Properties of the Principle-Based Sentence Processor

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Abstract

This paper defends a *principle-based* model of sentence processing, and demonstrates that such a model must have two specific properties: (1) it must use a partially top-down parsing mechanism, possibly restricted to functional structure, and (2) it must use an Active Trace Strategy, which freely posits traces before their linear string position. It is argued that both of the proposed mechanisms follow from an overarching *Principle of Incremental Comprehension.*

1. Introduction

Theories of linguistic performance have long sought direct psycholinguistic evidence for the representations and mechanisms posited by theories of syntactic competence. The line of reasoning which underlies this programme of research can be summarised as follows: Theories of syntax claim to provide an account of a persons knowledge of language. The human sentence processing mechanism (HSPM) must presumably make use of knowledge of language. Thus the most parsimonious account is one where the processing mechanism makes direct use of the rules and representations of syntax. The view has been expressed as the *Strong Competence Hypothesis* (SCH) which holds that the process model must make direct use of the principles of grammar: what Berwick and Weinberg call *type transparency* [BW84]. As psycholinguists have turned their attention to the recent *principles and parameters* (P&P) model of linguistic competence, two particular properties demand the attention of SCH proponents:

1. The theory makes use of a set of interacting, heterogeneous principles renderring traditional parsing technologies insufficient, as there is only a minimal phrase structure component.
2. The P&P model makes use of multiple-levels of syntactic representation, and posits the existence of empty categories, both in subcategorized, adjoined, and intermediate positions.

These issues have sparked research into a range of computational and psychological models of how principles of grammar may be used directly in parsing (see [Pri88], [Fon91], [Cro92] as examples). This paper endeavours to shed further light on the nature of a principle-based HSPM.

2. Complexity-Based Models

Traditional hypotheses concerning the parsing strategies and algorithms of the HSPM are founded upon some notion of syntactic 'complexity'. This view proposes that increases in processing complexity incurred during parsing are the result of some increased load on the syntactic processor. As a result, theories have stipulated their relevant metrics for assessing complexity as either representational parsimony, as in Frazier's model [Fra79], or computational efficiency as in the parser of Berwick and Weinberg [BW84]. Given this view, the parsing strategies operative within these models are motivated by the desire to minimise complexity: Frazier's *Minimal Attachment* strategy minimises the complexity of the phrase marker, while Marcus' parser operates deterministically.

Both of these approaches are based fundamentally upon the isolation of the parsing task. That is, they are isolated in the sense that the syntactic processing strategies are insensitive to the more general comprehension task. The parsing models proposed are motivated purely by a desire to minimise syntactic complexity, be it representational or computational. While it is reasonable to assume that both syntactic representation and computation will be relevant contributors to overall sentence processing complexity, it is possible that their importance may be overshadowed by the complexity of the more general comprehension task. In other words, simple time and space complexity considerations *within* the syntactic processor might not be of paramount importance, and thus processing strategies therein may rather be oriented towards the concerns of global comprehension.

3. An Alternative

On the grounds just outlined, the model we propose does not assume either computational or representational parsimony of the syntax to be fundamental. Rather, we assume that the sentence processor strives to optimise local, incremental comprehension of the input utterance. That is, decisions about the current syntactic analysis are made incrementally (for each input item) on the basis of principles which are intended to maximise the overall interpretation. The philosophy which underlies this position is that the syntactic processor's primary objective is to provide a maximal, partial interpretation of an utterance as input is received, such that it may be quickly integrated into the current context, thereby meeting the real-time demands of comprehension. As such, syntactic analysis will proceed first and foremost in a manner which will satisfy this objective. In sum, we propose that the operations of the autonomous syntactic processor are not determined by internal syntactic factors, but rather by the external demand for a maximal incremental analysis. We will dub this the *Principle of Incremental Comprehension* (PIC), defined as follows:

Principle of Incremental Comprehension: The sentence processor operates in such a way as to maximise the interpretation and comprehension of the sentence at each stage of processing (i.e. as each lexical item is encountered).

At first consideration this would seem satisfiable by any of the standard assumptions of incremental syntactic processing, such as Frazier's *Left-to-Right Constraint* [FR88]. As we will see, however, there is an important difference. While the traditional incremental parsing requirement is subsumed by PIC — i.e. each lexical item must be incorporated into the current "connected" partial syntactic analysis as it is encountered — there is the additional implication that any structure which can be built (according to the principles of grammar), must be. As we will see, this is especially relevant for the characterisation of both attachment and gap-filling preferences. The latter phenomena, in particular, is not considered by traditional definitions of incremental interpretation.

4. Building Phrase Structure

The PIC essentially demands that the syntactic processor make maximal use of all available information (lexical and syntactic) during parsing, such that it constructs a maximal, partial, syntactic analysis. This predicts not only that incoming lexical items will 'project' structure, but also that the parser will use grammatical knowledge to 'predict' structure whenever possible demanding a mechanism which is capable of both bottom-up and top-down operation.

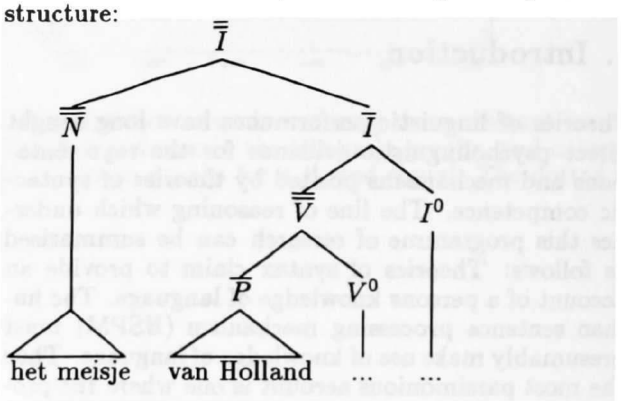
If we assume a parsing model which makes direct use of grammatical principles (not a compiled out set of phrase structure rules, for example), then we are immediately presented with a natural way in which to carve up the top-down and bottom-up components — the distinction between functional and lexical categories. Given a functional node, e.g. CP (S') or IP (S), we can immediately recruit syntactic knowledge to predict the structure of the clause. Given a lexical node, e.g. VP, however, predictions about its internal structure would be guess work and bottom-up attachment into the VP seems more sensible. Evidence for the top-down strategy has been particularly forthcoming in verb-final languages such as Dutch, where arguments must be attached before the verb is reached. Frazier demonstrates this for sentences of the following sort:

(1)

a. "...[$_{CP}$ dat [$_{IP}$ [$_{NP}$ het meisje] [$_{VP}$ [$_{PP}$ van Holland] houdt]]]."
   ...*that the girl Holland likes*

b. "...[$_{CP}$ dat [$_{IP}$ [$_{NP}$ het meisje [$_{PP}$ van Holland]] glimlachte]]."
   ...*that the girl from Holland smiled*

In a reading time experiment, Frazier demonstrated a clear preference for sentences consistent with the VP object analysis as in (1a). This suggests that before the verb is reached, the following is the preferred structure:



Regardless of the particular strategy used to account for this preference[1] this preference entails that the VP node exist as a potential site for attachment, necessitating some degree of top-down parsing. If we assume the prediction of functional structure suggested above, then the VP node would be posited top-down, and a necessary compliment of the functional head I (and IP would in turn have been predicted as the complement of C). See [Cro92] for further discussion of strategies employed in the construction of phrase structure.

[1] It is consistent with both Fraziers's *Minimal Attachment* strategy [Fra79] and Crocker's *Argument Attachment* principle [Cro92].

5. Parsing Empty Categories

Modern transformational grammar is distinguished by its use of empty categories to explicity represent positions vacated by movement. While this is a perfectly reasonable mechanism in the construction of syntactic theory, it poses an interesting question to psycholinguists: Are traces 'psychologically real'? Are traces explicitly recovered during comprehension of an utterance, or are they merely some formal mechanism of the competence theory (thereby weakening the SCH)? In the strict principle-based model we are assuming here, we take traces to be real since they participate crucially in the formation of Chains.

Of all the gap-filling strategies which have been proposed, perhaps the most descriptively successful is the *Active Filler Strategy* (AFS) which has been argued by Frazier and her colleagues. This can be most simply defined as follows [FC89]:

Active Filler Strategy: When a filler has been identified, rank the possibility of assigning it to a gap above all other options.

To illustrate the strategy, Clifton and Frazier [CF89] present the globally ambiguous examples given below in which there is a strong preference for the second interpretation (2b):

(2)

a. "Who$_i$ did Fred tell Mary ε_i left the country."
b. "Who$_i$ did Fred tell ε_i Mary left the country."

Further, they point to the experiments conducted by [CF85] and [Sto86], on sentences of the type in (3), which demonstrate significantly larger reading times for *us* in (3b) than in (3a) or (3c). This suggests that the AFS is operative, assigning the filler to the gap after *bring*, and that some expense results from revising this analysis.

(3)

a. "My brother wanted to know who$_i$ ε_i will bring us home at Christmas."
b. "My brother wanted to know who$_i$ Ruth will bring (* ε_i) us home to ε_i at Christmas."
c. "My brother wanted to know if Ruth will bring us home to Mom at Christmas."

For further evidence and discussion see [CF89]. In the remainder of this paper, we will consider some recent evidence which challenges traditional assumptions about the manner in which long distance dependencies are processed. Specifically, I will argue that, if a trace-based account is to be maintained, the postulation of traces must obey a radical version of Frazier's AFS, but that the revised strategy is in fact derivable from the PIC.

Evidence Against Traces

In a recent article, Pickering and Barry (P&B) contrast the trace-based mechanism of transformational grammar with a 'dependency-grammar' account, wherein a filler is associated directly with its subcategorizer (not mediated via a gap) [PB91]. This contrast is illustrated by the following pair:

(4)

a. "[Which man]$_i$ do you think Mary loves ε_i ?"
b. "[Which man]$_i$ do you think Mary loves$_i$?"

The transformational model of grammar which I have assumed throughout, posits a gap in the object position of *loves* as in (4a), while a dependency grammar account assumes that the filler is directly associated with *loves* as in (4b). P&B point out that, while there is significant evidence supporting the psychological reality of processing unbounded dependencies (see [MB89] and references cited therein) the evidence is equally consistent with the alternative grammatical account discussed above, since the filler and subcategorizer are typically adjacent.

This stalemate demands that we investigate sentences where the subcategorizing element and the position of the proposed trace are separated by intervening material. Consider the following PP extraction:

(5)

a. "[In which tin]$_i$ did you put the cake ε_i ?"
b. "[In which tin]$_i$ did you put$_i$ the cake ?"

The trace-based account prohibits the resolution of the filler-gap relation until the end of the sentence, while the dependency account permits this to be resolved immediately upon encountering *put*. Thus the gap-free model appears to permit a greater degree of incremental interpretation, which seems to be intuitively borne out if the direct object is lengthened:

(6) "[In which tin]$_i$ did you put$_i$ the cake that your little sister's friend baked for you ?"

It seems that we are quite capable of recovering the fact that *In which tin* is the indirect object of *put*, long before we finish processing the direct object NP. Indeed, if we do not pied-pipe the preposition, forcing the interpretation of the indirect object to be delayed until the preposition is reached (since it is the subcategorizer of the NP), then the sentence becomes rather unwieldly:

(7) "[Which tin]$_i$ did you put the cake that your little sister's friend baked for you in$_i$?"

P&B go on to consider examples with multiple long-distance dependencies, which provide further evidence that filler-gap constructions are resolved at the subcategorizer.

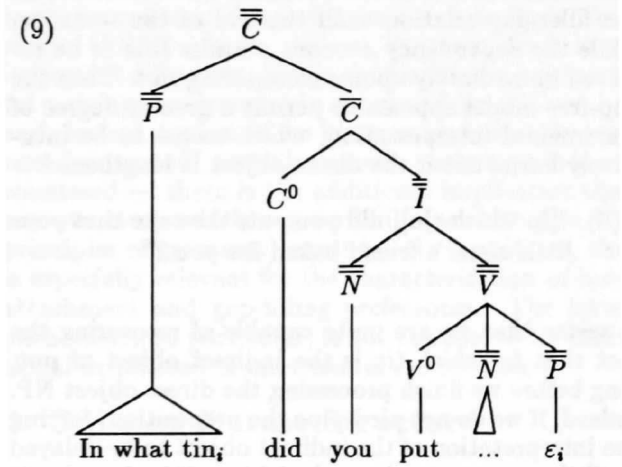
Parsing with Traces: The 2^{nd} Dimension

The arguments of P&B outlined above must be addressed by any model which claims to be principle-based. Crucially, however, traditional models of gap-filling tacitly assume that empty categories may only be posited once the relevant position in the string has been reached. In this way, traces are treated much as lexical items, despite the fact that they lack inherent phonological content. An alternative is to assume that empty categories do not constitute part of the PF level of representation — i.e. the phonetic, S-structure 'yield' of a syntactic analysis. Indeed, current transformational syntax to does not posit the existence of empty categories at any except the syntactic levels of representation (SS and LF). Rather, empty categories are simply another representational device in the syntactic structure of an utterance, with a psychological status similar to the branches of the phrase structure tree. If we adopt this view, then there is no *a priori* reason to delay positing a trace once an attachment site exists in the constituent structure — i.e there is no reason to 'hold off' until the corresponding string yield position is reached. Having relaxed this (unmotivated) constraint on gap-postulation, let us reconsider the following sentence, assuming the use of traces:

(8) "[In what tin]$_i$ did you put the cake ε_i ?"

If we follow the above suggestion, then — once the verb *put* and its VP projection are incorporated into the structure — there is no reason to delay the postulation of the PP-trace as a complement:

(9)



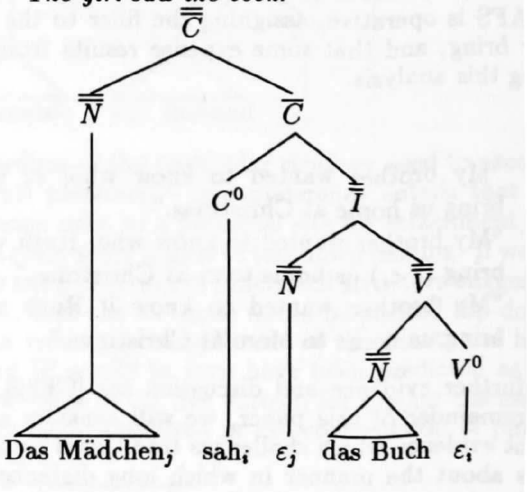
Once this structure is built we can proceed to parse the remaining lexical material (i.e. *the cake*) — whether the remaining input precedes the trace (i.e. intervenes in the structure) or follows it, is of no concern so long as the independent principles of grammar are upheld.

If this proposal seems at first controversial, it is because our existing perception of gap-filling has been shaped by the use of '1-dimensional' characterisations of syntactic analyses; e.g. the string in (8) above constitutes the terminal yield of the S-structure tree in (9), which is fundamentally a '2-dimensional' structure. We can see that the 1-D characterisation has the potential to misguide our intuitions about processing, which is inherently concerned with the recovery of the 2-D structure. Furthemore, empty categories should not be considered *a priori* part of the PF yield, and may therefore be processed as soon as the current partial syntactic representation permits.

This revised view entails that the AFS as proposed by Frazier must be ammended to operate such that it posits a trace in any potentially vacated position made available by the current partial analysis, regardless of where that position is in the string yield. This might be descriptively characterised as a the *hyper*-Active Filler Strategy — what we will dub this the Active Trace Strategy (ATS). Thus a trace may be postulated even sooner than was dictated by the AFS, as discussed earlier. In fact, the ATS is equivalent to the AFS, but is less 'inhibited' given our revised interpretation of the status of empty categories. Indeed, just as we argued that the active prediction of (functionally selected) constituent structure was derived from the PIC, we similarly claim that PIC forces the postulation of traces in an equally 'active' manner, so as to ensure that antecedent-trace relationships are resolved incrementally, and at the earliest possible moment.

Let us now consider some additional support for our approach which demonstrates that the ATS applies for traces resulting from both X^{max} (phrasal) and X^{min} (head) movement. To illustrate this, consider the following example:

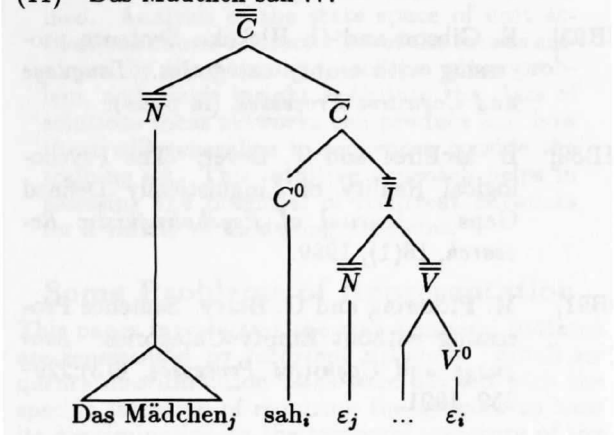
(10) "Das Mädchen sah das Buch."
The girl saw the book.



We follow the standard transformational analysis in assuming that the canonical structure of German and Dutch is V and I final. In both languages, however, the highest verb (either auxiliary or main) raises to

the beginning of the sentence (to C^0) followed by topicalisation of some phrase to the [Spec,CP] position; the so-called verb-second, or V-2, phenomena. Note, both the English and German sentences have similar word order, but the structure illustrates that in German, the D-structure position of the verb occurs at the end of the sentence. If we assumed the traditional gap-filling strategies, then German and Dutch hearers would be forced to delay the use of the verbs selectional information until the end of the sentence, after all the complements have been parsed.[2] This contrasts with Stowe's evidence for English which seems to demonstrate the incremental use of thematic information during processing [Sto89]. Thus the traditional assumptions about gap-filling imply that — for sentences with virtually identical word order — English hearers have the advantage of using thematic information incrementally, while German hearers do not. Given the account motivated above, however, we predict an equivalent degree of incrementality for both language types. Consider the structure for the following partial input:

(11) "Das Mädchen sah ..."



Given the prediction of functional constituent structure argued for earlier, the parser can posit both the subject trace (in [Spec,IP]) and the trace for the head of the VP immediately, since the necessary structure exists for the postulation of these traces (recall the functional prediction of IP by C, and VP by I). This in turn permits the relevant thematic structure to be recovered, allowing the selectional properties of the verb to be consulted immediately. Thus if the sentence fragment was *Das Buch sah ...*, the parser could quickly determine that the topicalised NP was not a plausible agentive subject, and reanalyse.

A similar proposal for early trace postulation is also presented in [GH93], and briefly considered in [Gor93]. The parsing model suggested by Gibson and Hickok (G&H) postulates a wh-trace immediately once the subcategorizer is found. Indeed, the model they propose should behave identically to that of P&B. In contrast, the present model does *not* stipulate that the the parser should wait for a subcategorizer, but rather that the trace should be postulated as soon as an attachment site is available. Thus while all models successfully account for the indirect wh-PP object examples above, both P&B and G&H fail to explain the broader evidence for early trace postulation. In particular, their subcategorization-driven parsers will be at a disadvantage in the case of verb final languages such as Dutch. Consider the following examples from [Fra87]:

(12)

a. "Jan houdt niet van de Amerikaanse die de Nederlander wil uitnodigen.(Amb.)"
   John liked not the American who the Dutchperson wants to invite.
   John liked not the American who wants to invite the Dutchperson.
b. "Karl hielp de mijnwerkers die de boswachter vonden.(Unamb.)"
   Karl helped the mineworkers who found-PL the forester.
c. "Karl hielp de mijnwerkers die de boswachter vond.(Unamb)"
   Karl helped the mineworkers who the forester found-SG.

For the data in (12), Frazier has identified a preference for the subject-gap reading (12b) even where the final verb forces an object-gap reading. This data is consistent with both the AFS and ATS, given the functional prediction of the subject NP we have argued for earlier. Clearly, waiting for the subcategorizer as G&H suggest will not explain this phenomena. Their model would simply leave the lexical NP unattached (or possibly attach it as the subject), and once the verb is reached try to posit the trace. If the NP is unattached, then they predict no preference either way (the agreement on the verb will unambiguously solve the problem). If the NP is preferentially attached as a subject, they predict a preference for object relative, *contra* Frazier's evidence. It is also clear that this preference is not captured by *direct-association* mechanism of P&B. Indeed, it is difficult to see how a non-trace-based theory could account for this data, thus providing positive evidence for the psychological reality of empty categories. Finally, t is unclear what either model predicts for the German head-movement example.

6. Conclusions

In this paper we have demonstrated that in order to account for incremental processing data from verb-final languages, the processor must operate at least partially top-down, as concluded in [Fra87]. This does not, however, entail a 'compiled out' phrase structure component as Frazier suggests. Rather the

[2] While in the example, we only have one complement, there could be more, and of arbitrary length.

degree of top-down processing can be explained simply by the prediction of functional structure as demanded by the *Principle of Incremental Comprehension*. We have further outlined the process of resolving antecedent-trace relations. On the basis of the recent, and rather convincing, arguments of P&B, we have argued traces are not part of the PF yield for a syntactic structure, and are manifest in the syntax alone. Given this, the notion of 'encountering' a gap is simply not well-formed. Insofar as this is the case, there is no reason to delay the postulation of traces until its string position is reached. This relaxation on trace postulation, combined with the PIC, predicts that a trace will be postulated as soon as an appropriate position in the syntactic structure exists. This *Active Trace Strategy* accounts not only for the relevant data presented by P&B, but also for a range of other data from English, Dutch, and German. We also demonstrate that the early-trace mechanism does not depend on subcategorisation information, as suggested by both P&B and G&H. Crucially, early trace postulation also hinges on the top-down parser, as illustrated in the case of Dutch relative clauses. This mitigates against the 'head-driven' proposals of G&H concerning the principle-based sentence processor (see also [Fra87], [Pri91]), and cannot be explained within non-trace-based accounts such as that of P&B.

References

[BW84] R. Berwick and A. Weinberg. *The Grammatical Basis of Linguistic Performance.* MIT Press, 1984.

[CF85] S. Crain and J. D. Fodor. How Can Grammars Help Parsers? In Dowty, Karttunen, and Zwicky, editors, *Natural Language Parsing*, chapter 3, pages 94–128. Cambridge University Press, 1985.

[CF89] C. Clifton and L. Frazier. Comprehending Sentences with Long-Distance Dependencies. In Carlson and Tanenhaus, editors, *Linguistic Structure in Language Processing*, pages 273–317. Kluwer Academic Publishers, 1989.

[Cro92] M. W. Crocker. *A Logical Model of Competence and Performance in the Human Sentence Processor.* PhD thesis, Edinburgh, U.K., 1992.

[FC89] L. Frazier and C. Clifton. Successive Cyclicity in the Grammar and Parser. *Language and Cognitive Processes*, 4(2):93–126, 1989.

[Fon91] S. Fong. *Computational Properties of Principle-Based Grammatical Theories.* PhD thesis, MIT, 1991.

[FR88] L. Frazier and K. Rayner. Parameterizing the Language Processing System: Left- vs. Right-branching Within and Across Languages. In J. Hawkins, editor, *Explaining Linguistic Universals*, pages 247–279. Blackwell, 1988.

[Fra79] L. Frazier. *On Comprehending Sentences: Syntactic Parsing Strategies.* PhD thesis, University of Connecticut, 1979.

[Fra87] L. Frazier. Syntactic Processing: Evidence from Dutch. *Natural Language and Linguistic Theory*, 5:519–559, 1987.

[Gor93] P. Gorrell. A note on the direct association hypothesis: A reply to pickering and barry (1991). *Language and Cognitive Processes*, (in press).

[GH93] E. Gibson and G. Hickok. Sentence processing with empty categories. *Language and Cognitive Processes*, (in press).

[MB89] B. McElree and T. Bever. The Psychological Reality of Linguistically Defined Gaps. *Journal of Psycholinguistic Research*, 18(1), 1989.

[PB91] M. Pickering and G. Barry. Sentence Processing without Empty Categories. *Language and Cognitive Processes*, 6(3):229–259, 1991.

[Pri88] B. Pritchett. Garden Path Phenomena and the Grammatical Basis of Language Processing. *Language*, 64:539–576, 1988.

[Pri91] B. Pritchett. Locality in language processing: head-driven parsing, head-position, & the CED. In H. Goodluck and M. Rochemont, editors, *Psycholinguistics of Island Constraints*, (in press).

[Sto86] L. Stowe. Parsing Wh-constructions: Evidence for on-line gap location. *Language and Cognitive Processes*, 1:227–246, 1986.

[Sto89] L. Stowe. Thematic Structures and Sentence Comprehension. In Carlson and Tanenhaus, editors, *Linguistic Structure in Language Processing*, pages 319–357. Kluwer Academic Publishers, 1989.