Incremental processing and resource usage

Deryle Lonsdale, Jeremiah McGhee, Ross Hendrickson, and Carl Christensen
Corresponding author: lonz@byu.edu
Department of Linguistics and English Language
Brigham Young University
Provo, UT 84602 USA

Keywords: Soar; incremental parsing; verb valency; resource usage.

Background

Within the community engaged in Soar-based cognitive modeling (Newell, 1990), some work has focused on parsing natural language input text. An early version of the system (Lewis, 1993) performed syntactic analysis based largely on the Government & Binding (aka Principles & Parameters) framework, including X-bar theory for constituency.

The system, called NL-Soar, receives lexical input word-by-word, and lexical access is performed for each word in turn. The system then attempts to integrate the incoming words and their related information incrementally into linguistic models: a syntactic X-bar parse tree (which will be the focus of this paper), as well as semantic and discourse structures (that will not be addressed here). All potential and possible syntactic material is considered in piecing together licit constructions. Constraints operate to rule out attachments that do not follow standard principles. In certain cases, some types of limited structure can be undone and reformulated when ongoing hypotheses prove untenable in the presence of new incoming words.

NL-Soar was later updated to retrieve knowledge from WordNet (Fellbaum, 1998) that provides relevant morphological and syntactic information for all of the senses and homographs of the word in question (Lonsdale & Rytting, 2001).

In more recent work (Lonsdale, 2006) following on directly from Lewis' prior contribution, we replaced the GB-style syntactic model with one more closely reflecting assumptions of the Minimalist Program (MP) (Chomsky, 1995). Though cognitive modeling has been pursued with other syntactic theories, Minimalism has not seen the same scrutiny, though some parsing and psycholinguistic research has been done within the MP (e.g. (Fong & Hirose, 2005)) and cognitive modeling within MP has been called for (Edelman & Christiansen, 2003). Our work has included adding more functional projections, feature checking, and movements. In addition, two hierarchies of projections—one for clausal structure and one for nominal structure—are available to specify and license construction of hierarchical layers in the syntactic model.

To simplify the work for this paper, no sentences with adjunction, coordination, or complex clauses are considered. We ignore movement of constituents, such as a subject's putative movement from its original position in the specifier of vP to its final position in the specifier of TP, due to the Extended Projection Principle. Finally, intransitives are treated identically whether unergative or unaccusative.

Ongoing work has focused on whether the new syntactic mechanism is capable of supporting incremental processing, and at what cost. In this paper we summarize work done to assess how two different parsing control strategies support parsing in as incremental a fashion as possible. We also attempt to quantify resource usage necessary to parse different types of sentences according to the two different processes.

General remarks

Our study of this question involved running several sentences through the system and running various statistical profiling processes to measure processing load. We are using the newest version of the Soar cognitive modeling system, which represents a substantial revision of the basic NL-Soar code base, not all of which has been converted to date.

The system is agent-based, and information enters from the exterior environment. In our case, incoming words are collected serially into a buffer until they are attended to. Attention involves a lexical access operator which retrieves associated information from WordNet and other lexical resources at the system's disposition. After lexical access, processing proceeds differentially depending on the strategy employed.

At the current time in this version of the system, learning is turned off. Hence the pursuit of hierarchical goals is not enabled, and the agent's only task is to solve the sentence.

The project/attach strategy

The first strategy retains some of the assumptions of the original GB-based theory. For example:

- Lexical categories are projected as completely as possible as soon as possible. Zero-level nodes are projected to XP nodes via one operator.
- Projections (except v) only grow when lexically licensed .
- Structures are extended via the hierarchy of projections as soon as possible.
- Attaching complements and specifiers into pre-existing structure is performed as a last resort, and only when licensed.
- New words aren't attended to until all possible structure is built incrementally.

Thus, in processing a simple intransitive sentence, the agent posits structure as soon as possible, completing the subject's NP and then DP structure before the verb is encountered. Once the verb is attended to, it is projected up to a TP per information provided via operators that consult the clausal hierarchy of projections. The subject is then attached into the specifier position of the TP node.

Processing is similar for transitive verbs, with an additional step to attach the direct object into the complement position of the V-bar node. For ditransitive verbs, the first object is attached into the specifier of the VP node as soon as it is completed; the second object is attached into the complement of the V-bar node as is done with transitive verbs.

The bottom-up merge strategy

This strategy follows recent assumptions for minimalist analysis (Adger, 2003). In particular:

- Structure is only projected when licensed at any stage.
- Projections (except v) only grow when lexically licensed .
- There are separate operators for projecting nodes at the intermediate (X-bar) and phrasal (XP) levels.
- Separate operators perform First Merge (incorporating complements) and Second Merge (incorporating specifiers).
- Projection to XP is only possible when licensed.
- Merge can only occur when licensed via features that need to be checked and deleted.
- New words aren't attended to until all possible structure is build incrementally.

In this case, the agent projects only as much structure as possible, one node at a time, as licensed. Intransitive verbs are constructed in a fashion largely similar to the previously mentioned strategy. However, with transitive verbs the V-bar node is not built until the direct object's structure has been completed. Similarly, the TP node is not constructed until the subject can be combined into the specifier position of a T-bar root node. More interestingly, ditransitive instances require that no V-bar node can be constructed until the second object has been completed. Only then can it undergo First Merge to combine with the lexical verb. Then the first object combines with the V-bar node (i.e. in its specifier) via Second Merge to create a VP.

Results

The second strategy required substantial resource usage, especially for ditransitive constructions. This is because verb phrasal structure must be held in abeyance until both internal arguments are completed.

A post-hoc analysis of the processing statistics showed that almost all of the changes in working memory are due to lexical access and the data retrieved at that time.

Figure 1 shows memory usage over time (measured in decision cycles) for the three canonical types of sentences (intransitive, transitive, and ditransitive).

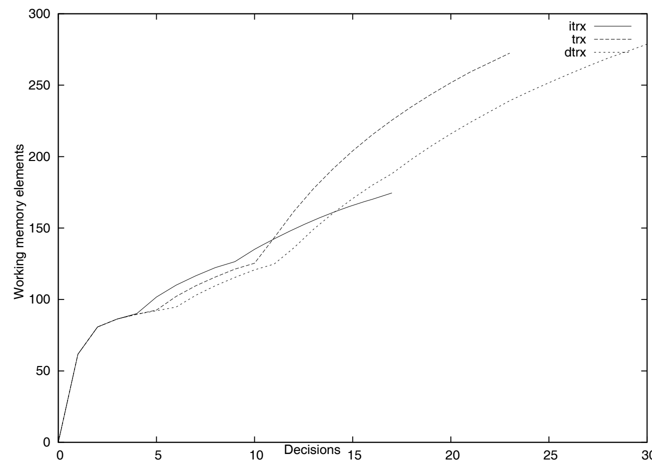

Figure 1: Working memory usage across decision cycles for intransitives, transitives, and ditransitive sentences.

Conclusions

Though only representing a core set of syntactic possibilities for sentences, this work has shown that the two strategies entail different amounts of resource usage, which can be quantified via profiling in the cognitive modeling system.

References

Adger, D. (2003). *Core syntax: A minimalist approach*. Oxford University Press.

Chomsky, N. (1995). *The Minimalist Program*. MIT Press.

Edelman, S., & Christiansen, M. H. (2003). How seriously should we take Minimalist syntax? *TRENDS in Cognitive Sciences*, *7*(2), 60–61.

Fellbaum, C. (1998). *WordNet: An electronic lexical database*. Cambridge, MA: MIT Press.

Fong, S., & Hirose, Y. (2005). Minimalist Parsing and Japanese: on theory and experiential factors. In Y. Otsu (Ed.), *Proceedings of the Sixth Tokyo Conference on Psycholinguistics* (pp. 95–116). Tokyo: Hituzi Syobo Publishing Co.

Lewis, R. L. (1993). *An architecturally-based theory of human sentence comprehension*. Unpublished doctoral dissertation, Carnegie Mellon University.

Lonsdale, D. (2006). Learning in minimalism-based language modeling. In *Proceedings of the 28th Annual Conference of the Cognitive Science Society* (p. 2651).

Lonsdale, D., & Rytting, C. A. (2001). Integrating WordNet with NL-Soar. In *Proceedings of NAACL-2001: WordNet and other lexical resources—Applications, extensions, and customizations.* Association for Computational Linguistics.

Newell, A. (1990). *Unified theories of cognition*. Harvard University Press.