pragmatic labor, I propose that this is the Horn strategy. The argument might be made that, since the likelihood of encountering either state of Nature, t_1 or t_2, is equally probable, this cannot be a Horn strategy. I contend that if we modify the probability function to match that of Van Rooy (497), we would find that the same strategy is the only (strictly dominant) Nash equilibrium (with EU = 0.9). Thus, the solution to this game is {S_1, H_1}, the Horn-strategy pair according to which an (un)marked expression receives an (un)marked meaning.

3.2. *Analysis of Chinese-to-English Accommodation Strategies*

Accommodation is by no means an exclusively unidirectional phenomenon. At this point, I entertain the possibility of accommodation under reciprocated conditions; that is, the user of Mandarin is assigned the role of speaker, while the user of English is given the role of hearer. Given this change of roles, the possible strategy profiles of the players must be redefined accordingly. Table 4 below illustrates the possible strategy profiles of the Mandarin speaker under this particular situational constraint. Note that, given that Mandarin does not permit f_* to map to both t_1 and t_2, the speaker is limited to two possible strategies. English, on the other hand, does permit such a mapping. Cf.:

	t_1	t_2
S_1	f_*	f_2
S_2	f_1	f_2

Speaker (Mandarin)

→

	f_*	f_1	f_2
H_1	t_1	t_1	t_2
H_2	t_2	t_1	t_2

Hearer (English)

Table 4 *Speaker (Mandarin) to Hearer (English) strategy mappings*

Following the same probability function, provided in (3), I assume that $P(\mathrm{N}(t_1)) = 0.5$ and $P(\mathrm{N}(t_2)) = 0.5$. For all practical purposes, under the basic model, it makes no difference which probabilities are selected for each state of Nature, as long as no particular state has a probability that is exactly 1. Accordingly, assuming the probability function espoused by Van Rooy (2004: 499), this would yield an identical equilibrium distribution, though the expected utilities would differ slightly in numerical value. Using the specified probability and utility functions, I calculate the following expected utilities (EUs) provided below (Table 6).

t_1	H_1	H_2
S_1	1	0
S_2	1	1

t_2	H_1	H_2
S_1	1	1
S_2	1	1

→

EU	H_1	H_2
S_1	1	0.5
S_2	1	1

Table 5 *Expected utilities under a basic utilities model*

As is reminiscent of the previous application of the basic utilities accommodation model, the above formulation of utilities offers little merit. We surmise that the strategy in which the English hearer maps t_2 to f_* is not a "winning strategy" in a Nash equilibrium sense. The model needs to be refined in such a way that a strictly dominant Nash equilibrium strategy is selected. As was the case with the previous model, I propose that a cost-sensitive utilities model will filter out such a strictly dominant speaker-hearer strategy combination.

Following the same utility and cost functions given in (18) and (19), the expected utilities of the speaker/hearer strategies can be calculated (Table 6).

t_1	H_1	H_2
S_1	1	0
S_2	0.5	0.5

t_2	H_1	H_2
S_1	0.5	0.5
S_2	0.5	0.5

→

EU	H_1	H_2
S_1	0.75	0.25
S_2	0.5	0.5

Table 5 *Expected utilities under a cost-sensitive utilities model*

The cost-sensitive utilities model provides one distinct, strictly-dominant Nash strategy {S_1, H_1} as evidenced by the expected utilities calculated above. Following Parikh's proposal to take the Pareto-efficient Nash equilibria as the solution concept with the highest expected utility, I do so while noting that there is no other Nash equilibrium available here. That is, regardless of the strategy chosen, neither the speaker nor the hearer can do better by (unilaterally) changing to any strategy other than {S_1, H_1}.

While a cost-sensitive utilities model does provide a solution that is evolutionarily stable in both Chinese-to-English and English-to-Chinese accommodation contexts, it also provides a distinct Horn-strategy pair according to which (un)marked expressions receive (un)marked meanings. Thus, the results of this analysis point to possible pragmatic strategy coordination under the accommodation context investigated here. I expect that this model will be valuable in application to actual cross-linguistic conversation data. Under the provisions of the cost-sensitive utilities model, I conjecture that the {S_1, H_1} strategy would be most frequently employed both in Chinese-English and English-Chinese accommodation situations, specifically under the context of scopally-ambiguous utterances (e.g., *Every policeman saw a thief*.).

4. Pragmatic inferencing via Bayesian updating

The language game model in this section explores pragmatic inference strategies. Although some aspects have been retained in this analysis (e.g. cost-sensitive utilities), Parikh's simultaneous game has been replaced by a sequential game (following Van Rooy's (2004: 507) model). In contrast to the previous section, this model operates under the assumption that the speaker and receiver are constrained only by English grammar. There is no cross-linguistic element to this investigation of pragmatic inferencing. Here, I assume that speaker/sender does not know the expected utilities, but she is aware of the marginal utilities. That is, speaker/sender does not know what a priori probabilities hearer/receiver has assigned to each possible state of the world t. Therefore, speaker/sender cannot possibly know the expected utilities, since they require knowledge of the probability function.

In brief, this game of pragmatic inference is one of incomplete information (speaker/sender does not know the expected utilities), asymmetric information (when speaker/sender moves, she knows something that hearer/receiver does not know) and certainty (Nature does not make a move *after* the other players have made theirs). Given this description, I have modeled the game as depicted in Figure 2. Here, Nature makes the first move and chooses the utilities of the game; speaker/sender observes Nature's move, but hearer/receiver does not. On each branch, a specific probability is given, which corresponds to that particular move being made with respect to the previous moves made by other players. (Read $P(S(f)|N(t))$ as 'the probability of S choosing f given that N chose t.')

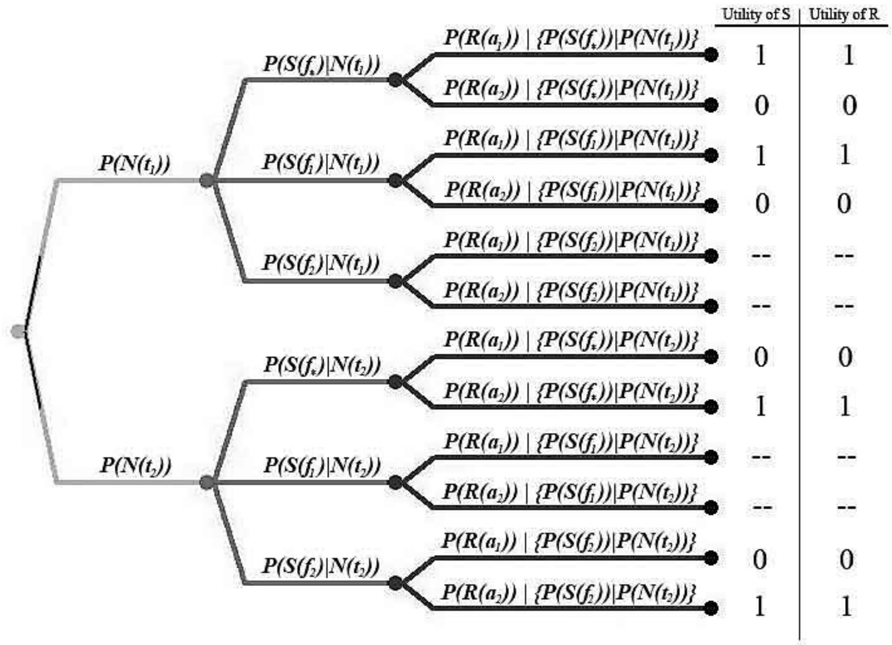

Figure 2 *A sequential game of inference (information partitions not included)*

Following Van Rooy's (2004: 507) signaling game framework, I assume that sender chooses some decision $f \in F$ while receiver chooses some decision $a \in A$.

In the same vein as the previous analyses of accommodation, I begin by specifying the context of this analysis. The sentence below (1) provides a scopally-ambiguous situation which may refer to one of two possible states of the world.

(20) Every policeman saw a thief.

Nature can choose one of two possible states of the world, t_1 or t_2, where each state having the denotations given in (2) and (3).

(21) Let t_1 denote a state in which, for every policeman, there is some thief that he/she saw.

(22) Let t_2 denote a state in which there is one thief, which every policeman saw.

Given that the game involves incomplete and asymmetric information, the sender starts off knowing something that the receiver does not know; that is, the sender knows the state of the world that Nature has chosen, but she has no substantive utility-relevant actions. The receiver, conversely, has a range of utility-relevant actions to choose from, but he has no private information. The receiver's prior beliefs concerning the state of the world are given by a probability function, which is common knowledge to both players (Rasmusen 2007: 53-5; Van Rooy 2004: 507).

Unlike the previous analysis where I selected Nash equilibria after specifying a number of functions and calculating the associated expected utilities, this analysis will be conducted differently. Here, I am interested in exploring how the receiver updates his strategy given the information at his disposal. The goal here is to find an equilibrium strategy for the receiver, such that he is always playing a best response given the information available to him. Such a best-response equilibrium, or Bayesian equilibrium, is a Nash equilibrium in which players update their beliefs according to Bayes' Rule (Rasmusen 2007: 57). To analyze the receiver's process of Bayesian updating, I adopt the three-step procedure outlined by Rasmusen (56).

(23) Propose a strategy profile.

(24) See what beliefs the strategy profile generates in response to each other player's moves.

(25) Check that, given those beliefs together with the strategies of the other players, each player is choosing the best response for him- or herself.

As Rasmusen's method prescribes, it is necessary that we find best-response (Nash) equilibria in which players update their beliefs according to Bayes' Rule. Thus, it serves to begin the analysis with a general version of Bayes' Rule (4), which will guide us through the process of Bayesian updating (Rasmusen 2007: 57).

(26) $$Prob(x|data) = \frac{Prob(data|x) \times Prob(x)}{Prob(data)}$$

Following Rasmusen (2007), I interpret *Prob(data)* as the marginal likelihood of seeing *data* as the result of one or another of the possible states chosen by Nature, namely $N(t_1)$ or $N(t_2)$. The marginal likelihood of seeing $S(f_*)$, for example, is given in (5).

(27) $$Prob((S(f_*)) = Prob(S(f_*)|N(t_1)) \times Prob(N(t_1)) + Prob(S(f_*)|N(t_2)) \times Prob(N(t_2))$$

Since the hearer/receiver is trying to calculate $Prob(N(t_1)|S(f_*))$, which is the updated posterior belief, he must use marginal likelihood of seeing $S(f_*)$, as follows in (9):

(28) $$Prob(N(t_1)|S(f_*)) = \frac{Prob(S(f_*)|N(t_1)) \times Prob(N(t_1))}{Marginal\ likelihood\ of\ S(f_*)}$$

Substituting the equation given in (8) for the *marginal likelihood of* $S(f_*)$, we are left with the following Bayesian belief-updating rule for the receiver.

(29) $$Prob(N(t_1)|S(f_*)) = \frac{Prob(S(f_*)|N(t_1)) \times Prob(N(t_1))}{Prob(S(f_*)|N(t_1)) \times Prob(N(t_1)) + Prob(S(f_*)|N(t_2)) \times Prob(N(t_2))}$$

Presently, I define a set of sender-receiver strategy combinations that are available to the players of this game. Once again, I cite the strategy profiles originally formulated by Van Rooy (2004: 500), which are provided below in Figure 3.

	t_1	t_2
S_1	f_*	f_2
S_2	f_*	f_*
S_3	f_1	f_*
S_4	f_1	f_2

Speaker

→

	f_*	f_1	f_2
H_1	t_1	t_1	t_2
H_2	t_2	t_1	t_2

Hearer

Table 6 *Strategy profiles available to Speaker and Hearer*

Further, I assume that the following prior belief (probability) and utility functions hold, which are common knowledge.

(30) Probability Function

$$Prob(N(t_1)) = 0.5, Prob(N(t_2)) = 0.5$$

(31) Utility Function

$$U\left(t, (N(t)), S(N(t)), R\left(S(N(t))\right)\right) = 1, iff\ R\left(S(N(t))\right) = 1$$

$$U\left(t, (N(t)), S(N(t)), R\left(S(N(t))\right)\right) = 0, otherwise$$

Having formalized the model, I will now provide an analysis of the receiver's Bayesian updating process.

Given the strategies available to each player in this game, there is little merit to exploring the equilibrium strategies employed by the receiver if he observes the sender play either f_1 or f_2. As Figure 3 clearly shows, there is no potential ambiguity that could result from these forms. Moreover, as this is model of strategic communication, it is assumed that no player would "lie" or miscommunicate. Thus, upon seeing f_1, the receiver would infer that the state of the world could only be t_1. My interest here is to analyze the receiver's response to observing the variable form, f_*.

Thus, returning to the formula provided in (29) above, it is apparent that we need the values of $Prob(S(f_*)|N(t_1))$ and $Prob(S(f_*)|N(t_2))$. Since these values depend on what sender does in equilibrium (see Rasmusen's (2007) three-step method, given in (23 – 25) above), I must first propose an equilibrium and then use it to calculate the beliefs. Following this, I will then verify that the equilibrium strategies are in fact the best responses given the beliefs that they generate (57-8). One candidate for equilibrium is for sender to choose f_1 if Nature chooses t_1 and f_2 if Nature chooses t_2. According to this equilibrium, receiver can rule out the possibility of

Nature having chosen t_2 if he sees that sender has chosen f_1, and vice versa. The other equilibrium is for sender to choose f_* in response to either t_1 or t_2, which places receiver in a quandary. In this equilibrium, Bayes' Rule (given in (10) above) tells receiver that the posterior probability of state t_1 is

(32) $$Prob(t_1|f_*) = \frac{(1)(0.5)}{(1)(0.5)+(1)(0.5)} = 0.5.$$

Similarly, the posterior probability of Nature having chosen state t_2 is

(33) $$Prob(t_2|f_*) = \frac{(1)(0.5)}{(1)(0.5)+(1)(0.5)} = 0.5.$$

That both posterior probabilities are equally likely is problematic for the receiver. In this case, the best possible inference that can be made via Bayes' Rule is that both states of the world are equally probable, given the observation of f_*.

To offer a more thorough analysis, I return to the cost-sensitive utilities model that was applied in the previous analyses of accommodation. Due to the fundamental differences between the present Harsanyi-transformed model and the Parikhian models of the previous sections, the utility function must be defined individually for both the sender and the receiver. Cf.:

(34) Utility Function (Hearer/Receiver)

$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 1, iff\ R\left(S\big(N(t)\big)\right) = N(t)$$
$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 1 - C, iff\ S(f_*)$$
$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 0, otherwise$$

(35) Utility Function (Speaker/Sender)

$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 1, iff\ S(f_*)$$
$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 1 - C, iff\ S(f_1)\ or\ S(f_2)$$
$$U\ (t, N(t), S\big(N(t)\big), R\left(S\big(N(t)\big)\right) = 0, otherwise$$

In addition, I assume that the utilities are ranked such that $1 > (1 - C) > 0$. Given these data, I provide a final model, which is a cost-sensitive utilities variation of the previous model (Figure 4).

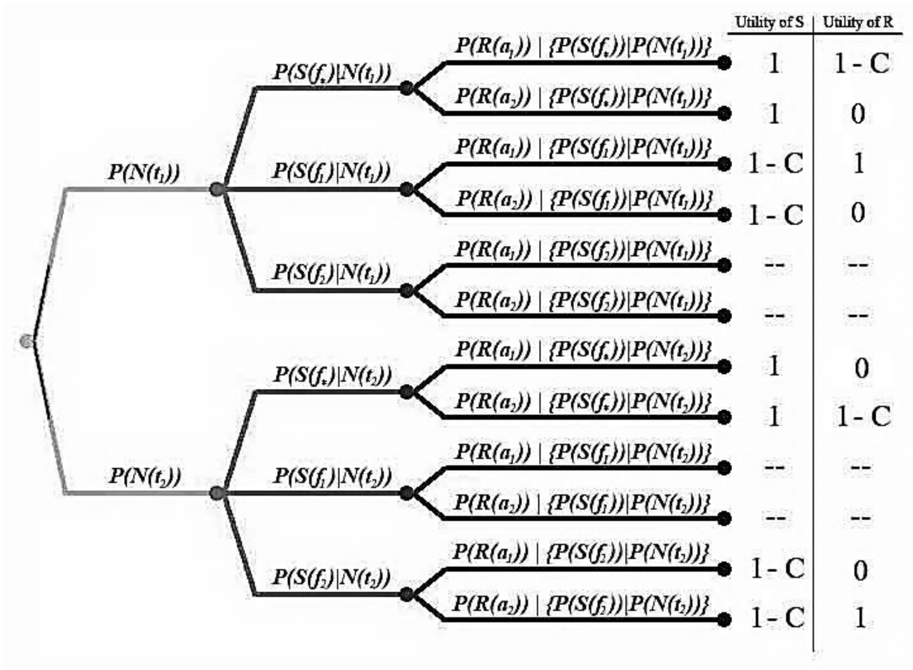

Figure 3 *Probabilistic inference under a cost-sensitive model*

Given that the receiver believes the state of the world is t_1 with a probability of 0.5, and state of the world t_2 with a probability of 0.5, his best response is to play a mixed strategy. Accordingly, he should play a_1 50% of the time and a_2 50% of the time. Clearly, communication in the real world does not generally take such a mixed strategy form. The simplest way to account for this is to assume that there is a preferential mapping, or a Schelling point (Schelling 1960), that players conventionally converge on.

The beauty of incorporating Harsanyi doctrine is that the probability of Nature's action is actually the belief that each player holds concerning the likelihood of Nature's action. This is, if I declare that $Prob\big(N(t_1)\big) = 0.8$, I am actually declaring that the players of the game believe that the prior probability of seeing t_1 is 0.8. Thus, Nature's actions are simply the opinions held by the sender and receiver. Here, I hold that t_1 is a Schelling point, or conventional state-of-the-world assignment, and therefore has a higher prior probability than state of the world t_2.

(36) $Prob(N(t_1)) > Prob(N(t_2))$

Again, I stress here that this probability function does not say that Nature more frequently chooses t_1 over t_2, but rather, it reflects the prior beliefs/opinions of the sender and receiver. The receiver has prior beliefs regarding which state is more likely, given the sender's action, and the sender has prior beliefs about which state she believes the receiver to believe to be more likely, and so on *ad inifinitum*.

5. Discussion

The present analysis has offered a formal and rigorous treatment of pragmatic accommodation from a game-theoretic perspective. Drawing from previous work by Parikh (1991, 2000) and Van Rooy (2004), I have reformulated the signaling game for strategic communication and applied the model to a number of data-inspired accommodation situations. Based on data from Huang (1982), Aoun and Li (1993), and Marsden (2004), I have employed the modified model to describe accommodation strategies between English and Mandarin Chinese-speaking interlocutors. In the first pair of experiments, I considered a set of formal strategy profiles describing both English-to-Mandarin accommodation and Mandarin-to-English accommodation. Here, it was observed that, under a cost-sensitive utilities model, there exists exactly one optimal (Nash equilibrium) strategy pair for Speaker and Hearer. As such, the results of this pair of theoretical experiments point to a division of pragmatic labor in the spirit of Horn (1984), wherein (un)marked expressions receive (un)marked meanings.

In addition to supporting previous work in formally defining Horn strategies (cf. Van Rooy 2004), the results of the cross-linguistic accommodation analysis have one monumental implication: these "optimal strategy pairs" suggest evolutionarily stable strategies. That is, on the basis of these models, it is predicted that the strategy pairs labeled as optimal will additionally be stable as a language evolves, and in the absence of any new (invasive) strategies, these pairs would remain stable even in the face of population phenotype shifts. One future aim of this line of research is to further explore the evolutionary stability of this and other such accommodation strategies, particularly in language contact situations.

One recurring motif in the present study has been the reiteration of the probability function—the adage "true as long as $Prob(N(t_1)) > Prob(N(t_2))$." This statement (and its associated implications) is built upon the assumption of a Schelling point (Schelling 1960), which in this particular study may be equated with the unmarked situation. Those situations which are unmarked (i.e. more likely to encounter) will, according to this and the analysis of Van Rooy (2004), be mapped to lower-cost (i.e. preferred) expressions/interpretations. Here, if we operate under the Laplacian assumption of probabilistic indifference, then no particular strategy profile will be optimal. Conversely, if we assume a Schelling point, or a state of the world that the Speaker/Hearer believes to be more probable than the other, then an optimal strategy profile does emerge. The emergence of strategic inference based on the expectations of a player (in this case, Hearer) is a phenomenon that I explored using a Harsanyi-transformed inference model. Exploring exactly how Schelling points emerge is a potential future application of such models as those considered in this paper.

In conclusion, the results of this analysis lead to several exciting potential applications for the models presented here. First and foremost, it is argued that such game-theoretic models can be applied to the emergence of pragmatic strategies (or pragmatic niches) in populations where competing strategies exist. In addition to explaining the emergence of such pragmatic niches, it is further argued that the present models hold a promising application with the Lotka-Volterra model (Sigmund 1993) toward the explanation of pragmatic niche evolution (following Clark, Parikh and Ryant 2007). In sum, the present models serve as stand-alone models of English-to-Mandarin and Mandarin-to-English pragmatic strategy accommodation; in conjunction with models from evolutionary ecology (e.g. the Lotka-Volterra model), the present models serve as a potential means to further our understanding of language evolution, language contact, and semantic/pragmatic niche emergence.

References

AOUN, Joseph and LI, Yen-hui Audrey 1993. *Syntax of scope*. Cambridge, Mass.: MIT Press.

BLUTNER, Reinhard 2000. Some aspects of optimality in natural language interpretation. *Journal of semantics,* 2000, vol. 17, pp. 189-216.

BLUTNER, Reinhard 2010. Some experimental aspects of optimality-theoretic pragmatics. In Nemeth, E. and K Bibok (eds.), The Role of Data at the Semantics-Pragmatics Interface (pp. 161-206). Berlin: De Gruyter.

BLUTNER, Reinhard and STRIGIN, A. 2011. Bidirectional grammar and bidirectional optimization. In BENZ, A. and MATTAUSCH, J. (eds.), *Bidirectional Optimality Theory*. Amsterdam: Benjamins, pp. 221-248.

CLARK, H. H., 1996. *Using language*. Cambridge (UK): Cambridge University Press.

CLARK, H. H., 1999. On the origins of conversation. *Verbum*, 1999, vol. 21, pp. 147-161.

CLARK, Robin 2011. *Meaningful games: exploring language with game theory*. Cambridge, Mass.: MIT Press.

CLARK, Robin, PARIKH, Prashant and RYANT, N. 2007. Evolving linguistic defaults. Ms., University of Pennsylvania.

DE HOOP, H., HENDRICKS, P and BLUTNER, R. 2007. On compositionality and bidirectional optimization. *Journal of cognitive science*, 2007, vol. 8, pp. 137-151.

DEKKER, P. and VAN ROOY, Robert 2000. Bi-directional optimality theory: an application of game theory. *Journal of semantics*, 2000, vol. 17, 217-242.

HARSANYI, J. 1967. Games with incomplete information played by "Bayesian" players, I-III: Part I: The basic model. *Management science*, 1967, vol. 14, pp. 159-182.

HORN, Lawrence 1984. Towards a new taxonomy of pragmatic inference: Q-based and R-based implicature. In SCHIFFRIN, D. (ed.), *Meaning, Form, and Use in Context: Linguistic Applications*. Washington: Georgetown University Press, pp. 11-42.

HUANG, James 1982. Logical relations in Chinese and the theory of grammar. Ph.D. dissertation, MIT.

JÄGER, Gerhard 2004. Evolutionary game theory for linguists: A primer. Ms., Stanford University and University of Potsdam.

JÄGER, Gerhard 2008. Applications of game theory in linguistics. Language and linguistics compass, 2008, vol. 2, pp. 406-421.

JÄGER, Gerhard 2011. Game-theoretical pragmatics. In VAN BENTHEM, J. and TER MEULEN, A. (eds.), *Handbook of Logic and Language*, 2nd ed. Elsevier, pp. 467-491.

JÄGER, J., METZGER, L. and RIEDEL, F. 2011. Voronoi languages: equilibria in cheap-talk games with high-dimensional types and few signals. *Games and economic behavior*, 2011, vol. 73, pp. 517-537.

KUHN, Steven 2004. Reflections on ethics and game theory. *Synthese*, 2004, vol. 141, pp. 1-44.

LEWIS, D. 1969. *Convention*. Cambridge, Mass.: Harvard University Press.

MARSDEN, Heather 2004. Quantifier scope in non-native Japanese: A comparative interlanguage study of Chinese, English, and Korean-speaking learners. Ph.D. dissertation, University of Durham.

MAYNARD-SMITH, J. 1982. *Evolution and the theory of games*. Cambridge (UK): Cambridge University Press.

MAYNARD-SMITH, J. and PRICE, G. 1973. The logic of animal conflict. *Nature*, 1973, vol. 246, pp. 15-18.

NASH, John 1950. Equilibrium points in n-person games. *Proceedings of the National Academy of Sciences*, 1950, vol. 36, pp. 48-9.

PARIKH, Prashant 1991. Communication and strategic inference. *Linguistics and philosophy* 1991, vol. 14, pp. 473-513.

PARIKH, Prashant 2000. Communication, meaning, and interpretation. *Linguistics and philosophy* 2000, vol. 23, pp. 185-212.

Potts, C., 2008. Interpretive economy, Schelling points, and evolutionary stability. Ms., Stanford Semantics Group. UMass: Amherst.

RASMUSEN, Eric 2007. *Games and information: an introduction to game theory*, 4th ed. Malden, Mass.: Blackwell.

SCHELLING, T. 1960. *The strategy of conflict*. Cambridge, Mass.: Harvard University Press.

SIGMUND, K. 1993. *Games of life: explorations in ecology, evolution and behavior*. Oxford: Oxford University Press.

VON NEUMANN, J. and MORGENSTERN, O. 1944. *Theory of games and economic behavior*. Princeton, New Jersey: John Wiley & Sons.

VAN ROOY, Robert 2004. Signalling games select Horn strategies. *Linguistics and philosophy*, 2004, vol. 27, pp. 493-527.

WÄRNERYD, K. 1993. Cheap talk, coordination and evolutionary stability. *Games and economic behavior*, 1993, vol. 5, pp. 532-46.

ZIPF, G. K. 1949. *Human behavior and the principle of least effort*. Cambridge, Mass.: Addison-Wesley.

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