

Formalizing the Pragmatics of Metaphor Understanding

Justine T. Kao¹ (justinek@stanford.edu), Leon Bergen² (bergen@mit.edu), Noah D. Goodman¹ (ngoodman@stanford.edu)
¹Department of Psychology, Stanford University. ²Department of Brain and Cognitive Science, MIT.

Abstract

While the ubiquity and importance of nonliteral language are clear, people's ability to use and understand it remains a mystery. Metaphor in particular has been studied extensively across many disciplines in cognitive science. One approach focuses on the pragmatic principles that listeners utilize to infer meaning from metaphorical utterances. While this approach has generated a number of insights about how people understand metaphor, to our knowledge there is no formal model showing that effects in metaphor understanding can arise from basic principles of communication. Building upon recent advances in formal models of pragmatics, we describe a computational model that uses pragmatic reasoning to interpret metaphorical utterances. We conduct behavioral experiments to evaluate the model's performance and show that our model produces metaphorical interpretations that closely fit behavioral data. We discuss implications of the model for metaphor understanding, principles of communication, and formal models of language understanding.

Keywords: language understanding; metaphor; pragmatics; computational models

Introduction

From "Juliet is the sun" to "That woman is a bombshell," nonliteral language is, quite literally, everywhere. Metaphor, hyperbole, and sarcasm are ubiquitous features of human communication, often creating poetic or humorous effects that add rich dimensions to language (Glucksberg, 2001; Pilkinson, 2000; Lakoff & Turner, 2009; Roberts & Kreuz, 1994). Metaphor has inspired a particularly large amount of research in cognitive science, spanning topics such as how metaphors structure and shape our thoughts (Ortony, 1993; Lakoff et al., 1993; Thibodeau & Boroditsky, 2011), whether metaphor processing recruits the same strategies as standard language processing (Giora, 1997; Gibbs, 2002; Glucksberg & Keysar, 1993) and what factors determine people's interpretation of a novel metaphor (Gentner & Wolff, 1997; Blasko & Connine, 1993; Tourangeau & Sternberg, 1981; Kintsch & Bowles, 2002). This overwhelming interest in metaphor research is due to both the ubiquity of metaphor in everyday language and the potential role of metaphor for helping us understand how the mind creates meaning.

One approach to studying metaphor focuses on the pragmatic principles that listeners utilize to infer meaning from metaphorical utterances (Tendahl & Gibbs, 2008). Rather than view metaphor as a separate mode of communication that requires specialized language processing strategies, this approach argues that basic principles of communication drive the meaning that a listener infers from a metaphor (Sperber & Wilson, 2008; Wilson & Carston, 2006). Relevance theory, in particular, posits that listeners interpret utterances with the assumption that speakers produced them because they are maximally relevant (Wilson & Sperber, 2002). Relevance

theorists argue that this principle explains how listeners infer the meaning of a novel metaphor as well as other forms of loose talk where the meaning of an utterance is underspecified (Sperber & Wilson, 1985). When interpreting the metaphor "My lawyer is a shark," for example, the listener assumes that the speaker aims to communicate features of "a shark" that are relevant to the person under discussion ("my lawyer") and do not make use of other shark features—*vicious* but not *has fins* or *swims*.

While many linguists and psychologists have argued for the benefits of studying metaphor using a pragmatics framework, to our knowledge there is no formal model showing that effects in metaphor understanding may arise from basic principles of communication. On the other hand, a recent body of work presents a series of computational models for pragmatic reasoning, where speaker and listener reason about each other to communicate effectively (Frank & Goodman, 2012; Jäger & Ebert, 2009). By formalizing principles of communication, these models are able to make quantitative predictions about a range of phenomena in language understanding, such as scalar implicature and the effect of alternative utterances (Goodman & Stuhlmüller, 2013; Bergen, Goodman, & Levy, 2012). However, a limitation of these models is that they are unable to explain the use of utterances which are known to have false literal interpretations. More recent work extends these models to consider affective goals in communication that may be optimally satisfied by nonliteral utterances such as hyperbole (under review). In this paper, we will be considering the role of communicative goals in the interpretation of metaphorical utterances. In our formalization, a listener assumes that the speaker chooses an utterance to maximize informativeness about a subject along dimensions that are relevant to the conversation and consistent with the speaker's communicative goal. This makes it possible for a literally false utterance to be optimal as long as it is informative along the target dimension. Our framework closely aligns with the relevance-theoretic view that a listener considers the relevance of a potential meaning to the speaker's goal in order to infer what the speaker intended to communicate.

To reasonably limit the scope of our work, we focus on metaphors of the classic form "X is a Y." We describe a computational model that can interpret such sentences metaphorically and conduct behavioral experiments to evaluate the model's performance. We show that peoples' interpretations of metaphors are driven by conversational context and that our model captures this effect. Finally, we show that our model predictions correlate significantly with people's fine-grained interpretations of metaphorical utterances.

Computational Model

In the basic Rational Speech Act model of (Frank & Goodman, 2012; Goodman & Stuhlmüller, 2013), a listener and a speaker recursively reason about each other to arrive at pragmatically enriched meanings. Given an intended meaning, a speaker reasons about a literal listener and chooses an utterance based on its informativeness. A pragmatic listener then reasons about the speaker and uses Bayes' rule to infer the meaning given the utterance. To account for nonliteral interpretation, we extend this model by considering the idea that a speaker may have a range of different communicative goals. Intuitively, an utterance is optimally informative and relevant if it satisfies the speaker's communicative goal. Since the speaker's precise communicative goal may be unknown to the listener, the listener performs joint inference on the goal as well as the intended meaning. By introducing multiple potential goals for communication, we open up the possibility for a speaker to produce an utterance that is literally false but still satisfies her goal. The speaker achieves this in part by exploiting her own and the listener's prior knowledge—their common ground (Clark, 1996)—to reason about what information the listener would gain if he takes the utterance literally.

To illustrate this idea more concretely and demonstrate how it is implemented in our model, we will use the metaphor “John is a shark” as an example. For simplicity, in this model we restrict the number of possible categories to which a member may belong to c_a and c_p , denoting an animal category or a person category, respectively. We also restrict the possible features of John under consideration to a vector of size three: $\vec{f} = [f_1, f_2, f_3]$, where f_i is either 0 or 1 (for example, the three features could be scary, sleek, and finned).¹ The literal listener L_0 will interpret the utterance “John is a shark” as meaning that John is literally a member of the category “shark” and has corresponding features. Formally, if u is the uttered category:

$$L_0(c, \vec{f}|u) = \begin{cases} P(\vec{f}|c) & \text{if } c = u \\ 0 & \text{otherwise} \end{cases}$$

where $P(\vec{f}|c)$ is the prior probability that a member of category c (in this case “shark” or “person”) has feature vector \vec{f} .

We assume that the speaker's goal is to communicate the value of a particular feature—a goal is thus a projection from the full feature space to the subset of interest to the speaker. Formally, the goal to communicate about feature $i \in \{1, 2, 3\}$ is the function $g_i(\vec{f}) = f_i$. Following the Rational Speech Act model, we define the speaker's utility as the negative surprisal of the true state under the listener's distribution, given an utterance. However, here we consider only the surprisal along the goal dimension. To do so we project along the goal dimension, which leads to the following utility function for

¹In principle the model can be extended to accommodate more categories and features.

speaker S_1 :

$$U(u|g, \vec{f}) = \log \sum_{c, \vec{f}'} \delta_{g(\vec{f})=g(\vec{f}')} L_0(c, \vec{f}'|u) \quad (1)$$

Given this utility function, the speaker chooses an utterance according to a softmax decision rule that describes an approximately rational planner (Sutton & Barto, 1998):

$$S_1(u|g, \vec{f}) \propto e^{\lambda U(u|g, \vec{f})}, \quad (2)$$

where λ is an optimality parameter.

Imagine that S_1 had the goal to convey f_1 , scariness, about John. Based on S_1 's understanding of L_0 's prior knowledge, she knows that if she produces the utterance “John is a shark,” L_0 will believe that John is literally a shark and hence very likely to be *scary*. Since S_1 's goal is satisfied if the listener believes that John is scary, S_1 is motivated to produce such a metaphorical utterance. A pragmatic listener, however, should be able to leverage this pattern to infer that John is scary without inferring that John is actually a shark.

The listener L_1 performs Bayesian inference to guess the intended meaning given prior knowledge and his internal model of the speaker. To determine the speaker's intended meaning, L_1 will marginalize over the possible speaker goals under consideration:

$$L_1(c, \vec{f}|u) \propto P(c)P(\vec{f}|c) \sum_g P(g)S_1(u|g, \vec{f})$$

While speaker and listener could continue to reason about each other recursively, resulting in L_n , we restrict ourselves to L_1 for present purposes. Past work has shown that this first level of pragmatic reasoning is often a good model of human comprehension.² If listener L_1 thinks it is likely that speaker S_1 's goal is to convey scariness but believes it is *a priori* very unlikely that John is actually a shark, she will determine that S_1 is using shark metaphorically—that John is a scary person.

Based on this formulation, the listener needs to consider the following prior probabilities to arrive at an interpretation:

- (1) $P(c)$: the prior probability that the entity discussed belongs to category c . We assume that the listener is extremely confident that the person under discussion (e.g. John) is a person, but that there is a non-zero probability that John is actually a non-human animal. We fit $P(c_a)$ to data with the assumption that $10^{-4} \leq P(c_a) \leq 10^{-1}$.
- (2) $P(\vec{f}|c)$: the prior probability that a member of category c has feature values \vec{f} . This is empirically estimated in Experiment 1.
- (3) $P(g)$: the probability a speaker has goal g . This prior can change based on the conversational context that a question

²The current model does not robustly predict metaphorical interpretations at recursion depths greater than 1. Future work will investigate which features of the model lead to this prediction, and whether this remains true under alternative model definitions.

Animal	$f_1 = 1$	$f_2 = 1$	$f_3 = 1$	$f_1 = 0$	$f_2 = 0$	$f_3 = 0$	Animal	$f_1 = 1$	$f_2 = 1$	$f_3 = 1$	$f_1 = 0$	$f_2 = 0$	$f_3 = 0$	
ant	small	strong	busy	large	weak	idle	goose	loud	mean	annoying	quiet	nice	weak	agreeable
bat	scary	blind	nocturnal	unalarming	sighted	diurnal	horse	fast	strong	beautiful	slow	weak	ugly	
bear	scary	big	fierce	unalarming	small	nonviolent	kangaroo	jumpy	bouncy	cute	relaxed	inelastic	unattractive	
bee	busy	small	angry	idle	large	unangry	lion	ferocious	scary	strong	nonviolent	unalarming	weak	
bird	free	graceful	small	unfree	awkward	large	monkey	funny	smart	playful	humorless	stupid	unplayful	
buffalo	big	strong	wild	small	weak	tame	owl	wise	quiet	nocturnal	foolish	loud	diurnal	
cat	independent	lazy	soft	dependent	fast	hard	penguin	strong	big	slow	weak	small	fast	
cow	fat	dumb	lazy	thin	smart	fast	pig	cold	cute	funny	hot	unattractive	humorless	
dog	loyal	friendly	happy	disloyal	unfriendly	unhappy	rabbit	dirty	fat	smelly	clean	thin	fragrant	
dolphin	smart	friendly	playful	stupid	unfriendly	unplayful	shark	scary	furry	cute	slow	hairless	unattractive	
duck	loud	cute	quacking	quiet	unattractive	non-quacking	sheep	dangerous	mean	unalarming	safe	hard	nice	
elephant	huge	smart	heavy	small	stupid	light	tiger	woolly	fluffy	dumb	hairless	hard	smart	
fish	scaly	wet	smelly	smooth	dry	fragrant	whale	striped	fierce	scary	unpatterned	nonviolent	unalarming	
fox	sly	smart	pretty	artless	stupid	ugly	wolf	large	graceful	majestic	small	awkward	inferior	
frog	slimy	noisy	jumpy	nonslippery	quiet	relaxed	zebra	scary	mean	angry	unalarming	nice	native	unangry
goat	funny	hungry	loud	humorless	full	quiet							slow	

Table 1: 32 animal categories, feature adjectives, and their antonyms. Feature adjectives were elicited from Experiment 1a and indicate when a feature is present ($f_i = 1$). Antonyms were generated using WordNet and indicate when a feature is not present ($f_i = 0$). Feature sets shown in Experiment 1b were created with this table, where $\vec{f} = [1, 0, 0]$ for category “ant” is represented by the words {small, weak, idle}. There are $2^3 = 8$ possible feature combinations for each animal category.

sets up. For example, if the speaker is responding to a vague question about John, e.g. “What is John like?”, the prior over goals is uniform. If the question targets a specific features, such as “Is John scary?”, then she is much more likely to have the goal of communicating John’s scariness. However, she may still want to communicate other features about John that were not asked about. We assume that when the question is specific, the prior probability that S_n ’s goal is to answer the specific question is greater than 0.5, fitting the value to data below.

Behavioral Experiments

To evaluate our model’s interpretation of metaphorical utterances, we focused on a set of 32 metaphors comparing human males to different non-human animals. We conducted Experiment 1a and 1b to elicit feature probabilities for the categories of interest. We then conducted Experiment 2 to measure people’s interpretations of the set of metaphors.

Experiment 1a: Feature Elicitation

Materials We selected 32 common non-human animal categories from an online resource for learning English (www.englishclub.com). The full list is shown in Table 1.

Methods 100 native English speakers with IP addresses in the United States were recruited on Amazon’s Mechanical Turk. Each participant read 32 animal category names presented in random order, e.g. “whale”, “ant”, “sheep”. For each animal category, participants were asked to type the first adjective that came to mind in a text box.

Results Using participants’ responses, we constructed a list of adjectives for each animal category and ordered them by the number of times they were given by a different subject (i.e. their popularity). We removed all color adjectives, such as “white” and “black,” to eliminate the possibility of interpreting these adjectives as racial descriptions. To avoid redundancy in the feature set, we used WordNet (Miller, 1995) to identify synonymous adjectives and only kept the most

popular adjective among a set of synonyms. We then took the three most popular adjectives for each animal category and used them as the set of features. In what follows, f_1 is the most popular adjective, f_2 the second, and f_3 the third. Table 1 shows the animal categories and their respective features.

Experiment 1b: Feature Prior Elicitation

Materials Using the features collected from Experiment 1a, we elicit the prior probability of a feature vector given an animal or person category (i.e. $P(\vec{f}|c)$). We assume that the adjective corresponding to a feature (e.g. *scary*) indicates that the value of that feature is 1 (present), while the adjective’s antonym indicates that the value of that feature is 0 (not present). We used WordNet to construct antonyms for each of the adjective features produced in Experiment 1a. When multiple antonyms existed or when no antonym could be found on WordNet, the first author used her judgment to choose the appropriate antonym. Table 1 shows the resulting list of antonyms. For each animal category, eight possible feature combinations were constructed from the three features and their antonyms. For example, the possible feature combinations for a member of the category “ant” are {small, strong, busy}, {small, strong, idle}, {small, weak, busy}, and so on.

Methods 60 native English speakers with IP addresses in the United States were recruited on Amazon’s Mechanical Turk. Each participant completed 16 trials in random order. Each trial consisted of the eight feature combinations for a particular animal category. Using slider bars with ends marked by “Impossible” and “Absolutely certain,” participants were asked to rate how likely it is for a member of the animal category to have each of the eight feature combinations. Participants also rated the probabilities of the feature combinations for a male person. We only elicited priors for males to minimize gender variation and to maintain consistency with Experiment 2.

Results We normalized each participant’s ratings for the eight feature combinations in a trial to sum up to 1 based

on the assumption that the feature combinations exhaustively describe a member of a particular category. Using the Spearman-Brown prediction equation, reliability of the ratings was 0.941 (95% CI = [0.9408, 0.9414]). Averaging across participants' normalized ratings, we obtained feature priors $P(f|c)$ for $c = c_a$ (animal) and $c = c_p$ (person). Since the features were created using the animal categories in Experiment 1a, by construction features are rated as significantly more likely to be present in the animal category than in the person category ($F(1, 190) = 207.1, p < 0.0001$). These results confirm that participants are fairly confident that each animal category has certain distinguishing features (mean = 0.61, $sd = 0.06$), while those same features are rated as appearing in people less often (mean = 0.48, $sd = 0.06$).

Experiment 2: Metaphor Understanding

Materials We created 32 scenarios based on the animal categories and results from Experiment 1. In each scenario, a person (e.g. Bob) is having a conversation with his friend about a person that he recently met. Since we are interested in how the communicative goals set up by context affect metaphor interpretation as well as the effectiveness of metaphorical versus literal utterances, we created four conditions for each scenario by crossing vague/specific goals and literal/metaphorical utterances. In vague goal conditions, Bob's friend asks a vague question about the person Bob recently met: "What is he like?" In specific goal conditions, Bob's friend targets f_1 and asks a specific question about the person: "Is he f_1 ?", where f_1 is the most popular adjective for a given animal category c_a . In literal conditions, Bob replies with a literal utterance, either by saying "He is f_1 ." to the question "What is he like?" or "Yes." to the question "Is he f_1 ?". In Metaphorical conditions, Bob replies with a metaphorical statement, e.g. "He is a c_a ," where c_a is an animal category. See Table 2 for examples of each condition.

Goal	Utterance	Example question	Example utterance
Vague	Literal	"What is he like?"	"He is scary."
Specific	Literal	"Is he scary?"	"Yes."
Vague	Metaphorical	"What is he like?"	"He is a shark."
Specific	Metaphorical	"Is he scary?"	"He is a shark."

Table 2: Example scenarios given the four experimental conditions in Experiment 2.

Methods 49 native English speakers with IP addresses in the United States were recruited on Amazon's Mechanical Turk. Each participant completed 32 trials in random order. The 32 trials were randomly and evenly assigned to one of the four conditions, i.e. each participant read 8 scenarios for each condition. For each trial, participants used sliders to indicate the probabilities that the person described has features f_1 , f_2 , and f_3 , respectively.

Results For each condition of each scenario, we obtained the average probability ratings for the three features. Fig-

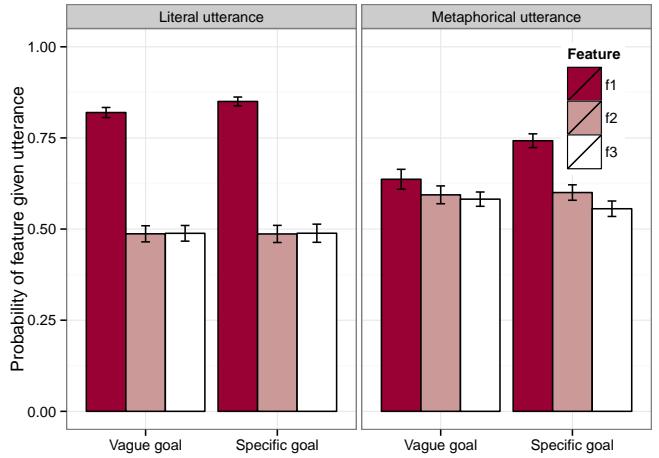


Figure 1: Average probability ratings for the three features given a vague/specific goal and a literal/metaphorical utterance. Error bars are standard error over the 32 items.

ure 1 shows the average ratings for each feature across animal categories given a vague or specific goal and a literal or metaphorical utterance. When the speaker gives a literal statement directly affirming the presence of f_1 , participants rate f_1 as significantly more likely than when the speaker gives a metaphorical statement ($F(1, 126) = 52.6, p < 0.00001$). However, participants rate f_2 and f_3 as significantly more likely when the speaker produces a metaphorical utterance than when the utterance is literal ($F(1, 126) = 23.7, p < 0.0001$; $F(1, 126) = 13.66, p < 0.0005$). Comparing feature probability ratings in Experiment 2 to the feature priors obtained in Experiment 1b, we can measure how literal and metaphorical utterances change listeners' inferences about a person's features. Given a literal utterance that directly confirms the existence of f_1 , probability ratings for f_1 are significantly higher than the prior probabilities of f_1 for a person ($t(63) = 59.19, p < 0.00001$). However, probability ratings for f_2 and f_3 are not significantly different from their prior probabilities ($t(63) = -0.13, p = 0.89$; $t(63) = 0.03, p = 0.97$). Given a metaphorical utterance, probability ratings for all three features are significantly higher than the prior probabilities ($t(63) = 15.74, p < 0.0001$; $t(63) = 7.29, p < 0.0001$; $t(63) = 5.91, p < 0.0001$). While preliminary, this analysis suggests that metaphorical utterances may convey richer information and update listeners' beliefs along more dimensions than literal utterances.

We now analyze the effect of the speaker's communicative goal on the interpretation of literal or metaphorical utterances. When the speaker's utterance is literal, the probability ratings for f_1 , f_2 , and f_3 are not significantly different given a vague or a specific question ($F(1, 62) = 2.73, p = 0.1$; $F(1, 62) = 0.0001, p = 0.99$; $F(1, 62) < 0.0001, p = 0.99$). For metaphorical utterances, however, the question type has an effect on participants' interpretations: partici-

participants rate the probability of f_1 as significantly higher when the question is specifically about f_1 than when it is vague ($F(1, 62) = 10.16, p < 0.005$). The probabilities of f_2 and f_3 are not significantly different given a vague question or a specific question about f_1 ($F(1, 62) = 0.04, p > 0.05$; $F(1, 62) = 0.8285, p > 0.05$). This suggests that people's interpretation of metaphor may be more sensitive to the communicative goals set up by context than their interpretation of literal utterances.

Model Evaluation

We used the feature priors obtained in Experiment 1b to compute model interpretations of the 32 metaphors. As discussed in the previous section, the behavioral results in Experiment 2 show evidence that the context set up by a question changes participants' interpretation of a metaphor. Our model naturally accounts for this using the speaker's prior over communicative goals $P(g)$. When a speaker is responding to a vague question, we set the prior distribution for $P(g)$ as uniform. When the speaker is responding to a question specifically about f_1 , we assume that $P(g_1) > 0.5$ and equal between $P(g_2) = P(g_3)$. Fitting the goal prior parameter to data yields a prior of $P(g_1) = 0.6$ when responding to a specific question about f_1 . We fit the category prior $P(c_a) = 0.01$ and the speaker optimality parameter $\lambda = 3$.

Using these parameters, we obtained interpretation probabilities for each of the 32 metaphors under both vague and specific goal conditions. For each metaphor and goal condition, the model produces a joint posterior distribution $P(c, \vec{f}|u)$. We first show a basic but important qualitative result, which is that the model is able to interpret utterances metaphorically. Marginalized over values of \vec{f} , the probability of the person category given the utterance is close to one ($P(c_p|u) = 0.994$), indicating that the pragmatic listener successfully infers that the person described as an animal is actually a person and not an animal. This shows that the model is able to combine prior knowledge and reason about the speaker's communicative goal to arrive at nonliteral interpretations of utterances.

We now turn to the second component of the interpretation, $P(\vec{f}|u)$. To quantitatively evaluate the model's performance, we correlated model predictions with human interpretations of the metaphorical utterances. Given a metaphorical utterance and a vague or specific goal condition, we computed the model's marginal posterior probabilities for f_1, f_2 , and f_3 . We then correlate these posterior probabilities with participants' probability ratings from Experiment 2. Figure 2 plots model interpretations for all metaphors, features, and goal conditions against human judgments. Correlation across the 192 items (32 metaphors \times 3 features \times 2 goal conditions) is 0.6 ($p < 0.001$). The predicted reliability of participants' ratings using the Spearman-Brown prediction formula is 0.828 (95% CI = [0.827, 0.829]), suggesting first that people do not agree perfectly on metaphorical interpretations, and second that our model captures a significant amount of the reliable variance in

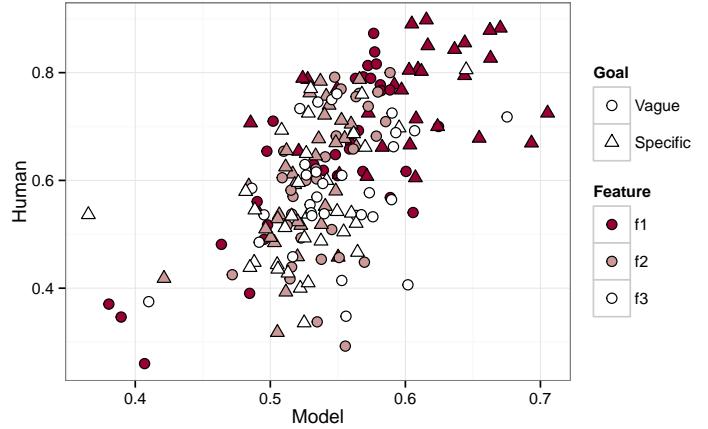


Figure 2: Model predictions (x axis) vs participants' probability ratings (y axis) for 192 items (32 metaphors \times 3 features \times 2 goal conditions). Shape of points indicates goal condition and color indicates feature number.

the behavioral data. In particular, our model does especially well at predicting participants' judgments of f_1 , which are the most salient features of the animal categories and were targeted by specific questions in Experiment 2. Correlation between model predictions and human judgments for f_1 is 0.7 ($p < 0.0001$), while the predicted reliability of participants' ratings for f_1 is 0.82 (95% CI = [0.818, 0.823]).

We now compare our model's performance to a baseline model that also considers the feature priors and the conversational context. We constructed a linear regression model that takes the marginal feature priors for the animal category, the marginal feature priors for the person category, and the vague or specific goal as predictors of participants' ratings. With four parameters, this model produced a fit of $r = 0.45$, which is significantly worse than our model ($p < 0.0001$ on a Cox test). This suggests that our computational model adequately combines people's prior knowledge as well as principles of pragmatics to produce metaphorical interpretations that closely fit behavioral data.

While our model predictions provide a close fit to behavioral data, some residual variance can be further addressed. Previous work has shown that alternative utterances—what the speaker could have said—can strongly affect listeners' interpretation of what the speaker *did* say (Bergen et al., 2012). Our model currently does not take into account the range of alternative utterances (both literal and metaphorical) that a listener considers when interpreting a speaker's utterance. We posit that this may account for some of the variance in the data that our model does not capture. Consider the metaphor "He is an ant" and the corresponding features *small*, *strong*, and *busy*. Our model currently assigns a high probability to the feature *strong* given the metaphor, while participants assign it a lower probability. Indeed, this data point has the highest residual in our model fit. To demonstrate that alternative

utterances may account for this discrepancy, we construct a model that has “He is an ox” as an alternative utterance. “Ox” has features that roughly align with the features of “ant”: *strong*, *big*, and *slow*. Since *strong* is a higher probability feature for “ox” than for “ant,” the listener reasons that if the speaker had intended to communicate the feature *strong*, she would have said “He is an ox” since it optimally satisfies that goal. Since the speaker did *not* produce the utterance “He is an ox,” the listener infers that *strong* is a less probable feature. Adding this alternative utterance to the model indeed lowers the marginal posterior probability of *strong* given the utterance “He is an ant.” As a result, we posit that adding alternative utterances across all animal categories may significantly improve model performance. Constructing a complete set of alternative utterances using our current set of metaphors is not possible because feature combinations are not aligned across animal categories (i.e., different animal categories have different feature sets, and not all features are shared by multiple animals). We aim to address the role of alternative utterances more specifically in future work.

Discussion

We have presented a computational model that predicts rich metaphorical interpretations using general communicative principles. Besides going beyond the literal meaning of an utterance to infer non-literal interpretations (e.g., John is a person and not a shark), our model provides quantitative judgments about the person’s features (e.g., John is very likely scary, dangerous, and mean). Furthermore, behavioral results show that the interpretation of a metaphor is shaped in part by the conversational context, which our model naturally accounts for using communicative goals. Together these results suggest that basic principles of communication may be an important driver of metaphor understanding.

Our model captures several intuitions about communication, including the importance of common ground between listener and speaker, the context-dependence of communicative goals, and the idea that speakers choose to produce utterances that maximize informativeness about features relevant to their communicative goal. Each of these components inspire research questions that can be further investigated using both our modeling framework and experimental paradigm. For example, are listeners less likely to interpret an utterance metaphorically when there is little common ground between speaker and listener? What additional communicative goals are metaphors able to satisfy more effectively than literal utterances? We aim to address these questions in future research to further clarify how communication principles interact to produce metaphorical meaning. In addition, previous work has shown that conventional metaphors such as “He is a pig” may be processed differently from novel metaphors (Bowdle & Gentner, 2005), which introduces a set of interesting questions to investigate with our model. We believe that our computational framework advances understanding of the computational basis of metaphor and of communication more

generally, and we hope that it will continue to shed metaphorical light on related questions.

Acknowledgments

This work was supported in part by NSF Graduate Research Fellowships to JTK and LB and by a John S. McDonnell Foundation Scholar Award and grants from the ONR to NDG.

References

Bergen, L., Goodman, N. D., & Levy, R. (2012). Thats what she (could have) said: How alternative utterances affect language use. In *Proceedings of the thirty-fourth annual conference of the cognitive science society*.

Blasko, D. G., & Connine, C. M. (1993). Effects of familiarity and aptness on metaphor processing. *Journal of experimental psychology: Learning, memory, and cognition*, 19(2), 295.

Bowdle, B. F., & Gentner, D. (2005). The career of metaphor. *Psychological review*, 112(1), 193.

Clark, H. H. (1996). *Using language* (Vol. 4). Cambridge University Press Cambridge.

Frank, M. C., & Goodman, N. D. (2012). Predicting pragmatic reasoning in language games. *Science*, 336(6084), 998–998.

Gentner, D., & Wolff, P. (1997). Alignment in the processing of metaphor. *Journal of memory and language*, 37(3), 331–355.

Gibbs, R. (2002). A new look at literal meaning in understanding what is said and implicated. *Journal of Pragmatics*, 34(4), 457–486.

Giora, R. (1997). Understanding figurative and literal language: The graded salience hypothesis. *Cognitive Linguistics*, 8, 183–206.

Glucksberg, S. (2001). *Understanding figurative language: From metaphors to idioms*. Oxford University Press.

Glucksberg, S., & Keysar, B. (1993). How metaphors work.

Goodman, N. D., & Stuhlmüller, A. (2013). Knowledge and implicature: Modeling language understanding as social cognition. *Topics in cognitive science*, 5(1), 173–184.

Jäger, G., & Ebert, C. (2009). Pragmatic rationalizability. In *Proceedings of Sinn und Bedeutung* (Vol. 13, pp. 1–15).

Kintsch, W., & Bowles, A. R. (2002). Metaphor comprehension: What makes a metaphor difficult to understand? *Metaphor and symbol*, 17(4), 249–262.

Lakoff, G., et al. (1993). The contemporary theory of metaphor. *Metaphor and thought*, 2, 202–251.

Lakoff, G., & Turner, M. (2009). *More than cool reason: A field guide to poetic metaphor*. University of Chicago Press.

Miller, G. A. (1995). Wordnet: A lexical database for english. *COMMUNICATIONS OF THE ACM*, 38, 39–41.

Ortony, A. (1993). *Metaphor and thought*. Cambridge University Press.

Pilkington, A. (2000). *Poetic effects: A revelance theory perspective* (Vol. 75). John Benjamins.

Roberts, R. M., & Kreuz, R. J. (1994). Why do people use figurative language? *Psychological Science*, 5(3), 159–163.

Sperber, D., & Wilson, D. (1985). Loose talk. In *Proceedings of the aristotelian society* (Vol. 86, pp. 153–171).

Sperber, D., & Wilson, D. (2008). A deflationary account of metaphors. *The Cambridge handbook of metaphor and thought*, 84–105.

Sutton, R. S., & Barto, A. G. (1998). *Reinforcement learning: An introduction* (Vol. 1) (No. 1). Cambridge Univ Press.

Tendahl, M., & Gibbs, R. W. (2008). Complementary perspectives on metaphor: Cognitive linguistics and relevance theory. *Journal of Pragmatics*, 40(11), 1823–1864.

Thibodeau, P. H., & Boroditsky, L. (2011). Metaphors we think with: The role of metaphor in reasoning. *PLoS One*, 6(2), e16782.

Tourangeau, R., & Sternberg, R. J. (1981). Aptness in metaphor. *Cognitive psychology*, 13(1), 27–55.

Wilson, D., & Carston, R. (2006). Metaphor, relevance and the emergent property issue. *Mind & Language*, 21(3), 404–433.

Wilson, D., & Sperber, D. (2002). Relevance theory. *Handbook of pragmatics*.