Predictive Processing of Coordination in CCG

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Human sentence processing is highly incremental at all levels, including semantic interpretations (Altmann & Kamide, 1999; Aoshima, Yoshida, & Phillips, 2009; Marslen-Wilson, 1973; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). Right adjuncts are interesting in this context because processing models often make adjunction a non-incremental operation, so that the structure they modify cannot be integrated with the prefix until the adjunct is complete. This observation holds of the left-corner approaches to generative grammar (Hale, 2014; Stanojević & Stabler, 2018) and of greedy shift-reduce approaches to parsing Combinatory Categorial Grammar (CCG, Steedman, 1989), making them appear inconsistent with psycholinguistic findings. Sturt and Lombardo (S&L, 2005) have shown that a greater degree of incrementality seems to be needed in processing coordinations as in Figure 1. Here the right conjunct can be interpreted as an instance of right-adjunction. S&L propose using the *adjoin* operation of *Tree-Adjoining Grammar (TAG)* (see also Demberg, Keller, and Koller (2013)) to explain this incrementality. However, for reasons elaborated below, alternative explanations in terms of other grammar formalisms are worth exploring.

In particular, no one has yet shown how to reconcile the result of S&L with CCG incremental parsing. We argue that the operations of tree *rotation* and *revealing* from Stanojević and Steedman (2019) are sufficient to explain the results of S&L (see also Pareschi and Steedman (1987) and Niv (1994)). The parser builds the structure as a left-branching CCG derivation (Figure 2a), which gets automatically *rotated* to be right branching (Figure 2b), making the VP available for modification by possible future right-adjunction. The rest of the derivation goes normally until "herself" is read, when there is a binding anomaly because of the gender-biased interpretation of the antecedent "the pilot". This binding cannot be accomplished with standard CCG parsing, but a predictive phase of the parser can detect from the type $((S\backslash NP)/PP)/NP$ of the verb "put" that there is a PP coming. In this predictive phase, a placeholder PP is made available to complete the right conjunct and attach it to the left conjunct using the *reveal* transition from Stanojević and Steedman (2019) as shown in Figure 3, allowing the bias-conflicting binding to disrupt processing, before returning to the standard phase of parsing to redo the same analysis when the actual PP is complete. The predictive behavior of verbs is supported by psycholinguistic experiments (Arai & Keller, 2013).

This CCG parsing approach bears a different relationship to linguistic theory than does the TAG approach of S&L and Demberg et al 2013. First, it obeys the Coordinate Structure Constraint (CSC). In order for TAG to respect CSC, the parser needs to use tree-unification (Sarkar & Joshi, 1996a) combined with lexical insertion. The addition of these operations to TAG makes the incremental TAG parser significantly more complex (Sarkar & Joshi, 1996b). Second, our approach conforms to the Strict Competence Hypothesis (SCH, Steedman, 1989) which states that the processor cannot build any structure that is not directly licensed by the competence grammar. Finally, the *reveal* operation from Stanojević and Steedman (2019) influences only the level of incrementality without changing the weak or strong generative capacity of CCG. Revealing combined with prediction addresses all the incrementality issues raised by Demberg (2012) and S&L.

When we consider S&L sentences, this CCG parsing model makes the same incrementality predictions as the S&L's TAG model, but it does so using a different mechanism. Derivations presented by S&L do not use tree-unification although they should since they coordinate verbs that share the same subject. If we consider the correct derivations with tree-unification, in order to keep the TAG parser incremental the parser would either have to use a top-down strategy that predicts coordination schema in advance, an approach that is argued against by S&L as being implausible, or it would be a predictive parser of the sort that is proposed is our work.

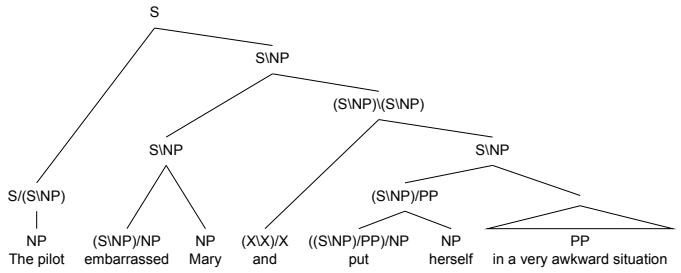
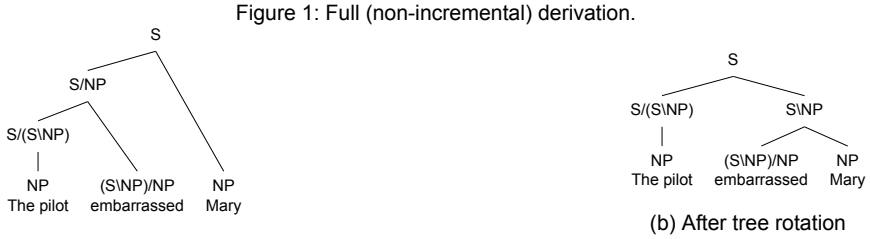


Figure 1: Full (non-incremental) derivation.



(a) Before tree rotation

(b) After tree rotation

Figure 2: The effect of tree rotation on the left conjunct.

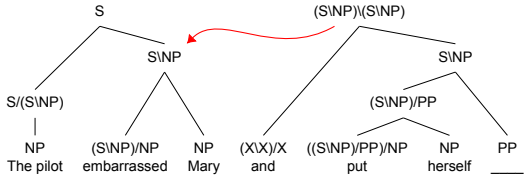


Figure 3: Attachment of the right conjunt with a hole.

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