Understanding the psychological sources of communicative behavior

Imagine that I showed you a ball and a novel object, and asked you to choose the "dax" (Figure 1a). You would likely choose the novel object (Markman & Wachtel, 1988). But what is the source of this judgment? Is it the pragmatic (contextual) inference that because I used a word that you didn't know, I was likely referring to the novel object? Or is it instead the lexical (context-independent) inference that because I know the word for the concept ball and most concepts have only one word to refer to them, the novel word likely matched the novel object?

Now consider a second scenario: two novel objects, a simple one and a complex one (Figure 1b). I ask you to choose the "gabu" and the "tupabugorn." You would likely match the longer label to the more complex object (Lewis & Frank, under review). This judgment has the same inherent ambiguity. Did you reason pragmatically — that I as a speaker was likely to choose a longer expression to talk about something more complex, unusual, or marked? Or did you reason in a context-independent way, that across the lexicon, longer words tend statistically to have meanings that are more complex?

Both of the scenarios described above illustrate a property of human communicative behavior: Any act of communication is supported both by our context-dependent, pragmatic abilities and communicative biases encoded in the structure of language. To understand the psychological basis of these behaviors, we must disentangle these supports empirically. In this paper, we explore the nature of this empirical challenge, the evidence for its existence in each of the case studies we described, and a potential way forward.

At Marr's computational level of analysis, a description of the listener's problem is straight forward: map a linguistic form to its intended meaning (Marr, 1982). An algorithmic account of this problem is more challenging, however. This is because there are multiple cognitive supports to the correct linguistic inference. These supports are distinguishable by the timescales of the information sources they rely on (McMurray, Horst, & Samuelson, 2012). One support is a pragmatic inference based on knowledge of the speaker's intended referent. This support relies only on information that is available in the moment of reference ("pragmatic timescale"). A second support is based on knowledge of the lexicon, where the lexicon is defined as a set of mappings between words and concepts. Lexical knowledge relies on information that is acquired over years of speaking language ("lexical timescale").

The empirical challenge is thus: For any act of reference, multiple cognitive supports, each relying on information operating over different timescales, could support the same linguistic inference. Because we can only observe the behavioral act of reference, it is difficult to tease apart the relative contributions of these supports empirically.[1] Importantly, although an empirical challenge, hypotheses about psychological supports of communicative behavior are not a priori mutually exclusive.

Historically, the presence of communicative structure in the lexicon was not considered as a major source of inferential behavior, but recent work motivates reconsidering this possibility.

[1] A similar issue of the relative contributions of cognitive supports has received recent attention in the language processing literature (e.g., Hanna & Tanenhaus, 2004; Barr, in press).

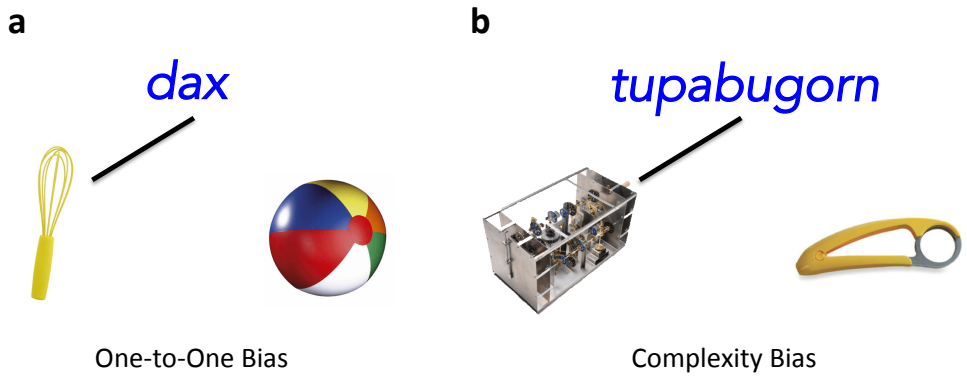

Figure 1: Two communicative biases.

Using an information theoretic framework, this work finds that the structure of the lexicon is optimized to facilitate the communicative goal of language — from the presence of lexical ambiguity (Piantadosi, Tily, & Gibson, 2011) to the organization of semantic domains (Kemp & Regier, 2012). There are several ways to account for this finding, but one parsimonious explanation is a theory that posits a causal link between the pragmatic and lexical timescales. That is, a theory suggesting that in-the-moment pragmatic inferences, over time, lead to a lexicon that reflects communicative structure. However, like in the case of individual acts of reference, theories of the origins of lexical structure are limited by our ability to distinguish between multiple causal forces operating over different timescales.

Below, we consider research exploring the psychological basis of the two communicative behaviors described above: a bias to map a novel word onto a novel object ("a one-to-one bias") and a bias to map a longer word onto a relatively more complex object ("a complexity bias"). We conclude by considering hierarchical models as a solution for linking the two timescales in a single framework.

One-to-One Bias

A one-to-one behavioral bias is supported by both a pragmatic inference (Clark, 1987, 1988) and a lexical constraint (Markman & Wachtel, 1988). To disentangle these two possible supports, the research strategy has been to study the bias in experimental contexts in which the alternative support is unavailable. For example, the bias has been observed in the context of facts about objects (instead of labels), providing evidence that a pragmatic support is sufficient to give rise to the bias (Diesendruck & Markson, 2001). Similarly, the bias has been observed in children who have pragmatic impairments, providing evidence that a lexical support is sufficient for the bias (Preissler & Carey, 2005). However, this type of evidence is critically limited because the experimental context differs in important ways from the contexts researchers aim to generalize to. Thus, while there is evidence that neither support is necessary for a one-to-one bias, no work addresses the question of the relative contributions of these different supports in typical referential contexts.

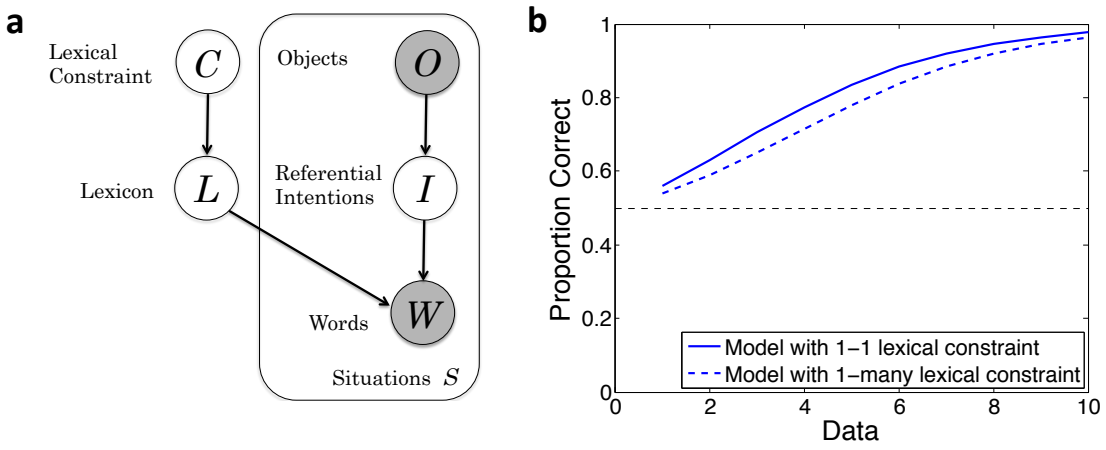

Figure 2: (a) Generative process of the Lewis & Frank (2013) model, adopted from M. Frank, Goodman, and Tenenbaum (2009). (b) A simulation in which the model is tested in a mutual exclusivity task with either a 1-1 or 1-many lexical constraint.

Complexity Bias

There is recent evidence that adults and children have a bias to map a relatively long novel word to a relatively complex object in a referential communication task (Lewis & Frank, under review). In addition, we find evidence that this bias is present in the structure of the lexicon. This behavioral bias is predicted by theories of communication that suggest that speakers should reason in the moment that longer utterances should be associated with less predictable, and arguably more complex, meanings (Horn, 1984; A. Frank & Jaeger, 2008). Given that this bias is also present in the structure of the lexicon, a behavioral complexity bias is also supported by lexical knowledge. Thus, as for the one-to-one bias, the complexity bias is supported by information at both the pragmatic and lexical timescales. The current data cannot speak to the relative contributions of each.

Solutions to this empirical challenge

These two behavioral phenomena — a one-to-one bias and a complexity bias — provide two examples of instances in which supports at two timescales are consistent with the observable data. How can we study the relative contributions of these two supports?

One strategy is to rely on neurological correlates of these supports. Using this strategy, researchers might examine brain activation patterns of participants completing a referential communication task, and then use reverse inference to identify the pattern associated with each support (Poldrack, 2011). However, the utility of this approach is severely limited by the need to find unique and dissociable signatures for the two supports, and the ability to observe graded activation in the two signatures.

We suggest hierarchical Bayesian modeling as an alternative, particularly promising approach. The key feature of this approach is that it captures inferences at both the pragmatic and lexical timescales. In other work (Lewis & Frank, 2013), this approach has been used to begin to model

the one-to-one bias. The generative process of the model is presented in Figure 2a. Words are assumed to be generated by intentions. This feature allows the model to jointly solve the problems of mapping a word to an object in ambiguous contexts and learning a long term mapping between a word and concept. In addition, lexicons are assumed to be generated from a space of lexicons with different constraints on their structures. This allows the model to learn that the lexicon has a one-to-one structure between words and concepts as opposed to other possible structures (e.g., one-to-many).

Figure 2b shows the result of a simple simulation in each we gave two versions of the model varying amounts of data about a familiar word mapping. In one version of the model, there was a 1-1 mapping between words and objects in the data, and in another version, there was a 1-many mapping. The model was then queried on the meaning of a novel word given a familiar and a novel alternative, just as children in the mutual exclusivity task. Two things are important to notice about the predictions. First, in the 1-many model, the model is correctly biased (above chance) toward the novel object by relying only on knowledge of the speaker's intended referent. Second, in the 1-1 model, knowledge of the correct lexical constraint provides an additional support. This suggests that supports at both the pragmatic and lexical timescales are sufficient to give rise to a one-to-one behavioral bias.

Thus, in the effort to understand the psychological sources of communicative behavior, hierarchical models provide a theoretical tool to make predictions about the independent contributions of supports at different timescales. With further development of these models, combined with the appropriate experimental data, there is promise in making progress on this empirical challenge.

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