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## Parsing

Introductory article

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*Introduction*

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*Parsing refers to the way that people assign a syntactic (grammatical) analysis to a sentence as they hear or read it.*

### INTRODUCTION

Our understanding of language is normally extremely efficient and often appears effortless. However, the underlying processes are extremely complex and sophisticated. They clearly make use of very specific information, as is apparent from the inability we have to perform any kind of analysis

on an utterance in a language we are unfamiliar with. Researchers in the area assume that comprehension can be broken into several components, including word recognition and comprehension of entire discourses. Between such 'early' and 'late' stages lies a component that is concerned with processing combinations of words. Psycholinguists normally refer to this component as the 'parser'.

As a first approximation, parsing is concerned with assigning a syntactic analysis and a semantic interpretation to a sentence (or complete utterance). Hence, it is sometimes referred to as 'sentence

processing'. The most important source of linguistic information that it employs is knowledge of syntax and semantics – in other words, the information that is discussed in most linguistic textbooks concerned with grammar. However, instead of simply describing analyses that can be assigned to sentences, a theory of parsing is concerned with understanding how people actually convert an uninterpreted string of words into a syntactic analysis and associated meaning.

Many studies of parsing involve reading or listening to sentences containing some syntactic ambiguity. Consider, for example, *The farmer hit the tramp with the stick*. According to linguistic theory, this sentence is ambiguous, not because a word has two meanings, but because the phrase *with the stick* can modify either the verb phrase *hit the tramp* or the noun phrase *the tramp*. In the former case, the sentence means that the farmer used the stick to hit the tramp; in the latter, it means that the farmer hit the tramp who had the stick. Theories of parsing attempt to determine how people analyze sentences, and they often use evidence about the processing of syntactically ambiguous sentences to do this. In order to do this, they examine what happens while (and sometimes after) people are reading or listening to such sentences.

One thing that we can now be certain of is that sentence comprehension begins almost immediately. We know this because a 'unified' interpretation is assigned to each sentence fragment as every word is encountered. For instance, people are disrupted by a word whose interpretation is incompatible with preceding context as soon as that word is encountered. But can information such as semantic plausibility be used to 'guide' parsing in cases of ambiguity? This has been the dominant question in parsing research and is motivated, ultimately, by the question of whether parsing constitutes an autonomous process that occurs before true interpretation takes place. In other words, answering this question may help resolve one aspect of the 'modularity' debate that has played such an important role in cognitive science. This article first considers the evidence for and against an autonomous parser, and then briefly considers ways in which parsing research is currently reaching beyond this question.

## AUTONOMOUS ACCOUNTS

The 'classic' autonomous account is the 'garden-path' theory. On this account, the parser makes initial parsing decisions using some syntactic information and very little else. It uses a core principle known as 'minimal attachment' to decide which

analysis to pursue in cases of ambiguity. This says adopt the simplest analysis, which is defined as the one involving fewest nodes in a phrase structure tree. According to Frazier's syntactic assumptions, the verb-phrase analysis of *The farmer hit the tramp with the stick* is simpler than the noun-phrase analysis, and so that analysis is initially adopted. In this case the sentence is globally ambiguous (because the sentence has two interpretations). But the parser applies the principle as soon as an ambiguity emerges, and so the principle affects the processing of sentences that are locally ambiguous but which are eventually disambiguated. An example of a local ambiguity occurs in *The defendant examined by the lawyer turned out to be unreliable*, where *examined by the lawyer* is a 'reduced relative' that modifies *the defendant*; however, after *examined*, it might continue as a simple 'main-clause' sentence (e.g. *The defendant examined the jurors*). Because the main-clause analysis involves fewer nodes, the garden-path theory predicts that readers initially adopt this analysis. This analysis turns out to be incompatible with the words after *examined*, and so readers are 'led up the garden path': they experience processing difficulty and are forced to re-analyze (or fail to parse the sentence at all) (e.g. Frazier and Rayner, 1982).

If the two analyses have the same number of nodes, another principle, known as 'late closure', is applied. This says, when possible, attach new words into the phrase that is currently being processed. So for instance, in *John said Fred died yesterday*, the word *yesterday* is preferentially attached to *died* (i.e. Fred died yesterday). Neither minimal attachment nor late closure draws upon any information apart from phrase-structure geometry. According to garden-path theory, initial parsing pays no attention either to the relative frequency of the analyses or to whether the interpretation of one analysis is more compatible with background knowledge than the others (in other words, to plausibility). According to garden-path theory, information like frequency or plausibility can be used during subsequent processing. In other words, they can affect re-analysis, but not initial analysis. Thus, the model is called a 'two-stage' account, because the stages of initial analysis and re-analysis employ different sources of information. Additionally, notice that this theory assumes that the processor always adopts a single analysis at a time. Because alternative analyses are only ever considered if the initial analysis is abandoned, the garden-path theory is often called a serial account (i.e. one analysis at a time). Other autonomous accounts exist (including ones that make reference to thematic

role assignment), but the garden-path theory is by far the best known.

Early experimental evidence provided strong support for the garden-path theory. For example, some work found that people had difficulty with sentences like *The spy saw the cop with a revolver*, where the verb-phrase analysis is implausible. This suggested that they initially adopted the verb-phrase analysis and then re-analyzed. Similarly, people appeared to have difficulty with reduced-relative sentences. But reduced-relatives are generally fairly rare types of sentence, so an alternative explanation for this result is surely that people have adopted the more frequent analysis.

## INTERACTIVE ACCOUNTS

More recently, a great deal of experimental work has critiqued autonomous parsing accounts. In general, such research has attempted to show that a source of information, such as frequency or plausibility, plays a role in initial parsing decisions. This work supports 'interactive' accounts, in which all potentially relevant sources of information can be drawn upon at the same time. Although interactive accounts have a long history in language comprehension, the recent resurgence in their popularity has been associated with so-called constraint-based theories. These theories are broadly based on connectionist models and assume that language comprehension involves the integration of a large number of 'soft' constraints and that alternative analyses compete for activation. Importantly, such models assume that many analyses can be considered in parallel.

To explicate such accounts, consider a study that contrasted sentences like (a) *The defendant examined by the lawyer turned out to be unreliable* with (b) *The evidence examined by the lawyer turned out to be unreliable*. As in most good parsing research, the sentences are very closely related (only one critical word differs between them, and between other pairs of sentences used in the study). According to garden-path theory, people should initially adopt the reduced-relative analysis in both (a) and (b), because they are syntactically identical. But notice that while a defendant can examine things, evidence cannot. This means that the main-clause analysis of (b) is implausible at the word *examined*. Constraint-based accounts therefore predict that people will find it much easier to adopt the reduced relative analysis in (b) than (a). In accord with this, Trueswell *et al.* (1994) found that people were disrupted reading *by the lawyer* in (a) but not in (b). Early effects of 'referential' semantic processing

have also been demonstrated, though alternative interpretations of these data are possible.

Constraint-based accounts also assume that the relative frequency of different analyses affects initial parsing preferences rather than (for example) minimal attachment. In other words, people initially prefer frequent analyses, not simple ones. The sentence *The criminal confessed his sins harmed too many people* is locally ambiguous, in that *confessed* can either take a noun-phrase object (e.g. *his sins*) or a sentential complement (as turns out to be the case). If people experience difficulty reading *harmed*, this suggests that they initially interpreted *his sins* as the object, and then had to re-analyze. As the object analysis is simpler, garden-path theory predicts that it will always be adopted initially, and hence that re-analysis will always be necessary. While some recent work has supported this, other work has found that people re-analyze if the main verb more frequently takes an object than a sentential complement, but not if it more frequently takes a sentential complement.

Overall, there is good evidence that people use many relevant sources of information rapidly, but it is unclear precisely which model of comprehension is correct. Although it is by now unlikely that the garden-path model is correct, other autonomous parsing accounts may well be able to explain current data. Constraint-based accounts face challenges too (for instance to their claims that ambiguity resolution involves competition between alternatives and that lexical ambiguity resolution is a form of syntactic ambiguity resolution).

## PARSING AND COMPREHENSION

The traditional focus on the nature of ambiguity resolution and its implications for the initial stages of parsing is, to some extent, being replaced by an interest in a series of broader questions about parsing and its relation to other aspects of language comprehension. One critical issue is what people do when they realize they have adopted the wrong analysis (or have preferred it, within a parallel architecture). Some recent evidence in this area suggests that some kinds of re-analysis are easier than others and that people adopt particular re-analysis strategies (e.g. when more than one alternative analysis is available). Another interesting question is whether people only re-analyze as a last resort or whether they sometimes 'bail out' of an analysis before being absolutely certain that it is incorrect.

Questions of re-analysis, however, still relate entirely to syntactic processing, that is how people

adopt a syntactic analysis. However, the ultimate goal of parsing is, of course, to determine the appropriate interpretation that should be assigned to a string of words and to integrate that interpretation with discourse context and general knowledge. Thus, researchers have asked how people use context to decide on the appropriate interpretation for expressions – for example how people interpret elliptical phrases, how they should interpret a pronoun or other referring expression, and so on. It is clear that theories of parsing need to be fully integrated into more general accounts of language comprehension. This is likely to be a major focus of future research.

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## Parsing: Overview

Introductory article

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*Parsing is the task of determining how the words in a sentence combine to yield a structured representation of the sentence meaning, given a grammar.*

### INTRODUCTION

To understand a sentence, one has to determine how the words in the sentence are combined to arrive at a meaning for the sentence. Consider the following examples:

- a. The dog bites the man.
- b. The man bites the dog. (1)

Sentences (1a) and (1b) have the same words. However, the words are combined differently, resulting in two very different sentence meanings. The set of rules governing how words are combined for a given language is called a *grammar* of that language. Sentences (1a) and (1b) are acceptable English sentences, whereas the asterisk preceding (2) indicates that this sentence is unacceptable.