Representing the effort in resolving ambiguous scope

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By definition, incrementality forces representations of the input to be only partially available, and yet linguistic constraints on interpretation are sometimes created by objects that are late in appearing. Predictive frameworks for syntactic parsing perform well in matching human behaviour in experimental settings by employing *underspecification*. At each step, the parser posits a maximum hypothesized structure with constraint-laden placeholders for as-yet-unavailable structure. Prediction quality and its match to human behaviour is controlled by fine-tuning the appearance of these placeholders and the costs of satisfying their constraints.

The same method could be used for quantifier scope ambiguity (Koller et al., 2013). The difference with syntactic parsing is that scope ambiguities and their associated structure belong to the covert part of the grammar with no direct observation available on the string. It could be that an underspecification approach is sufficient if the parser is "shallow" and only assigns semantic representation for which there is evidence in the surface string. The alternative, *reanalysis*, posits that the "deeper" interpretive constraints proposed by theories like quantifier raising (QR) apply at processing time. If reanalysis approaches can be empirically validated for scope ambiguity, then constraints on quantifier raising would need to be built into the semantic representation.

Dotlačil and Brasoveanu (2014) test sentences like these on adult speakers:

(1) A caregiver (x) comforted a child (y) every night (n).
   a. The caregivers wanted the children to get some rest. ($\forall n > \exists x \exists y$)
   b. The caregivers wanted the child to get some rest. ($\forall n > \exists x$)

Using eye-tracking, D&B presented a sentence like (1) to a given subject with a continuation from (1a,b) as well as "caregiver"-singular controls. They found in (1a) facilitation of the plural reading of "caregiver" on the plural reading of "child". Otherwise, the presence of a singular reading of "child" after a plural reading of "caregiver" (1b) forces regressions and rereadings. In a purely underspecified framework, the readings of "caregiver" and "child" should be independent of one another; the opposite would imply a default structure already posited by the parser, defeated by the forced raising of "every night" on encountering the plural.

While D&B present evidence for the dynamic reanalysis of scope relations, there is even evidence for within-sentence covert movements of quantifiers, particularly from antecedent-contained deletion (ACD). Hackl et al. (2012) used self-paced reading to show that a quantifier in the matrix clause of an ACD sentence helps facilitate the resolution of the ACD itself, as opposed to a definite NP. Syrett and Lidz (2011) found that children and some adults do not respect a tensed clause barrier in ACD interpretation; they suggest that online processing capacity affects QR-constraining ability.

Sayeed and Demberg (2012, 2013) proposed a neo-Davidsonian formalism to represent semantics fully incrementally. Neo-Davidsonian events provide a great deal of representational flexibility. It allows the expression to grow mostly rightwards:

(2) a. A caregiver comforted ...
   b. $\exists x \mathsf{caregiver}(x) \wedge \exists e \mathsf{comfort}(e) \wedge \mathsf{agent}(x, e)$
   c. A caregiver comforted a child.
   d. $\exists x \mathsf{caregiver}(x) \wedge \exists e \mathsf{comfort}(e) \wedge \mathsf{agent}(x, e) \wedge \exists y \mathsf{child}(y) \wedge \mathsf{patient}(y, e)$

S&D's system represents ambiguous variable scopes without resorting to inference rules that directly edit the semantic representation. They propose a parallel structure called a "variable scope tree" (VST), in which strictly the participants in covert operations (event and entity variables) are contained in relations analogous to a syntactic tree. Then QR-style restrictions can be imposed over an operation called VST-move, which uses the event variable as a phase-like ceiling over QR. Results such as Syrett and Lidz can be explained by memory constraints "blurring" event variables together, creating escape-hatches for otherwise illicit raising.

We propose improvements to their system that enhance the generally rightward expansion of semantic expressions under parsing while allowing us to account for observations such as those of D&B and Syrett and Lidz. To proceed, when we include "every night" as in (1) in the expressions in (2b,d), the universal quantifier must take precedence over the existentially quantified event, requiring late leftward insertion of the universal quantifier:

(3) $\exists x \mathsf{caregiver}(x) \wedge \forall n \mathsf{night}(n) \rightarrow \exists e \mathsf{comfort}(e) \wedge \mathsf{OCCUR}(n, e) \wedge \mathsf{agent}(x, e) \wedge \exists y \mathsf{child}(y) \wedge \mathsf{patient}(y, e)$

This late insertion also forces an incorrect default scope order, as well as requiring complex inference rules. Rather than have the quantifiers mixed among the predicates, we hold quantifier bindings entirely in the VST and concatenate predicates more consistently rightward:

(4) $\mathsf{caregiver}(x) \bullet \mathsf{comfort}(e) \bullet \mathsf{agent}(x, e) \bullet \mathsf{child}(y) \bullet \mathsf{patient}(y, e) \bullet \mathsf{night}(n) \bullet \mathsf{OCCUR}(n, e)$

where $\bullet \in \{\wedge, \rightarrow\}$, to be left underspecified until quantifier order selects a final interpretation. VSTs are built top-down, with e as a kind of maximal projection that is expanded every time a two-place predicate with a quantified entity variable appears, as in (5a), in which $\forall n$ scopes correctly over the event and under other quantifiers as in linear scope. The top-down approach assures that inverse scope is achieved principally by raising and that the event variable can act as VST-move's ceiling; a bottom-up method would not describe all the relationships between event and entity variables necessary to make interim incremental judgements about scope.

Reaching the interpretation of (1a) corresponds to (5b), a single VST-move and an additional VST-move for (1b) to reach (5c), parallel with D&B's experimental data. Repopulating the expression in (4) with quantifiers and logical operators is straightforward and can be done as necessary. This structure represents a limited degree of underspecification, without requiring the semantics to parallel a full bottom-up syntax, while leaving a structure in which the experimentally-observed reanalysis takes place.

(5) a. $[_{e}\ \exists x\ [_{e}\ \exists y\ [_{e}\ \forall n\ \exists e]]]$

b. $[_{e}\ \forall n\ [_{e}\ \exists x\ [_{e}\ \exists y\ [_{e}\ t_n\ \exists e]]]]$

c. $[_{e}\ \exists y\ [_{e}\ \forall n\ [_{e}\ \exists x\ [_{e}\ t_y\ [_{e}\ t_n\ \exists e]]]]]$

J. Dotlačil and A. Brasoveanu. (2014) The manner and time course of updating quantifier scope representations in discourse. *Lang., Cog., and Neuro.*

M. Hackl, J. Foster-Hale, and J. Varvoutis. (2012) Quantification and ACD: evidence from real-time sentence processing. *Semantics.*

A. Koller, J. Niehren, and S. Thater. (2003) Bridging the gap between underspecification formalisms: hole semantics as dominance constraints. *EACL.*

A. Sayeed and V. Demberg. (2012) Incremental neo-Davidsonian semantic construction for TAG. *TAG+11.*

A. Sayeed and V. Demberg. (2013) Covert without overt: QR for movementless parsing frameworks. *GLOW 36.*

K. Syrett and J. Lidz. (2011) Competence, Performance, and the Locality of Quantifier Raising: Evidence from 4-Year-Old Children. *Ling. Inq.*