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Sentence Comprehension: The Integration of Habits and Rules

David J. Townsend and Thomas G. Bever

(Montclair State University and University of Arizona)

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Reviewed by

Matthew W. Crocker

Saarland University

The last two decades have witnessed a great deal of activity in the development of computational theories of human sentence processing. The aim of such research is to explicitly identify and model the architectures and mechanisms that underlie human comprehension (see Crocker, Pickering, and Clifton [2000] for a recent collection on the topic). Although there is often relatively little interaction between the *computational psycholinguistics* and *natural language processing* (NLP) communities, both have been concerned with how various symbolic, connectionist, probabilistic, and hybrid techniques can be applied to the task of recovering interpretations of ambiguous linguistic input according to some set of underlying linguistic rules and principles. The difference between the two enterprises concerns their respective goals. Models of human sentence comprehension are concerned with replicating human behavior during the on-line, incremental (word-by-word) processing of an utterance as it unfolds. Particular emphasis is therefore placed on the resolution of local or temporary ambiguities, which occur as each initial substring of an utterance is encountered. Identifying human preferences in the face of local ambiguity is not a goal in itself but provides critical insight into the kinds of mechanisms (parallel, serial, underspecified) and information sources that are used (e.g., syntactic, semantic, visual, probabilistic). Traditional NLP systems, on the other hand, are typically concerned with trying to resolve global ambiguities (language models for speech recognition being a notable exception) and often strive only to recover partial interpretations (e.g., keyword finding, chunking, template filling). Interestingly, the work reviewed here can be seen as arguing for greater convergence between psychological and technical models in that it argues for the existence of a shallow, partial parser within the human sentence-processing mechanism.

Sentence Comprehension: The Integration of Habits and Rules is an ambitious work that aims to integrate ideas and evidence from sentence-processing research that have accrued over the last 40 years. This is essentially two books in one: an introductory text and a research monograph. The need for these two subbooks arises from the highly interdisciplinary nature of the topic: The development of an algorithmic model of human sentence processing based on state-of-the-art linguistic theory necessarily draws upon background in linguistics, computational linguistics, and psycholinguistics. The first 150 pages of the book are devoted to providing this. After a brief introductory chapter sketching the perspective and goals of the book, we are presented with a rather historical review of early theories of sentence processing (Chapter 2) and an introduction to some of the key aspects of current linguistic theory (Chapter 3). The latter concludes

with an overview of minimalist syntactic theory (Chomsky 1995), which the authors later assume in developing their own model.

Of these introductory chapters, Chapter 4 is worthy of particular mention. It gives a truly comprehensive and relatively detailed review of the prevailing theories of sentence processing. Not only are the models well presented, but similarities, differences, advantages, and disadvantages are also clearly identified. The chapter begins with the deterministic parser of Marcus (1980) and Frazier's Garden Path theory (1978) and moves on through principle-based parsing and reanalysis (e.g., Pritchett 1992; Crocker 1996). The final half of the chapter then considers more-recent probabilistic models, which I loosely take to encompass statistical parsing (Jurafsky 1996), connectionist, and competitive constraint-based approaches (Spivey and Tanenhaus 1998) as well as hybrid models (Stevenson 1994). This part of the book is particularly interesting in revealing how probabilistic mechanisms can be used in extremely different ways and how such models face fundamental challenges, for example, in establishing the "level of grain" at which statistical frequency information is accrued (Mitchell et al. 1995), and the scalability of recent connectionist proposals (Spivey and Tanenhaus 1998).

We now turn our attention to the model proposed by the authors, which is introduced in Chapter 5. The central hypothesis of the book, and core idea of the model, is that sentence comprehension involves associative and syntactic components. An associative component is assumed to be necessary for rapid, shallow recognition of major phrases. Configurational surface schemata, or *canonical sentence templates*, and verb-frame information are then exploited to construct a preliminary conceptual representation. The syntactic component, in turn, is responsible for recovering the full cyclic structure of the sentence, including the longer-distance relationships introduced by movement transformations. The syntactic component takes the shallow "quick and dirty" analysis as its input, derives a complete syntactic parse, and then checks that this is still consistent with the input string. The result is the so-called analysis-by-synthesis model.

This two-tiered model of processing is broadly motivated by an apparent duality in the evidence from human language processing. On the one hand it is clear that people are sensitive to certain kinds of probabilistic information in building interpretations of ambiguous linguistic input and even in generating predictions of what is to come next (and recovering material that was unclear in the original, noisy input signal). On the other hand, people clearly demonstrate the ability to apply rich and productive linguistic principles in dealing with complex and novel input. The authors argue that trying to recover the interpretation of a sentence directly by means of the grammar is intractable. In particular, they argue that reversing the transformational derivations of the grammar incrementally would simply not be possible, given the recursive complexity of language. The idea is that the associative component "isolates a candidate analysis based on surface cues, and syntactic processes check that the analysis can derive the sequence" (p. 164, para. 1). Since full parsing follows an initial syntactic and semantic analysis, it is argued that the tremendous search space required for full parsing can be substantially reduced.

The following chapters further develop the *Late Assignment of Syntax Theory* (LAST). Chapter 6 presents a wide range of empirical data, which are interpreted as supporting the model, and also takes the opportunity to introduce a range of experimental psycholinguistic techniques for the uninitiated. Chapter 7 delves into greater detail concerning the associative component and the use of canonical sentence templates in particular. Chapter 8 then situates the model of sentence processing within language processing more generally (e.g., discourse and conceptual understanding). Finally, Chapter 9 considers a range of other, more peripheral issues, such as evidence

from language acquisition and neurological support for the model. Chapter 10 gives a concise summary of the theory and its motivation and some further rationalization.

To their credit (and the benefit of the seriously interested reader), these chapters cover a tremendous amount of psycholinguistic data in building support for the authors' proposals. It must be accepted, of course, that empirical *facts* are typically consistent with many possible *interpretations*, and it will be up to readers to decide whether they are persuaded by the authors' attempt to interpret the facts presented as supporting the LAST model. One serious criticism of the empirical discussion, however, is that the book considers only evidence from English. Sentence processing has seen an increasing emphasis on crosslinguistic research over the last 10 years, as it became evident that earlier models were "overfitted" to English. LAST seems to fall prey to this in its heavy reliance on two properties of English, namely that (1) verbs precede their complements and (2) clauses have a relatively fixed word order. The former is essential for the prediction of complements on the basis of the verb's most frequent subcategorization frame (which the authors propose guides the associative component), and the latter seems crucial in order for *canonical sentence templates* to have any substantive value. An additional (and important) consequence of the model is that it sacrifices full, word-by-word incremental interpretation. Although the authors attempt to justify this move, it is certainly at odds with current consensus in the sentence-processing community. Experimental evidence suggests that people can and do rapidly integrate the full complement of linguistic constraints that follow from a left context in processing the words that follow. I remain unconvinced that the associative stage of the LAST model would be able to account for the full range of facts here.

Although the theory's ability to explain the empirical phenomena it is intended to elucidate will be crucial to its ultimate success, it is worth making some observations on the theory itself. It has to be said that, despite its being couched in terms of modern minimalist linguistic theory, and despite all the attention paid in the book to the full complement of modern models (symbolic, probabilistic, and connectionist), the proposed model has a decidedly "retro" feel to it. In particular, it resurrects notions like the old N-V-N (agent-action-patient) canonical sentence templates (Fodor, Bever, and Garrett 1974), not to mention something closely resembling the transformational theory of grammar, in that the syntactic component is assumed to perform some direct form of reverse transformation operations. The rather literal interpretation of transformations has all but been abandoned even in principle-based models (Crocker 1996). I was also disappointed to discover that the claimed reconciliation and "integration of symbolic-computational and associative-connectionist" approaches amounted to simply having one of each. Although this is a possible position to take, it is certainly at odds with Occam's razor to have two mechanisms doing essentially the same task. A theory that can explain the evidence with a single mechanism would surely be preferable. Whereas earlier models indeed failed to account adequately for both symbolic and probabilistic behavior, recent models have shown that they can be integrated by applying ideas from probabilistic language modeling, such as hidden Markov models and stochastic parsing (Jurafsky 1996; Crocker and Brants 2000).

Furthermore, although the model might be considered algorithmic, it has not been implemented computationally, in contrast with many competing models. Given the complexity of human language comprehension and the range of interacting mechanisms and information sources, it is difficult to ensure that the theory is being invoked consistently and uniformly in accounting for the full range of empirical findings. This potential pitfall seems especially important for LAST given that two almost autonomous mechanisms are involved. The only way to achieve the necessary consistency in evaluating a model, and to make clear predictions, is through implementation.

To conclude, *Sentence Comprehension* functions as an excellent introduction to the history of sentence processing, the methods used, and prevailing theories. It strives to identify both the truths that have been revealed and the outstanding conundrums and presents evidence and concepts in both a detailed and comprehensible fashion. The book is well written and organized, including a detailed bibliography, as well as subject and author indices. Other psycholinguists may not always be convinced by the authors' interpretation of competing theories and empirical data, but that will always be the case. This book nonetheless provides exceptional coverage and would function as a thorough introduction for newcomers and a valued resource to those already in the field. It could certainly be used as a text, although, given the emphasis on what I take to be a rather controversial proposal, I would probably prefer to use it alongside other material. Despite the criticisms detailed above, the authors' proposals certainly offer numerous insights and put into sharp focus the importance of considering probabilistic, experience-based aspects of language use as well as general linguistic principles.

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Matthew W. Crocker is a Professor of Psycholinguistics in the Department of Computational Linguistics, Saarland University. His research is concerned with computational models of human sentence processing, focusing in particular on the development of probabilistic models of sentence comprehension, statistical language processing, and experimental psycholinguistics. Crocker's address is: Department of Computational Linguistics, Building 17, Saarland University, 66041 Saarbrücken, Germany; e-mail: crocker@coli.uni-sb.de; <http://www.coli.uni-sb.de/~crocker/>.