Non-literal Quantification as Reasoning about Strength

We show how a general model of rational inference in communication, together with a standard semantics for quantification and modality, delivers the at times puzzling non-maximal interpretation for universal quantifiers in three seemingly disparate domains. Each of the following sentences admits a non-literal interpretation such that *all* means most, *always* means usually, and *must* means very likely. In addition to weaker interpretations, use of these terms communicates information about the speaker's relationship to the statement she is making. With *all* and *always*, this information concerns the speaker's affective dimension (e.g., feeling positively or negatively about some state of affairs). With *must*, this information concerns the quality of the speaker's evidence. As we show below using both experimental evidence and structured probabilistic models, this evidential information with *must* plays the same role as the affective information with *all* and *always*: Given our prior knowledge about the world, we know it is highly unlikely that the literal, maximal interpretation of the terms could be true. We therefore infer that the speaker intends to communicate 1) a slightly weaker but much more likely statement, and 2) an additional dimension of meaning.

(1)   John ate all of the pie! ⇒ John at most of the pie and I am unhappy about it.

(2)   John always arrives late! ⇒ John usually arrives late and I am unhappy about it.

(3)   John must be in the kitchen! ⇒ John is very likely to be in the kitchen but I do not have direct evidence of this fact.

Because it has received the most scrutiny (and been subject to the most contention), we focus here primarily on the epistemic necessity modal *must*. Since Karttunen 1972, researches have debated the lexical entry for this modal, arguing about its semantic strength. At issue is the failed inference in (4): How could $\Box p$ not entail p? Karttunen and decades of semanticists that follow posit that the inference fails because *must p* is a weaker statement than bare *p*.

(4)   It must be raining.   ⇏   It is raining.

von Fintel and Gillies 2010 claim that the "*must* is weak" mantra cannot be right, showing first that it is not always weak, and then that it never is. They propose instead that *must p* quantifies universally over epistemically possible worlds while presupposing that the speaker has no direct evidence of *p*. However, the strength of *must p* requires the speaker to have direct evidence of something that entails *p*. Lassiter *to appear* shows how this implementation of a strong semantics for *must* makes unreasonable claims about the knowledge states of speakers, and proposes instead a weak probabilistic semantics: *must p* entails that the likelihood of *p* given the speakers direct knowledge is greater than chance, and requires that the question of whether *p* not be resolved by this direct knowledge.

Our approach incorporates elements from both von Fintel and Gillies 2010 and Lassiter *to appear*: *Must* is strong, but reasoning about its strong meaning yields a weaker interpretation. First, to establish the relative strength of *must*, we asked XX subjects on Mechanical Turk to rate the likelihood of a state of affairs given a modalized or bare statement. The results qualitatively confirm Karttunen original observation, and quantitatively demonstrate the relative weakness of *must*: whereas subjects rate the likelihood of *p* after hearing a bare statement at XX%, after hearing *must* (also *know*) subjects rate *p*'s likelihood at XX%.

To address the source of *must*'s weakness, we added a free response to the rating paradigm. Subjects commented on the epistemic state of the speaker: "How do you think they know about p?" Responses were annotated and separated into three main classes: a) perceptual (direct perceptual or experiential access to the state of the world), b) reportative (hearsay, source is a friend or the weather report, etc.), and c) inferential (state of the world is inferred based on other evidence or the way the world 'usually' is). Comparing responses to bare and modal statements, we see that in the former subjects attribute perceptual knowledge to the speaker XX% of the time, whereas in the latter subjects attribute perceptual knowledge XX% of the time. In other words, *must* communicates information about how the speaker came to their epistemic state. However, the XX% of responses that do attribute direct perceptual evidence to *must* statements argues against coding evidentiality into the semantics of this modal. We propose a computational model to show that this empirically verified interpretation of *must* does not require encoding weakness or indirectness into the semantics of modals, but can instead arise from pragmatic reasoning.

Our model follows the basic structure of Rational Speech Act (RSA) models, a family of models that capture rich pragmatic interpretations by viewing language understanding as recursive reasoning between speaker and listener (cite). Suppose we consider the set of utterances $U = \{$ "must p", "probably p", "p"$\}$ and the set of possible worlds $W = \{w_1, \ldots, w_A, \ldots, w_N\}$, where w_A is the actual world. The model utilizes a simple semantics for utterances, such that "must p" is true if p is true for all $w \in W$, "probably p" is true if p is true for some $w \in W$, and bare "p" is true if p is true for w_A. We assume that the full pragmatic interpretation of an utterance u involves four dimensions: whether p is true in w_A (denoted as variable $a \in \{0, 1\}$), the number of worlds in which p is true ($n \in \{0, \ldots, N\}$), whether the speaker has direct evidence of p ($e_D \in \{0, 1\}$), and whether the speaker has indirect evidence of p ($e_I \in \{0, 1\}$). This results in a four-dimensional meaning of u: $m = \{a, n, e_D, e_I\}$. These dimensions are not independent; for example, it is more likely that p is true in w_A for if p is true in most possible worlds, and the speaker is more likely to get direct evidence of p if p is true in w_A. Following recent extensions to the basic RSA model (cite), we assume that the speaker's goal is to communicate the value of a particular dimension; for example, the speaker may want to communicate whether she has indirect evidence e_I about p, regardless of whether p is true in w_A or whether p is true in all possible worlds. A goal g is thus a projection from the full meaning space to the dimension of interest to the speaker, such that, for example, $g_{e_I}(m) = e_I$. This leads to the following utility function for the speaker:

$$U(u|g, m) = \log \sum_m \delta_{g(m)=g(m')} L_0(m|u) \tag{1}$$

Given this utility function, the speaker chooses u using a softmax decision rule, where λ is an optimality parameter:

$$S_1(u|g, m) \propto e^{\lambda U(u|g,m)} \tag{2}$$

The pragmatic listener L_1 marginalizes over possible speaker goals and performs Bayesian inference to recover m given prior knowledge and his internal model of the speaker:

$$L_1(m|u) \propto P(a, n)P(e_D, e_I|a, n) \sum_g P(g)S_1(u|g, m)$$

Consider for example "must p." According to the literal semantics, p is true in all worlds, which entails that p is true in w_A. However, the pragmatic listener has prior knowledge that p is extremely unlikely to be true in all worlds (if the probability of p in one world is q, the probability of p in all worlds is q^N). The listener also knows that the more possible worlds there are in which p is true, the more likely the speaker has indirect evidence of p. If the speaker's goal is to communicate that she has indirect evidence of p, then saying "must p" is maximally informative with respect to that goal. The pragmatic listener thus infers that the number of possible worlds n in which p is true is likely smaller than N, but that the speaker has indirect evidence that p. Since the probability that p is true in w_A is $\frac{n}{N}$ and $n < N$, the probability that p is true in w_A is less than 1, resulting in the interpretation that "must p" means *probably p*. By incorporating standard literal semantics, prior knowledge, and reasoning about informativity with respect to the speaker's communicative goal, the model produces a nonliteral and weakened interpretation of "must" as well as a subtext of indirect evidentiality without encoding it into the semantics.

References

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