# Incremental Syntax Processing and Parsing Strategies

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## Abstract

Psycholinguistic models of language processing usually postulate that parsing the syntactic structure of a sentence proceeds incrementally in some way, which means that the syntactic analysis is not delayed until the end of the clause or sentence. In this paper we will discuss different conceptions of incrementality in the light of empirical studies on the influence of grammatical case on structure building in German subject-object asymmetries. It will be shown that neither word-by-word attachment of partial structures into the phrase marker of the sentence (Frazier, 1987a), nor head corner parsing (Abney, 1987; Kay, 1989) can explain the data found in our experiments. As a strategy which is consistent with our data, left-corner parsing (Johnson-Laird, 1983) will be discussed.

## Introduction

Most current theories on human language processing postulate that syntactic structures or phrase markers are built up incrementally in some way (e.g., Abney, 1987; Crain, & Steedman, 1985; Frazier, 1987; Marslen-Wilson, 1976). This means that syntactic structure building is not delayed until clause boundaries, as has been proposed in earlier work (MacKay, 1966; Jarvella, 1979). One of the main questions now is exactly when partial structures which are derived from the input words are integrated into the phrase marker of the sentence. Two alternatives will be discussed in the following sections: the *word-by-word* integration proposed by Frazier's *Garden-Path Model*, and the *head-corner* approach which can be found in Abney's *Licensing-Structure Parser*. The predictions which can be derived from these approaches will be discussed in the light of empirical findings on the influence of grammatical-case information on structure building in German subject-object asymmetries.

## Word-by-word attachment versus attachment via licensing relations

One of the basics of Frazier's Garden-Path Model is what might be called the principle of *word-by-word integration*: *"In this model perceivers incorporate each word of an input into a constituent structure representation of the sentence, roughly as each item is encountered."* (Frazier, 1987a, p. 562)

For reasons of clarity, we will ignore the term "roughly" for the following discussion, because the quoted formulation of the principle is too vague to lead to concrete empirical predictions. In its more rigid version, it says that sentences are built up in a strictly word-by-word fashion. Each word is attached to the phrase marker of the sentence as soon as it is read.

An alternative to this conception of attachment is realized in Abney's Licensing Structure Parser (Abney, 1987, 1989). Abney postulates that items are only attached when there is a lexical head which provides a licensing relation. Licensing relations are the theta-relation (e.g., for the arguments of verbs, noun,s or adjectives), the modifier-relation (e.g., for noun-modifying adjectives or PPs), or the subject-relation which is provided by INFL, the head of the inflection-phrase (IP). A consequence of Abney's principle of attachment via licensing relations is that verb arguments cannot be attached to the phrase marker of the sentence until the verb is encountered, and a potential subject-NP cannot be attached before the finite verb has been found. Using a classical NP analysis, the determiner, as well as potential adjective phrases, cannot be attached before the noun is perceived.[1] Since in Abney's model of human sentence processing constituents can only be attached to phrases when the respective lexical head is encountered, the strategy underlying the parser is a kind of *head-corner* parsing (Kay, 1989).

What has been shown empirically up to now is that prepositional phrases (PPs) or noun phrases (NPs) are at-

1. Things look a little different when a DP-(determiner phrase)-analysis with the determiner as its lexical head is preferred. Due to the space limitations we cannot discuss the consequences of DP-analyses for our empirical questions.

tached at least soon after they have been completely read, which means that they are certainly attached before the end of the clause or sentence (Frazier, 1987b). However, these findings do not distinguish between the attachment alternatives just described. In English or Dutch, where many of the relevant experiments have been carried out, it is not easy to find out whether an attachment of a partial noun phrase has taken place as soon as the determiner has been read (which would be predicted by word-by-word attachment). The richer morphology in German makes it possible to put this question to an empirical test.

## Subject-Object Asymmetries in German

In contrast to the more rigid word order constraints in English, there is considerable variability in constituent placement in German. So, you can express the fact that there is a chicken which has been noticed by a fox by a subject-verb-object (SVO) sentence like (1a), as well as by an object-verb-subject (OVS) sentence like (1b). Structurally (1a) and (1b) are ambiguous with respect to the grammatical roles of the noun phrases. Mostly, but not always, this ambiguity is resolved by the grammatical case of the noun phrases which are involved. In (1a,b), the case of the NP *der hungrige Fuchs* is unambiguously nominative, therefore it must be the subject of the sentence. In (1c), both NPs can be either subject or object of the sentence. There is a strong tendency, however, to analyze the first NP as the subject of the sentence if grammatically permissible. This tendency leads to a garden-path effect in sentences like (1b), where the first NP can be, and consequently is, understood as the subject of the sentence in a first analysis. A reanalysis is forced by the second NP, which must be the subject, because its case is unambiguously nominative. Different strategies have been proposed to be responsible for this preference for SVO-structures. Although these strategies will not be discussed in detail here, it should be noted that what kind of strategy will have to be adopted depends very much on the presumed linguistic representation underlying the structures under investigation.[2]

(1) a. *Der hungrige Fuchs bemerkte das fette Huhn.*
the hungry fox (nominative) noticed the fat chicken (nominative or accusative)

b. *Das fette Huhn bemerkte der hungrige Fuchs.*
the fat chicken (nominative or accusative) noticed the hungry fox (nominative)

c. *Die hungrige Katze bemerkte das fette Huhn.*
the hungry cat (nominative or accusative) noticed the fat chicken (nominative or accusative)

d. * *Der hungrige Fuchs bemerkte der fette Hahn.*
the hungry fox (nominative) noticed the fat cock (nominative)

This preference for SVO structures can now be used to find out exactly when NPs are integrated into the phrase marker of the sentence. Only when the NP currently being processed, or a partial representation of that NP, is attached to the sentence, can the above-mentioned garden path effect occur. The same is true for ungrammatical sentences like (1d), where two NPs compete for the same grammatical role (the subject-role in this case) which each of them unambiguously must take. Only when an attachment of the (partial) representation of the second NP to the sentence is attempted, does it become obvious that the sentence cannot be grammatically correct, because it would have to be attached to the subject-position which is already filled.

## Experiments

### Design and Materials

In German, there are three possibilities of how case information can relate to the grammatical roles of subject or direct object. Depending on the gender of the phrase, the NP may either be unambiguously nominative (nom, masculine) which means that it must be the subject of the sentence, it may be unambiguously accusative (acc, masculine), which means that it must be the direct object of the sentence, or it is ambiguous (amb, feminine or neuter) with respect to these cases, and accordingly to these grammatical roles. Sentences were constructed with two-place verbs, varying the first and the second NP independently according to these three possibilities. From these variations result two ungrammatical structures (2a,e), three SVO-sentences (2d, f, g), three OVS-sentences (2b, c, h), and one ambiguous sentence (2i).Test sentences for each subject consisted of 2 sentences for each of these 9 conditions. No conceptually similar sentence was presented more than once. The 18 test items were randomly mixed with 92 filler sentences. Each session started with a set of 10 training sentences.

2. If both subject and object fronting result from moving the respective constituent into the topic position (e.g., SpecC), as it has been assumed for quite a while, the *Active Filler Hypothesis* (Frazier, 1987b) leads to the correct predictions: it roughly says that if a filler is identified, it should be bound to a gap as soon as possible. Binding the first NP to the first gap leads to the subject-first reading of the sentence (Hemforth, in press). Since now it can be shown that the topic-analysis of subjects is conceptually implausible (Hemforth, in press) and empirically wrong (Wilder, 1992), we prefer an explanation according to the *Minimal Gap Principle* (Hemforth, in press), supposing that only non-subject fronting leads to a gap in the phrase marker of the sentence.

(2) a. * *Der hungrige Fuchs (nom) bemerkte der fette Hahn (nom).*
b. *Den hungrigen Fuchs (acc) bemerkte der fette Hahn (nom).*
c. *Die hungrige Füchsin (amb) bemerkte der fette Hahn (nom).*
d. *Der hungrige Fuchs (nom) bemerkte den fetten Hahn (acc).*
e. * *Den hungrigen Fuchs (acc) bemerkte den alten Hahn (acc).*
f. *Die hungrige Füchsin (amb) bemerkte den alten Hahn (acc).*
g. *Der hungrige Fuchs (nom) bemerkte das alte Huhn (amb).*
h. *Den hungrigen Fuchs (acc) bemerkte das alte Huhn (amb).*
i. *Die hungrige Füchsin (amb) bemerkte das alte Huhn (amb).*

## Methods

Two techniques were used in our experiments:

**Self-paced reading task:** Sentences were presented word by word on a computer screen. Subjects controlled the speed of the presentation by pressing a button. As soon as the button was pressed, the current word disappeared from the computer screen and the next word of the sentence appeared. Each sentence was followed by a question concerning its acceptability and a question concerning the interpretation of the sentence. Both questions had to be answered by pressing one of two buttons (yes or no).

**Continuous decision task:** In this experiment the presentation of the material was almost exactly like that of the self-paced reading experiment. The only difference was that subjects had to decide word by word by pressing one of two buttons (yes or no) whether or not the sentence they were reading was acceptable up to the word they were currently processing.

In both experiments word recognition times were controlled by using standardized lexical decision times as a covariate. The decision times were recorded in a pretest with 48 subjects who didn't participate in the main experiments. 32 subjects participated in the self-paced reading experiment, 34 in the continuous decision experiment. All subjects were students at the Ruhr-University of Bochum, and native speakers of German.

## Hypotheses

From preference for SVO-sentences[3] it can be concluded that it should be more difficult to process the first NP of a sentence if it cannot be the subject of the sentence, i.e., if it is unambiguously an accusative-NP (2b,e,h). For the second NP, it can be predicted that it should be more difficult to process when its case leads to an ungrammatical sentence (2a,e), or if a garden path is produced by an ambiguous first NP and a second NP which must be the subject of the sentence (2c).

Presuming that each word of a sentence is integrated into the phrase marker of the sentence as soon as it is read,

- higher reading and decision times should be found from the beginning of the first NP if it unambiguously has to be the direct object of the sentence, i.e., if its case is accusative.

- higher reading and decision times should be found from the beginning of the second NP, if its case leads to an ungrammatical sentence, or if an ambiguous first NP is followed by an unambiguous NP which has to be the subject of the sentence.

Presuming that an attachment is only possible if the lexical head which provides the respective licensing relation has already been read,

- higher reading and decision times for a first NP whose case is accusative should be found when the finite verb has been read, and not beforehand, because no attachment is possible before this point.

- for the second NP, higher reading and decision times, which are predicted for the structures described above, should be found at the end of the second NP, and not before.[4]

## Results

For the first NP we didn't find any effects of case at the determiner or at the adjective, either for reading times or for decision times (all F's < 1). Reading times (RT)

3. In an experiment which will not be presented here in detail, it was found that OVS-sentences are more difficult to process than SVO-structures, and ungrammatical sentences are more difficult to process than grammatical ones.

4. For DP-analyses, of course, predictions would be more complicated. An effect would be predicted for the determiner, because the partial DP generated by its head can be directly attached to the phrase marker of the sentence. No effects should be found for adjectives which can only be integrated via the noun which provides the licensing relations necessary for the attachment.

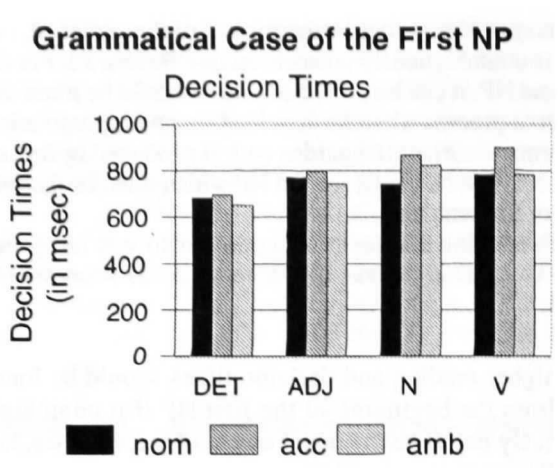


FIGURE 1

and decision times (DT) for accusative-NPs were higher when the noun of the first NP and the verb of the sentence were encountered (DT: noun: main effects: F1 = 4.77, df = 2, 65, $p < 0.02$; F2 = 2.21, df = 2,33, $p < 0.13$; acc vs. nom: F1 = 6.91, df = 1, 32, $p < 0.02$; F2 = 7.83, df = 1, 16, $p < 0.02$; acc. vs. amb. not significant (ns); verb: main effects F1 = 5.76, df = 2, 65, $p < 0.01$; F2 = 1.96, df = 2, 34, $p < 0.16$; acc. vs. nom: F1 = 8.21, df = 1, 32, $p < 0.01$; F2 = 2.71, df = 1, 17, $p < 0.12$; acc. vs. amb: F1 = 8.53, df = 1, 32, $p < 0.01$; F2 = 2.11, df = 1, 17, $p < 0.17$); RT: noun: main effects: F1 = 4.76, df = 2, 59, $p < 0.02$; F2 = 3.08, df = 2,33, $p < 0.06$; acc vs. nom: F1 = 5.88, df = 1, 29, $p < 0.12$; acc. vs. amb: F1 = 3.47, df = 1, 29, $p < 0.08$; F2 = 2.79, df = 1, 16, $p < 0.12$; verb: main effects: F1 = 3.50, df = 2, 59, $p < 0.04$; F2 = 3.47, df = 2, 34, $p < 0.05$; acc vs. nom: F1 = 4.16, df = 1, 29, $p < 0.06$; F2 = 3.60, df = 1, 17,

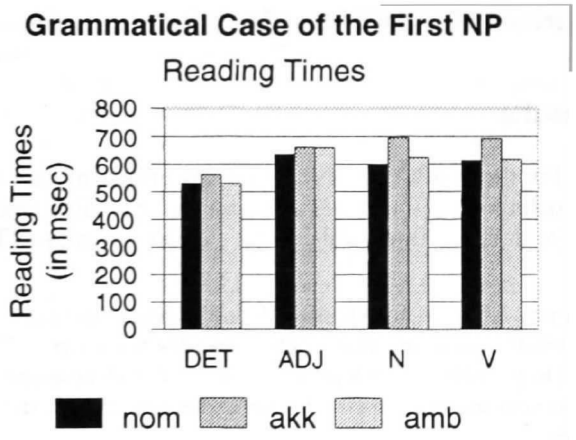


FIGURE 2

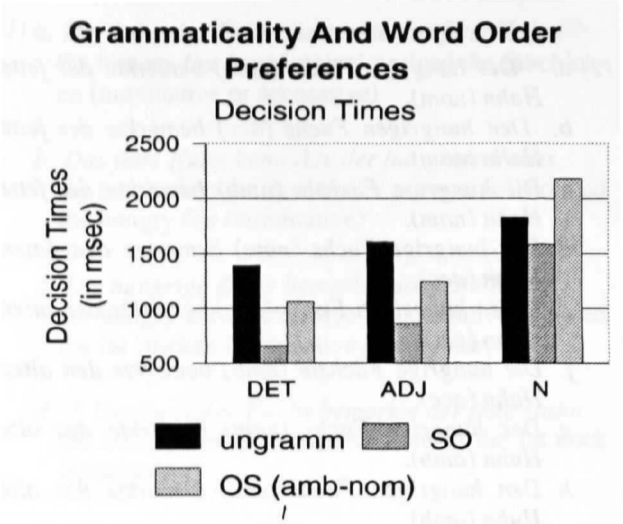


FIGURE 3

$p < 0.08$; acc vs. amb: F1 = 4.19, df = 1, 29, $p < 0.06$; F2 = 4.73, df = 1, 17, $p < 0.05$; see Fig. 1,2).

When the second NP was processed[5] (see Fig. 3,4) effects of grammaticality were found for reading and decision times, as soon as the determiner was read (ungramm vs. SO, RT: det: F1 = 16.03, df = 1, 30, $p < 0.001$; F2 = 4.63, df = 1, 17, $p < 0.05$; adj: F1 = 4.36, df = 1,29, $p < 0.05$; F2 = 6.19, df = 1, 16, $p < 0.03$; DT: det: F1 = 28.64, df = 1, 33, $p < 0.001$; F2 = 39.30, df = 1, 17, $p < 0.001$; adj: F1 = 30.91, df = 1, 32, $p < 0.001$; F2 = 92.42, df = 1, 16, $p < 0.001$). Effects of word order preferences at the determiner and the adjective were only found for decision times (SO vs. OS, det: F 1 = 20.46, df = 1,33, $p < 0.001$; F2 = 6.65, df = 1, 17, $p < 0.03$; adj: F1 = 9.20, df = 1, 32, $p < 0.01$; F2 = 8.67, df = 1, 17, $p < 0.01$). At these positions, higher reading times were found, especially when an ambiguous first NP was followed by an NP which had to be the subject of the sentence (i. e., a nominative NP; amb/nom vs. amb/amb: F1 = 9.79, df = 1, 33, $p < 0.01$; F2 = 3.16, df = 1, 17, $p < 0.10$; amb/nom vs. amb/acc: F1 = 13.37, df = 1, 33, $p < 0.01$; F2 = 7.85, df = 1, 17, $p < 0.02$). A marginal word order effect was found in the reading time experiment, when an ambiguous NP was followed by a nominative NP (amb/nom vs. amb/acc: F1 = 3.38, df = 1, 17, $p < 0.09$; F2 ns). No significant effects can be reported for the noun of the sec-

5.For the following analyses sentences with two accusative or two nominative NPs have been put together in the condition "ungrammatical", sentences with a first accusative or ambiguous NP and a second nominative NP are "Object-Subject" (OS)-sentences, all other conditions are put together as "Subject-Object" (SO)-sentences. We added sentences with two ambiguous NPs to this condition, because, according to questions we asked after these sentences, they were nearly always understood as SO-sentences.

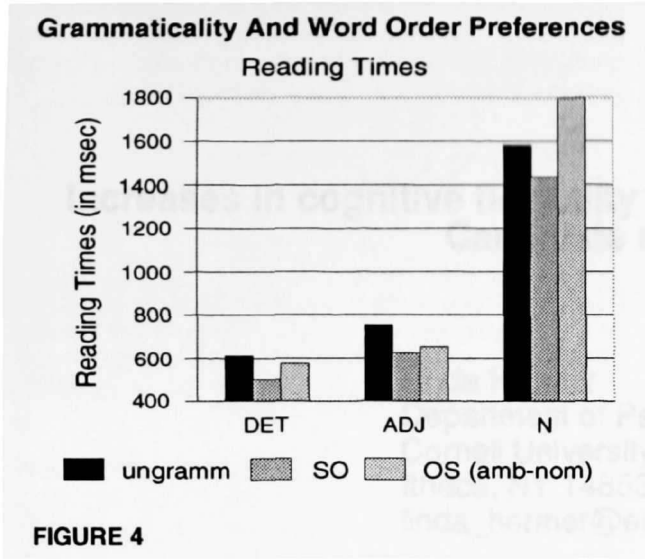


**FIGURE 4**

ond NP, probably due to higher variances which are very often found at the end of sentences.

## Conclusions

What can be concluded from the empirical results is that none of the attachment strategies discussed in section 2 could be confirmed. We couldn't find word-by-word integration for the first NP, but integration obviously takes place before the verb is encountered, namely at the noun of the first NP. However, in processing the second NP, subjects did not delay attachment until the noun was read; rather they started the integration at the very beginning of that NP. Neither word-by-word attachment nor head-corner parsing seems to be empirically persuasive.

Of course, an alternative has to be found which is consistent with the data. One processing strategy that has been assumed to be psychologically plausible by Johnson-Laird (1983) is a special variant of left-corner parsing (Earley, 1970; Aho, Hopcroft, & Ullmann, 1974). He proposes that the human sentence processing system "... parses the left-hand corner of each tree (or subtree) from the bottom up and the rest of the tree (or subtree) top down" (p. 298). According to this left-corner algorithm attachments for sentences like those under investigation in our experiments would proceed as follows:

The determiner is recognized as the left-hand corner of the first NP. The following N' will be predicted and the adjective, as well as the noun, can easily be attached to the NP-node. No attachment to the phrase marker of the sentence has taken place up to this point. When the NP is completed, it is recognized as a potential left corner of a sentence. According to the preferences described above, an attachment as the subject of the sentence is attempted. If this attachment fails, in the case of an accusative-NP, a time-consuming reanalysis will be necessary. When the verb has been read, the second NP can be predicted top-down. Therefore, the partial NP generated by the determiner can be directly attached. This left-corner strategy is completely consistent with the data from both experiments, especially the effects of grammaticality at the beginning of the second NP which have been found for decision times as well as for reading times.[6]

Of course, further research will have to be done to evaluate the psychological validity of left-corner parsing. It will have to be empirically tested as to how far this strategy applies to different kinds of sentence material.

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6.The inconsistencies of decision and reading times especially concerning word order effects at the second NP can have different explanations. It might be possible that the grammaticality judgments lead to artificial results which cannot be obtained when the experimental task is more "natural". Another possibility is that reading times are not sensitive enough for the effects under investigation. To us, the "sensitivity" explanation seems more plausible, since the pattern of results in the reading time experiment was very similar to that of the decision time experiment, although the differences did not reach significance. We will evaluate the different explanations in the near future by eye movement experiments.

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