The role of hierarchical structure in syntactic dependency integration

Peter Baumann (Northwestern University)
baumann@u.northwestern.edu

Processing complexity; Dependency integration; Locality; Regression analysis; Eye-tracking; British English

The role of the hierarchical syntactic structure has been controversial in sentence processing: while experience-based models of syntactic expectations or *surprisal* (Hale, 2001) generally rely on hierarchical sentence structure, memory-based models like the Dependency-Locality Theory (DLT; Gibson, 2000) tend to emphasize the importance of linear distance. Although DLT successfully predicts the difference between object and subject relative clauses in English (Gibson, 2000), it has problems accounting for a similar pattern in Korean (Kwon et al., 2006), where the linear distance between the verb and its object is the same in both constructions. One possible way to remedy this shortcoming of DLT is to replace linear distance by a structural distance measuring the number of syntactic nodes crossed (cf. O'Grady, 1997) when integrating the dependent(s) of a head.

We tested to what degree structural distance could replace linear distance by evaluating their relative importance as predictors for reading times in the Dundee Corpus (Kennedy & Pynte, 2005). Both distances were calculated based on dependency relations obtained from parsing the corpus with the Stanford Parser (de Marneffe et al., 2006): for each dependency relation the distance was determined as the number of words (LINEAR DISTANCE) between the head and its dependent and as the number of non-terminal nodes crossed (STRUCTURAL DISTANCE) when traversing the syntactic tree structure from the head to its dependent.

First-pass reading times were modeled using linear mixed-effects regressions with subjects and word tokens as random effects. We first fitted a baseline model with the predictors *word position*, *word length*, *unigram* and *bigram frequency* and all two-way interactions that significantly improved the model in a log-likelihood ratio test. All predictors were centered and scaled to reduce collinearity. We then added linear and structural distance as a predictor to the baseline model: while *structural distance* yields a reliably better model fit ($\chi^2(1, N=189{,}704) = 14.53$, $p < .001$), *linear distance* does not significantly improve over the baseline model ($\chi^2 = 1.02$, $p = .31$).

To test whether the effect of structural distance can be attributed to other measures of syntactic expectations or syntactic structure, we calculated the depth of embedding of each word and surprisal based on a non-lexicalized PCFG, and added them to the baseline model. While both predictors improved the model fit independently and together (cf. Pynte et al., 2008; Demberg & Keller, 2008), adding *linear distance* to a model with either *surprisal* or *depth of embedding* yielded no significantly better model fit (p's > .11). *Structural distance*, however, was a significant predictor ($|t| = 3.4$) when added to *surprisal* and *depth of embedding*, and the resulting model is a better fit to the data than the baseline model with *surprisal* and *depth of embedding* only ($\chi^2 = 11.17$, $p < .001$). The model improvement still holds ($\chi^2 = 9.95$, $p < .01$) if structural distance is residualized by linear distance to account for possible traces of lexical information (e.g. sub-categorization) contained within the dependency structure.

These results suggest that dependency integration costs for heads are more sensitive to structural distance than to linear distance, and that structural distance could improve the empirical adequacy of memory-based models not only for Korean relative clauses, but also for English. The independent contributions of surprisal and structural distance indicate that hierarchical structure plays a role not only in the formation of syntactic expectations, but also in dependency integration.

References

Demberg, V. & Keller, F. (2008). *Cognition* 109:2, 193-210

Gibson, E. (2000). In Y. Miyashita, A. Marantz, & W. O'Neil (eds.). *Image, Language, Brain*. MIT Press, 95-126

Hale, J. (2001). *NAACL 2*. 159-166

Kennedy, A., & Pynte, J. (2005). *Vision Research*, 45, 153–168

Kwon, N., Polinsky, M., & Kluender, R. (2006). *WCCFL 25*, 1-14.

de Marneffe, M.-C., MacCartney, B., & Manning, C. D. (2006). *LREC 2006*

O'Grady, W. (1997). *Syntactic Development*. University of Chicago Press.

Pynte, J., New, B., & Kennedy, A. (2008). *Journal of Eye Movement Research* 2(1):4, 1-11.