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INVITED COMMENTARY

The importance of modeling pragmatic syntactic bootstrapping

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Syntactic bootstrapping is based on the premise that there are probabilistic correspondences between the syntactic structure in which a word occurs and the word's meaning, and that such links hold, with some degree of generality, cross-linguistically. The procedure has been extensively discussed with respect to verbs, where it has been proposed as a mechanism for constraining the massive ambiguity that arises when inferring the meaning of a verb that is used to describe an event (Fisher, Hall, Rakowitz & Gleitman, 1994; Gleitman, 1990; Gleitman, Cassidy, Nappa, Papafragou & Trueswell, 2005). In her keynote paper (Hacquard, 2022), Hacquard focuses on classes of verbs for which inferences about meaning are arguably even harder, because they involve concepts that have no observable counterparts: these are attitude verbs such as *think* and *want*, and modals such as *must* and *can*. She walks us through, in meticulous detail, the limits of a purely syntactic bootstrapping mechanism, and she describes how augmenting syntactic information with pragmatic information, via PRAGMATIC SYNTACTIC BOOTSTRAPPING (Hacquard, 2022; Hacquard & Lidz, 2019), might address these limitations. The proposal is exciting, and the detail with which Hacquard works through these examples is impressive; she supports her arguments with behavioral experiments, corpus analyses, and two very targeted computational analyses. In this commentary I suggest that Hacquard's proposal is laid out in sufficient detail such that a comprehensive computational modeling effort would be fruitful for evaluating and further developing her account.

A computational investigation could be enlightening because the logical reasoning chain in pragmatic syntactic bootstrapping is intricate, and requires considerable alignment between the learner's current knowledge state and their input. Whether or not all the pieces will work together correctly in this process is hard to determine without implementing a model. Such an investigation is tractable, because Hacquard and her colleagues have provided highly detailed descriptions of the kind of information learners would require, with respect to these verb classes.

In what ways could a computational investigation be informative? Hacquard's proposal posits that learners evaluate pragmatic and syntactic information in particular ways to resolve two critical logical problems that specify preconditions for syntactic bootstrapping to work, what she calls the CLUSTERING PROBLEM and the LABELING

PROBLEM. To see how computational modeling could be constructive in evaluating Hacquard's approach, it will help to review these logical problems and how Hacquard's proposal addresses them. The clustering problem refers to the problem the learner faces of figuring out which elements of the syntactic structure in which a word occurs are informative as to the word's meaning. The labeling problem refers to the problem of figuring out what the semantic correlates of the syntactic structures are. For example, as Hacquard describes, in English, declarative clauses are realized as finite complements and are indicative of belief verbs (e.g., *think, know*), and nonfinite complements are indicative of desire verbs (e.g., *want, hope*). The informativeness of the finite versus nonfinite complements with respect to belief and desire meanings is not universal, because the same correspondences do not hold in German or Romance languages, so learners of English need to LEARN that finiteness is informative for separating belief and desire verbs, and learners of German need to learn that word order is what's important, etc. – this is an example of the clustering problem. Moreover, learners need to then determine what the semantic consequences of the structural distinction are: for example, how belief and desire pattern with finiteness (the labeling problem). I will also add to these "problems" what I will call the FILTERING PROBLEM, which pertains to how learners are able to ignore input that deviates from the informative correspondences. Although Hacquard does not explicitly label it, filtering plays a role in much of her discussion and analyses, as I'll touch on below.

In her pragmatic syntactic bootstrapping account (Hacquard, 2022; Hacquard & Lidz, 2019), Hacquard proposed that pragmatic information allows learners to resolve the clustering and labeling problems. For example, in Hacquard's example (13-14), repeated as (1-2) here, the learner is hypothesized to be able to perceive the intended force of the utterances as an assertion in the case of (1), and a request in the case of (2), and this in turn leads the learner to draw conclusions that the main verb, *think*, in (1) involves belief, and *want* in (2) involves desire.

(1) I think it's 5pm.
(2) I want you to tell me the time.

Moreover, sentences (1-2) provide evidence to learners of English that assertions pattern with finite complement clauses, and requests with nonfinite complements. Sentences like those could thus provide learners with information about the relevant syntactic distinctions in English for belief versus desire attitude verbs (clustering), as well how the particular structures relate to meaning (labeling). Related sets of utterances would be informative about word order in German, and mood in Romance languages, which are the relevant dimensions for belief and desire distinctions in those languages (Hacquard, 2022). In addition, as Hacquard discusses, declarative main clauses generally express a truth commitment on the part of the speaker (e.g., *It's raining*), and so the learner can associate the syntax of declaratives with truth commitment. Once the learner has made these associations, they would be able to determine aspects of an attitude verb's meaning from the syntax of the complement clause, even when the pragmatic information might not be available.

In order for such a procedure to work, the relevant input with respect to clause types and speech acts not only need to be present in children's input – a question that corpus analyses can address (as Hacquard points out in many important ways they have) – but the properties of the learner need to be such that they can detect the signal in input data

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that is noisy and imperfect. A computational model is informative in this regard, as it requires a specification of the learning mechanism and its computational properties. Then one can ask, for example, how often it would be possible for a learner to be unable to perceive the illocutionary force of an utterance, or worse, to mis-perceive it, for the bootstrapping procedure to still work. The answer will require specifying facts about the linguistic input – for which corpora are a reasonable proxy – the assumptions about children's pragmatic abilities, as well as their syntactic representations. Hacquard cites computational modeling research (Huang, White, Liao, Hacquard & Lidz, 2021; Yang, 2022) that has begun to address these kinds of questions with some aspects of the clustering and labeling problems, within the pragmatic syntactic bootstrapping approach. Building on these modeling efforts in a way that integrates more of the pieces of Hacquard's proposal could be very informative.

One aspect of the proposal that would benefit from computational modeling is what I called the filtering problem earlier. A critical component of Hacquard's proposal requires learners to be able to filter out data that are in conflict with the general pragmatic, syntactic, and semantic correspondences. For example, in Hacquard's example (16), repeated as (3), the syntax and pragmatics indicate conflicting meanings: the finite complement clause indicates a belief meaning, but the pragmatics – a request for the child to go to bed – indicates a desire meaning.

(3) I think it's time for bed!

Hacquard proposes that a misalignment of syntax and pragmatics would cause the learner to withhold making inferences about the verb's meaning from this utterance. Such a filtering system would work, however, only if the learner had already been successful in using pragmatic syntactic bootstrapping to associate finiteness with assertions and belief meanings. Otherwise, they would not register any misalignment of syntactic and pragmatic information, and they might attribute a desire meaning to *think*. One could speculate as to whether such an assumption is reasonable using corpus analyses to assess the frequency of such misalignments. But corpora offer a limited snapshot of a learner's input, and they do not account for how that input is processed. A computational analysis would provide a more rigorous assessment and test the robustness of the proposal under a number of different scenarios, asking, for example, what proportion of sentences like (3) versus (1-2) would throw off pragmatic syntactic bootstrapping? How does the ordering of these sentences interact with those proportions? Under reasonable assumptions about the parameters for tolerance for unfiltered but misleading input, what would the input properties need to be for pragmatic syntactic bootstrapping to work? Developing a computational model forces one to be specific about the processing and representational mechanisms that can help one to evaluate the viability of a learning theory. Moreover, by developing a comprehensive model that attempts to capture all the bootstrapping steps that Hacquard so meticulously laid out, one can evaluate whether the learning parameters that are necessary for solving filtering problems are also sufficient for clustering and labeling, and pragmatic syntactic bootstrapping in general.

In her concluding paragraph, Hacquard writes, "We are thus in a much better position to ask which information children actually make use of, which they ignore, and what hypotheses they make or fail to make on the basis of that information…" The proposal Hacquard develops, and the research that supports it, is perhaps now detailed

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enough so that these questions can be further explored with the aid of computational models.

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