CHAPTER 10

UNDERSTANDING THE STRUCTURE OF SENTENCES

INTRODUCTION

I'm going to be honest here; most students find this chapter difficult, and many say they can't see the point of parsing. But how do you tell the difference between "Vlad killed Boris" and "Vlad was killed by Boris"? And when you hear "I saw the Pennines flying to Dundee," why don't you think, "Cor, those Pennines are overhead on their way to Dundee again." And when you come across sentences such as "The cop shot the burglar the gun," how do you know just who had a gun? These are details that give language its fantastic expressive power.

So far we have largely been concerned with the processing of individual words. What happens after we recognize a word? When we access the lexical entry for a word, two major types of information become available: information about the word's meaning, and information about the syntactic and thematic roles that the word can take. The goal of sentence interpretation is to assign thematic roles to words in the sentence being processed—who is doing what to whom (see Box 10.1). One of the most important guides to thematic roles comes from an analysis of the **verb**'s **argument structure** (sometimes called subcategorization frame). For example, the verb "give" has the structure AGENT gives THEME to RECIPIENT (e.g., "Vlad gave the ring to Agnes"). Hence verbs and their argument structures play a central role in **parsing**. Indeed, people are likely to identify sentences as being similar on the basis of the main verb rather than on the basis of the subject of the sentence, with argument structure being particularly important (Bencini & Goldberg, 2000; Healy & Miller, 1970). To assign thematic roles, at least some of the time we must compute the syntactic structure of the sentence, a process known as parsing. The first step in parsing is to determine the syntactic category to which each word in the sentence belongs (e.g., noun, verb, adjective, adverb, and so on). We then combine those categories to form phrases. An important step in parsing is to determine the subject of the sentence (what the sentence is about). From such information about individual words we start to construct a representation of the meaning of the sentence we are reading or hearing. This chapter is about the process of assembling this representation.

Box 10.1 Thematic roles

Agent	The instigator of an action (corresponding to the subject, usually animate)
Theme	The thing that has a particular location or change of location
Recipient	The person receiving the theme
Location	Where the theme is
Source	Where the theme is coming from
Goal	Where the theme is moving to
Time	Time of the event
Instrument	The thing used in causing the event

When we hear and understand a sentence, information about the word order is often crucial (at least in languages such as English). This is information about the syntax of the sentence. Sentences (1) and (2) have the same word order structure but different meanings; (1) and (3) have different word order structures but the same meaning:

(1) The ghost chased the vampire.
(2) The vampire chased the ghost.
(3) The vampire was chased by the ghost.

A number of important questions arise about parsing and the human sentence parsing mechanism. How does parsing operate? Why are some sentences more difficult to parse than others? What happens to the syntactic representation after parsing? Why are sentences assigned the structures that they are? How many stages of parsing are there? What principles guide the operation of these stages? What happens if there is a choice of possible structures at any point? At what stage is non-structural (semantic, discourse, and frequency-based) information used? This last question is another manifestation of the issue of whether language processes are modular or not. Is there an enclosed syntactic module that uses only syntactic information to parse a sentence, or can other types of information guide the parsing process? Any account of parsing must be able to specify why sentences are assigned the structure that they are, why we are biased to parse structurally ambiguous sentences in a certain way, and why some sentences are harder to parse than others.

We should distinguish between autonomous and interactive models of parsing, and one-stage and two-stage models. In autonomous models, the initial stages of parsing at least can only use syntactic information to construct a syntactic representation. According to interactive models, other sources of information (e.g., semantic information) can influence the syntactic processor at an early stage.

In one-stage models, syntactic and semantic information are both used to construct the syntactic representation in one go. In two-stage models, the first stage is invariably seen as an autonomous stage of syntactic processing. Semantic information is used only in the second stage. Hence the question about the number of stages is really the same question as whether parsing is modular or interactive.

The goal of understanding is to extract the meaning from what we hear or read. Syntactic processing is only one stage in doing this, but it is nevertheless an important one. Whether it is always an essential one is an important issue. There is, however, another reason why we should study syntax. Fodor (1975) argued that there is a "language of thought" that bears a close resemblance to our surface language. In particular, the syntax that governs the language of thought may be very similar or identical to that of external language. Studying syntax may therefore provide a window onto fundamental cognitive processes.

Different languages use different syntactic rules. English in particular is a strongly configurational language whose interpretation depends heavily on word order. In inflectional languages such as German, word order is less important. It is therefore possible that the predominance of studies that have examined parsing in English may have given a misleading view of how human parsing operates. For this reason, an important recent development has been the study of parsing in languages other than English. Most psycholinguists hope and expect that the important parsing mechanisms will be common to speakers of all languages. By the end of this chapter you should:

- Know that parsing is incremental.
- Understand how we assign syntactic structures to ambiguous sentences.
- Be able to evaluate the extent to which parsing is autonomous or interactive.
- Understand the importance of verbs in parsing.
- Understand how brain damage can disrupt parsing.

DEALING WITH STRUCTURAL AMBIGUITY

My local newspaper, *The Dundee Courier*, recently had a headline that read "Police seek orange attackers." Do you think that the headline meant "Police seek attackers who are orange," "Police seek attackers of an orange," or "Police seek attackers who attacked with an orange"? (It was meant to be the last of these.) Here is another example: "Enraged cow injures farmer with axe." In this example the ambiguity arises because the **prepositional phrase** "with axe" could be attached to either "farmer" or "injures"; that is, there are two possible structures for this sentence. So, as well as being poorly written, these sentences are ambiguous.

It is difficult to discern the operations of the processor when all is working well. For this reason, most research on parsing has involved syntactic ambiguity because ambiguity causes processing difficulty. Studying syntactic ambiguity is an excellent way of discovering how sentence processing works.

There are different types of ambiguity involving more than one word. We have the bracketing ambiguity of example (4), which could be interpreted either in the sense of (5) or in the sense of (6):

(4) old men and women leave first
(5) ([old men] and women)
(6) (old [men and women])

More complex are structural ambiguities associated with parsing, such as in sentence (7). What was done yesterday—Boris saying or Vlad finishing? Although both structures are equally plausible in (7), this is not the case in (8):

(7) Boris said that Vlad finished it yesterday.
(8) I saw the Alps flying to Romania.

Many of us would not initially recognize a sentence such as (8) as ambiguous. On consideration, this might be because one of its two meanings is so semantically anomalous (the interpretation that I looked up and saw a mountain range in the sky flying to a country) that it does not appear even to be considered. But psychology has shown us many times that we cannot rely on our intuitions. Recording eye movements has been particularly important in studying parsing. The bulk of evidence shows that we spend no longer reading the ambiguous regions of sentences than the unambiguous regions of control sentences, but we often spend longer in reading the disambiguation region.

The central issue in parsing is when different types of information are used. In principle there are two alternative parse trees that could be constructed for (8). We could construct one of them on purely syntactic grounds, and then decide using semantic information whether it makes sense or not. If it does, we accept that representation; if it does not, we go back and try again. This is a serial autonomous model. Alternatively, we could construct all possible syntactic representations in parallel, again using solely syntactic information, and then use semantic or other information to choose the most appropriate one (Mitchell, 1994). This would be a parallel autonomous model. Or we could use semantic information from the earliest stages to guide parsing so that we only construct semantically plausible syntactic representations. Or we could activate representations of all possible analyses, with the level of activation affected by the plausibility of each. The final two are versions of an interactive model.

So far we have just looked at examples of permanent (also called global) ambiguity. In these cases, when you get to the end of the sentence it is still syntactically ambiguous. Many sentences are locally (or temporarily, or transiently) ambiguous, but the ambiguity is disambiguated (or resolved) by subsequent material (the disambiguation region). We are sometimes made forcefully aware of temporary ambiguity when we appear to have chosen an incorrect syntactic representation. Consider (9) from Bever (1970). The verb "raced" is ambiguous in that it could be a main verb (the most frequent sense) or a past **participle** (a word derived from a verb acting as an adjective):

(9) The horse raced past the barn fell.
(10) The log floated past the bridge sank.
(11) The ship sailed round the Cape sank.
(12) The old man the boats.

When you hear or read a sentence like (9), it can be interpreted in a straightforward way until the final unexpected word "fell." When we come across the last word we realize that we have been led up the garden path. We realize that our original analysis was wrong and we have to go back and reanalyze. We have the experience of having to backtrack. We then arrive at the interpretation of "The horse that was raced past the barn was the one that fell." (Some people take some time to work out what the correct interpretation is.) That is, we initially try to parse it as a simple noun phrase followed by a verb phrase. In fact, it contains a **reduced relative** clause. (A **relative clause** is one that modifies the main noun, and it is "reduced" because it lacks the relative pronoun "which" or "that.") Examples (10), (11), and (12) should also lead you up the garden path. **Garden path sentence**s are favorite tools of researchers interested in parsing.

Many people might think that garden path sentences are rather odd: Often there would be pauses in normal speech and commas in written language, which, although strictly optional, are usually there to prevent the ambiguity in the first place. For example, Rayner and Frazier (1987) intentionally omitted punctuation in order to mislead the participants' processors. Deletion of the **complementizer** "that" can also produce misleading results (Trueswell, Tanenhaus, & Kello, 1993). In such cases it might be possible that these sentences are not telling us as much about normal parsing as we think. In fact, reduced relatives are surprisingly common; "that" was omitted in 33% of sentences containing relative clauses in a sample from the *Wall Street Journal* (Elsness, 1984; Garnsey, Pearlmutter, Myers, & Lotocky, 1997; McDavid, 1964; Thompson & Mulac, 1991). There is evidence that appropriate punctuation such as commas can reduce (but not obliterate) the magnitude of the garden path effect by enhancing the reader's awareness of the phrasal structure (Hill & Murray, 2000; Mitchell & Holmes, 1985). In real life, speakers give prosodic cues to provide disambiguating information, and listeners are sensitive to this type of information; for example, speakers tend to emphasize the direct-object nouns, and insert pauses akin to punctuation (Snedeker & Trueswell, 2003). Similarly, disfluencies influence the way in which people interpret garden path sentences. When an interruption (saying "uh") comes before an unambiguous noun phrase, listeners are more likely to think that the noun phrase is the subject of a new clause rather than the object of an old one (Bailey & Ferreira, 2003). Disfluencies can help, but only as long as they are in the right place. They are helpful in (13) where they correctly flag a new subject, but not in (14), where they do not.

(13) Vlad bumped into the ghost and the (um) ghoul told him to be careful.
(14) Vlad bumped into the (um) ghost and the ghoul told him to be careful.

Garden path sentences, such as "The horse raced past the barn fell," are favorite tools of researchers interested in parsing.

However, just because speakers give prosodic cues, and listeners make use of these cues, does not mean that speakers always mean to give these cues for the express purpose of helping the listener (what has been called the **audience design** hypothesis). Speakers are not always aware that what they are saying is ambiguous, and they tend to produce the same cues even when there is no audience (Kraljic & Brennan, 2005). Prosody and pauses probably reflect both the planning needs of the speaker (see Chapter 13) as well as a deliberate source of information to aid the listener.

Perhaps even more tellingly, McKoon and Ratcliff (2003) showed that sentences with reduced relatives with verbs like "race" (e.g., (9)) occur in natural language with near-zero probability. So, although such sentences might technically be syntactically correct, most people find these sorts of sentence unacceptable. Indeed, McKoon and Ratcliff go so far as to argue that sentences with reduced relatives with verbs similar to "race" are ungrammatical. Hence considerable caution is necessary when drawing conclusions about the syntactic processor from studies of garden path sentences.

At first sight, our experience of garden path sentences is evidence for a serial autonomous processor. But what has led us up the garden path? We could have been taken there by either semantic or syntactic factors. There has been a great deal of research on trying to decide which. According to the serial autonomy model, we experience the garden path effect because the single syntactic representation we are constructing on syntactic grounds turns out to be incorrect. According to the parallel autonomy model, one representation is much more active than the others because of the strength of the syntactic cues, but this turns out to be wrong. According to the interactive model, various sources of information support the analysis more than its alternative. However, later information is inconsistent with these initial activation levels.

EARLY WORK ON PARSING

Early models of parsing were based on Chomsky's theory of generative grammar. In particular, psychologists tested the idea that understanding sentences involved retrieving their deep structure. As it became apparent that this could not provide a complete account of parsing, emphasis shifted to examining strategies based on the surface structure of sentences.

For early psycholinguists still influenced by ideas from transformational grammar such as the autonomy of syntax, the process of language understanding was a simple story (e.g., Fodor, Bever, & Garrett, 1974). First, we identify the words on the basis of perceptual data. Recognition and lexical access give us access to the syntactic category of the words. We can use this information to build a parse tree for each clause. It is only when each clause is completely analyzed that we finally start to build a semantic representation of the sentence. It is often said that "syntax proposes; semantics disposes." The simplest approach treats syntax as an independent or autonomous processing module: Only syntactic information is used to construct the parse tree. Is this true?

What size are the units of parsing?

What are the constituents used in parsing, and how big are they? Jarvella (1971) showed that listeners only begin to purge memory of the details of syntactic constituents after a sentence boundary has been passed (see Chapter 12 for more details). Once a sentence has been processed, verbatim memory for it fades away very quickly. Hence, perhaps not surprisingly, the sentence is a major processing unit. Beneath this, the clause also turns out to be an important unit. A clause is a part of a sentence that has both a subject and predicate. Furthermore, people find material easier to read a line at a time if each line corresponds to a major constituent (Anderson, 2010; Graf & Torrey, 1966). There is a clause boundary effect in recalling words: it is easiest to recall words from within the clause currently being processed, independent of the number of words in the clause (Caplan, 1972). The processing load is highest at the end of the clause, and eye fixations are longer on the final word of a clause (Just & Carpenter, 1980).

One of the first techniques used to explore the size of the syntactic unit in parsing was the click displacement technique (Fodor & Bever, 1965; Garrett, Bever, & Fodor, 1966). The basic idea was that major processing units resist interruption: We finish what we are doing, and then process other material at the first suitable opportunity. Participants heard speech over headphones in one ear, and at certain points in the sentence, extraneous clicks were presented in the other ear. Even if the click falls in the middle of a real constituent, it should be perceived as falling at a constituent boundary. That is, the clicks should appear to migrate according to listeners' reports. This is what was observed:

(15) That he was* happy was evident from the way he smiled.

For example, a click presented at * in (15) migrated to after the end of the word "happy." This is at the end of a major constituent, at the end of the clause. The original study claimed to show that the clause is a major perceptual unit. The same results were found when all non-syntactic perceptual cues, such as intonation and pauses, were removed. This suggests that the clause is a major unit of perceptual and syntactic processing.

However, this interpretation is premature. The participants' task is a complex one: They have to perceive the sentence, parse it, understand it, remember it, and give their response. Click migration could occur at any of these points, not just perception or parsing. Reber and Anderson (1970) carried out a variant of the technique in which participants listened to sentences that actually had no clicks at all. They were told that it was an experiment on subliminal perception, and were asked to say where they thought the clicks occurred. Participants still placed the non-existent clicks at constituent boundaries. This suggested that click migration occurs in the response stage: Participants are intuitively aware of the existence of constituent boundaries and have a response bias to put clicks there. Wingfield and Klein (1971) showed that the size of the migration effect is greatly reduced if participants can point to places in the sentence on a visual display at the same time as they hear them, rather than having to remember them. It was also unclear whether intonation and pausing are as unimportant in determining structural boundaries as was originally claimed.

Hence these early studies probably reflect the operations of memory rather than the operations of syntactic processing. It is now agreed that parsing is largely an incremental process—we try to build structures on a word-by-word basis. That is, we do not sit idly by while we wait for the clause to finish. The experiments of Marslen-Wilson (1973, 1975) and Marslen-Wilson and Welsh (1978; see Chapter 9 for details) demonstrate that we try to integrate each word into a semantic representation as soon as possible. Many studies have shown that syntactic and semantic analysis is incremental (Just & Carpenter, 1980; Tyler & Marslen-Wilson, 1977). For example, Traxler and Pickering (1996) found that readers' processing was disrupted immediately after they read the word "shot" in (16). The immediate disruption means that they must have processed the sentence syntactically and semantically up to that point. However, syntactic effects are often delayed so that they occur a few words later.

(16) That is the very small pistol with which the heartless killer shot the hapless man yesterday afternoon.

Not only do people construct the representation incrementally, they try to anticipate what is coming next. In an experiment with Dutch speakers, van Berkum, Brown, Zwitserlood, Kooijman, and Hagoort (2005) examined the ERPs of people listening to stories. The stories led people to expect specific nouns. However, if participants then heard a gender-marked adjective immediately before the expected noun, and the gender was not the right match for the expected noun, the inconsistent adjectives elicited a marked ERP.

Indeed, people even anticipate properties of upcoming words in the sentence, so that, for example, the argument structure of a verb can be used to anticipate the subsequent theme (Altmann & Kamide, 1999). For example, the verb "drink" requires that the direct object is something drinkable; this information is used to predict what is coming next, and people only pay attention to drinkable things thereafter (as measured by their eye movements while looking at a picture). That is, people make anticipatory eye movements towards probable upcoming objects. In a related experiment, Kamide, Altmann, and Haywood (2003) tracked the eye movements of people looking at a visual scene. They found that people anticipated a great deal of information, even with more complex verb structures. For example, given a picture containing a man and a slice of bread, on hearing "The woman will spread the butter –" people make anticipatory eye movements to the bread when they hear butter, but to the man when they hear "The woman will slide the butter –." In general, language processing interacts with the representation of a visual scene so linguistic information can determine where we look next (Altmann & Kamide, 2009). The conclusion is that the processor draws on different sources of information, some of them non-linguistic, at the earliest opportunity, to construct as full an interpretation as possible.

We saw earlier that Chomsky's description of language placed great emphasis on the hierarchical and recursive nature of syntactic structure. There is, however, debate as to which hierarchical structure is actually used in cognitive processing. In line with the incremental models, Frank and Bod (2011) found that reading times are best predicted by purely sequential models; people do not appear to use hierarchical structure information to predict what word is coming next.

In summary, the language processor operates incrementally: It rapidly constructs a syntactical analysis for a sentence fragment, assigns it a semantic interpretation, and relates this interpretation to world knowledge (Pickering, 1999). Any delay in this process is usually very slight. Incremental analysis makes a lot of sense from a processing point of view: Imagine having to wait until the sentence finishes or the other person stops speaking before you can begin analyzing what you have seen or heard.

Parsing strategies based on surface-structure cues

The surface structure of the sentence often provides a number of obvious cues to the underlying syntactic representation. One obvious approach is to use these cues and a number of simple strategies that enable us to compute the syntactic structure. The earliest detailed expositions of this idea were by Bever (1970) and Fodor and Garrett (1967). These researchers detailed a number of parsing strategies that used only syntactic cues. Perhaps the simplest example is that when we see or hear a determiner such as "the" or "a," we know a noun phrase has just started. A second example is based on the observation that although word order is variable in English, and transformations such as passivization can change it, the common structure noun–verb–noun often maps on to what is called the canonical sentence structure SVO (subject–verb–object). That is, in most sentences we hear or read, the first noun is the subject, and the second one the object. In fact, if we made use of this strategy we could get a long way in comprehension. This is called the canonical sentence strategy. We try the simpler strategies first, and if these do not work, we try other ones. If the battery of surface structure strategies become exhausted by a sentence, we must try something else.

Fodor, Bever, and Garrett (1974) developed this type of approach in one of the most influential works in the history of psycholinguistics. They argued that the goal of parsing was to recover the underlying, deep structure of a sentence. As it had been shown that this was not done by explicitly undoing transformations, it must be done by perceptual heuristics; that is, using our surface structure cues. However, there is little evidence that deep structure is represented mentally independently of meaning (Johnson-Laird, 1983). Nevertheless, the general principle that when we parse we use surface structure cues has remained influential, and has been increasingly formalized.

Two early accounts of parsing

Kimball (1973) also argued that surface structure provides cues that enable us to uncover the underlying syntactic structure. He proposed seven principles of parsing to explain the behavior of the human sentence parsing mechanism. He argued that we initially compute the surface structure of a sentence guided by rules that are based on psychological constraints such as minimizing memory load. He argued that these principles explained why sentences are assigned the structure that they are, why some sentences are harder to parse than others, and why we are biased to parse many structurally ambiguous sentences in a certain way.

The first principle is that parsing is top-down, except when a conjunction (such as "and") is encountered. It means that we start from the sentence node and predict constituents. To avoid an excessive amount of backtracking, the processor employs limited lookahead of one or two words. For example, if you see that the first word of the next constituent is "the," then you know that you are parsing a noun phrase.

The second principle is called right association, which is that new words are preferentially attached to the lowest possible node in the structure constructed so far. This places less of a load on memory. Consider (17):

(17) Vlad figured that Boris wanted to take the pet rat out.

Here we attach "out" to the right-most available constituent, "take" rather than "figured." This means that although this structure is potentially ambiguous, we prefer the interpretation "take out" to "figured out" (see Figure 10.1). Right association gives English its typically right-branching structure, and it also explains why structures that are not right-branching are more difficult to understand (e.g., "the ghost who Vlad expected to leave's ball").

Kimball's third principle was new nodes. Function words signal a new phrase. The fourth principle is that the processor can only cope with nodes associated with two sentence nodes at any one time. For example, center-embedding splits up noun phrases and verb phrases associated with the sentences so that they have to be held in memory. When there are two embedded clauses, three sentence nodes will have to be kept active at once. Hence sentences of this sort, such as (18), will be difficult, but corresponding right-branching paraphrases such as (19) cause no difficulty, because the sentence nodes do not need to be kept open in memory:

(18) The vampire the ghost the witch liked loved died.

(19) The witch liked the ghost that loved the vampire that died.

The fifth principle is that of closure, which says that the processor prefers to close a phrase as soon as possible. The sixth principle is called fixed structure. Having closed a phrase, it is computationally costly to reopen it and reorganize the previously closed constituents, and so this is avoided if possible. This principle explains our difficulty with garden path sentences. The final principle is the principle of processing. When a phrase is closed it exits from short-term memory and is passed on to a second stage of deeper, semantic processing. Short-term memory has limited capacity, and details of the syntactic structure of a sentence are very quickly forgotten.

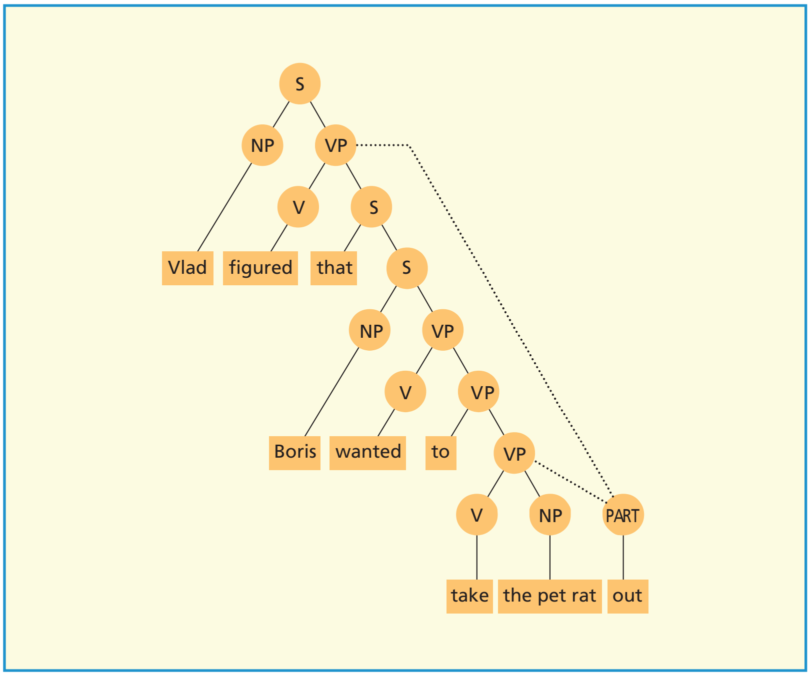

FIGURE 10.1 Alternative structures for the sentence "Vlad figured that Boris wanted to take the pet rat out," showing how right association leads us to attach "out" to the right-most verb phrase node ("take") rather than to the higher verb node ("figured"). S = sentence; NP = noun phrase; VP = verb phrase; V = verb; PART = participle.

Kimball's principles do a good job of explaining a number of properties of the processor. However, given that the principle of processing underlies so many of the others, perhaps the model can be simplified to reflect this? In addition, there are some problems with particular strategies. For example, the role of function words in parsing might not be as essential as Kimball thought. Eye fixation research shows that we may not always gaze directly at some function words: Very short words are frequently skipped (Rayner & McConkie, 1976; although we might be able to process them parafoveally—that is, we could still extract information from them even though they are not centrally located in our visual field; see Kennedy, 2000, and Rayner & Pollatsek, 1989).

Frazier and Fodor (1978) simplified Kimball's account by proposing a model they called the "sausage machine," because it divides the language input into something that looks like a link of sausages. The sausage machine is a two-stage model of parsing. The first stage is called the preliminary phrase packager, or PPP. This is followed by the sentence structure supervisor, or SSS. The PPP has a limited viewing window of about six words, and cannot attach words to structures that reflect dependencies longer than this. The SSS assembles the packets produced by the PPP, but cannot undo the work of the PPP. The idea of the limited length of the PPP, and a second stage of processing that cannot undo the work of the first, operationalizes Kimball's principle of processing. The PPP can only make use of syntactic knowledge and uses syntactic heuristics, such as preferring simpler syntactic structures if there is a choice of structures (known as minimal attachment).

Wanner (1980) pointed out a number of problems with the sausage machine model. For example, there are some six-word sentences that are triply embedded, but because they are so short, should fit easily into the PPP window, such as (20). Nevertheless, we still find them difficult to understand. There are also some six-word sentences where right association operates when minimal attachment is unable to choose between the alternatives, as they are both of equal complexity (21). Here we prefer the interpretation "cried yesterday" to "said yesterday." The sausage machine cannot account for the preference for right association in some six-word sentences.

(20) Vampires werewolves rats kiss love sleep.
(21) Vlad said that Boris cried yesterday.

Fodor and Frazier (1980) conceded that right association does not arise directly from the sausage machine's architecture. They added a new principle that governs the performance of the sausage machine, which says that right association operates when minimal attachment cannot determine where a constituent should go. The sausage machine evolved into one of the most influential models of parsing, the garden path model.

PROCESSING STRUCTURAL AMBIGUITY

One of the major foci of current work on parsing is on trying to understand how we process syntactic ambiguity, because this gives us an important tool in evaluating alternative models of how the syntactic processor operates.

Two models have dominated research on parsing. The garden path model is an autonomous two-stage model, while the constraint-based model is an interactive one-stage model. Choosing between the two depends on how early discourse context, frequency, and other semantic information can be shown to influence parsing choices. Is initial attachment—the way in which syntactic constituents are attached to the growing parse tree—made on the basis of syntactic knowledge alone, or is it influenced by semantic factors?

The garden path model

According to the garden path model (e.g., Frazier, 1987a), parsing takes place in two stages. In the first stage, the processor draws only on syntactic information. If the incoming material is ambiguous, only one structure is created. Initial attachment is determined only by syntactic preferences dictated by the two principles of minimal attachment and late closure. If the results of the first pass turn out to be incompatible with further syntactic, pragmatic, or semantic and thematic information generated by an independent thematic processor, then a second pass is necessary to revise the parse tree. In the garden path model, thematic information about semantic roles can only be used in the second stage of parsing (Rayner, Carlson, & Frazier, 1983).

Two fundamental principles of parsing determine initial attachment, called minimal attachment and late closure. According to minimal attachment, incoming material should be attached to the phrase marker being constructed using the fewest nodes possible. According to late closure, incoming material should be incorporated into the clause or phrase currently being processed. If there is a conflict between these two principles, then minimal attachment takes precedence.

Constraint-based models of parsing

A type of interactive model called the constraint-based approach has become very popular (e.g., Boland, Tanenhaus, & Garnsey, 1990; MacDonald, 1994; MacDonald, Pearlmutter, & Seidenberg, 1994a; Tanenhaus, Carlson, & Trueswell, 1989; Taraban & McClelland, 1988; Trueswell et al., 1993). On this account, the processor uses multiple sources of information, including syntactic, semantic, discourse, and frequency-based, called constraints. The construction that is most strongly supported by these multiple constraints is most activated, although less plausible alternatives might also remain active. Garden paths occur when the correct analysis of a local ambiguity receives little activation.

Evidence for autonomy in syntactic processing

The garden path model says that we resolve ambiguity using minimal attachment and late closure, without semantic assistance. As (22) is consistent with late closure, it does not cause the processor any problem; (23) is not ultimately consistent with late closure, however, and the processor tries in the first instance to attach the NP "a mile and a half" to the first verb. When we come to "seems" it is apparent that this structure is incorrect—we have been led up a garden path. In an eye-movement study, Frazier and Rayner (1982) found that the reading time was longer for (23) than (22), and in (23) the first fixation in the disambiguating region was longer.

(22) Since Jay always jogs a mile and a half this seems a short distance to him.
(23) Since Jay always jogs a mile and a half seems a very short distance to him.

Rayner and Frazier (1987) monitored participants' eye movements while they read sentences such as (24) and (25).

(24) The criminal confessed his sins harmed many people.
(25) The criminal confessed that his sins harmed many people.

When we start to read (24), minimal attachment leads to the adoption of the structure that contains the fewest number of nodes. Hence when we get to "his sins" the simplest analysis is that "his sins" is the object of "confessed," rather than the more complex analysis that it is the subject of the complement clause (as later turns out to be the case). Readers should therefore be led up the garden path in (24), and will then be forced to reanalyze when they come to "harmed." However, (25) should not lead to a garden path, because "that" blocks the object analysis of the sentence. Rayner and Frazier found that participants did indeed experience difficulty when they reached "harmed" in (24) but not in (25).

Ferreira and Clifton (1986) described an experiment that suggests that semantic factors cannot prevent us from being garden-pathed. Garden path theory predicts that, because of minimal attachment, when we come across the word "examined" we should take it to be the main verb in (26) and (27) rather than the verb in a reduced relative clause:

(26) The defendant examined by the lawyer turned out to be unreliable.
(27) The evidence examined by the lawyer turned out to be unreliable.

Consider what sorts of structure we might have generated by the time we get to the word "examined" in (26) and (27). "Examined" requires an agent. In (26), "the defendant" is animate and can therefore fulfill the role of agent, as in "the defendant examined the evidence"; but of course, "the defendant" can also be what is examined, so the syntactic structure is ambiguous between a reduced relative clause and a main verb analysis. In (27) "the evidence" is inanimate and therefore cannot fulfill the role of the agent; it must be what is examined, and therefore this structure can only be a reduced relative. However, analysis of eye-movement evidence suggested that the semantic evidence available in sentences such as (27) did not prevent participants from getting garden-pathed. Instead, we still appear to construct the initial interpretation to be the syntactically most simple according to minimal attachment. Ferreira and Clifton argued that semantic information does not prevent or cause garden-pathing, but can hasten recovery from it. The difficulty caused by the ambiguity is very short in duration, and is resolved while reading the word following the verb, "by" (Clifton & Ferreira, 1989).

Mitchell (1987), on the basis of data from a self-paced reading task (where participants read a computer display and press a key every time they are ready for a new word or phrase), concluded that the initial stage only makes use of part-of-speech information, and that detailed information from the verb only affects the second, evaluative, stage of processing. Consider sentences (28) and (29). In (28), according to garden path theory, the processor prefers to assign the phrase "the doctor" as direct object of "visited" (to comply with late closure, keeping the first phrase open for as long as possible). As expected, participants were garden-pathed by (28). However, if semantic and thematic information about verbs is available from an early stage, then in (29) thematic information should tell the processor that "sneezed" cannot take a direct object (a process called lexical guidance). Nevertheless, participants are still led up the garden path with (29); hence the initial parse must be ignoring verb information.

(28) After the child had visited the doctor prescribed a course of injections.

(29) After the child had sneezed the doctor prescribed a course of injections.

Van Gompel and Pickering (2001) came to the same conclusion using an eye-movement methodology: readers experience difficulty after "sneezed." These experiments suggest that the first stage of parsing is short-sighted and does not use semantic or thematic information. Similarly, Ferreira and Henderson (1990) examined data from eye movements and word-by-word self-paced reading of ambiguous sentences, concluding that verb information does not affect the initial parse, although it might guide the second stage of reanalysis.

We can manipulate the semantic relatedness of nouns and verbs in contexts where they are either syntactically appropriate or inappropriate. Their different effects can then be teased out in lexical decision and naming tasks (O'Seaghdha, 1997). The results suggest that syntactic analysis precedes semantic analysis and is independent of it. Consider (30) and (31):

(30) The message that was shut.

(31) The message of that shut.

In (30), the target word "shut" is syntactically appropriate but semantically anomalous. In (31), the target is both syntactically and semantically anomalous. In the lexical decision task, in (30) we observe meaning-based inhibition relative to a baseline. In (31), we do not observe any inhibition. In the naming task, there is no sensitivity to semantic anomaly, but there is sensitivity to the syntactic inappropriateness of the target in (31). O'Seaghdha suggested that the inhibition occurs in (30) in the lexical decision task because of a difficulty in integrating the target word into a high-level text representation. We do not get that far in (31) because the failure to construct a syntactic representation blocks any semantic integration. The results look as though they support interactivity because the lexical decision task is sensitive to post-access integration processes. The naming data are less contaminated by post-access processing and suggest that syntactic analysis is prior to semantic integration and independent of it.

Evidence from neuroscience suggests that semantic and syntactic processing are independent. Breedin and Saffran (1999) described a patient, DM, who had a significant and pervasive loss of semantic knowledge as a result of dementia. For example, he found it very difficult to match a picture of an object to another appropriate picture (e.g., knowing that a pyramid is associated with a palm tree rather than a pine tree). Yet his semantic deficit had no apparent effect on his syntactic abilities. He performed extremely well at detecting grammatical violations (e.g., he knew that "what did the exhausted young woman sit?" was ungrammatical). He also had no difficulty in assigning semantic roles in a sentence. For example, he could correctly identify who was being carried in the sentence "The tiger is being carried by the lion," even though he had difficulty in recognizing lions and tigers by name.

Brain-imaging studies are also useful here. A negative event-related potential (ERP) found 400 ms after an event (and hence called the N400) is thought to be particularly sensitive to semantic processing, and is particularly indicative of violations of semantic expectancy (Batterink, Karns, Yamada, & Neville, 2010; Kounios & Holcomb, 1992; Kutas & Hillyard, 1980; Nigram, Hoffman, & Simons, 1992). A sentence such as (32) generates a semantic anomaly:

(32) Boris noticed a puncture and got out to change the wheel on the castle.

The N400 occurs 400 ms after the anomalous word "castle."

There is also a positive wave found 600 ms after a syntactic violation (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994). A P600 would be observed with (33):

(33) Boris persuaded to fly.

These anomalies can be used to map the time course of syntactic and semantic processing. These ERP data suggest that syntactic and semantic processing are distinct (Ainsworth-Darnell, Shulman, & Boland, 1998; Friederici, 2002; Neville, Nicol, Barss, Forster, & Garrett, 1991; Ni et al., 2000; Osterhout & Nicol, 1999). For example, Ainsworth-Darnell et al. examined ERPs when people heard sentences that contained a syntactic anomaly, a semantic anomaly, or both. The sentences that contained both types of anomaly still provoked both an N400 and a P600. Ainsworth-Darnell et al. concluded that different parts of the brain automatically become involved when syntactic and semantic anomalies are present, and therefore that these processes are represented separately. Osterhout and Nicol (1999) gave participants sentences with different types of anomaly to read (34)–(37):

(34) The cats won't eat the food that Mary leaves them. (non-anomalous)
(35) The cats won't bake the food that Mary leaves them. (semantic anomaly)
(36) The cats won't eating the food that Mary leaves them. (syntactic anomaly)
(37) The cats won't baking the food that Mary leaves them. (doubly anomalous)

As expected, semantically anomalous sentences, such as (35), elicited the N400, and syntactically anomalous sentences, such as (36), elicited the P600. Doubly anomalous sentences, such as (37), elicited both an N400 and a P600, with the magnitude of each effect being about the same as if each anomaly were present in isolation. The brain responds differently to syntactic and semantic anomalies, and the response to each type of anomaly is unaffected by the presence of the other type. Osterhout and Nicol concluded that syntactic and semantic processes are separable and independent.

There has been some debate as to the strength of this claim. It is useful to distinguish between representational modularity and processing modularity (Pickering, 1999; Trueswell, Tanenhaus, & Garnsey, 1994). Representational modularity says that semantic and syntactic knowledge are represented separately. That is, there are distinct types of linguistic representation, which might be stored or processed in different parts of the brain.

This is relatively uncontroversial. Most of the debate is about processing modularity: Is initial processing restricted to syntactic information, or can all sources of information influence the earliest stages of processing?

Evidence for interaction in syntactic processing

The experiments discussed so far suggest that the first stage of parsing only makes use of syntactic preferences based on minimal attachment and late closure, and does not use semantic or thematic information. On the interactive account, however, semantic factors influence whether or not we get garden-pathed. What is the evidence that semantic factors play an early role in parsing?

Perhaps the syntactic principles of minimal attachment and late closure can be better explained by semantic biases? Taraban and McClelland (1988) compared self-paced reading times for sentences such as (38) and (39) (see Figure 10.2):

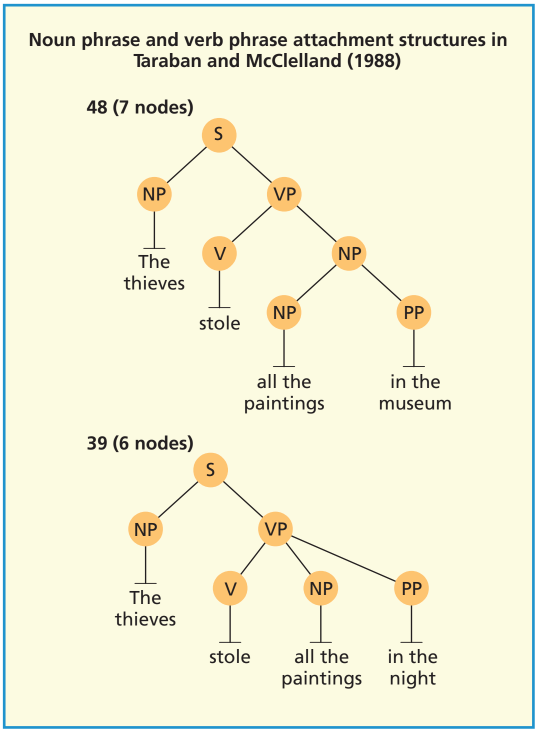

FIGURE 10.2

(38) The thieves stole all the paintings in the museum while the guard slept.
(39) The thieves stole all the paintings in the night while the guard slept.

Sentence (39) is a minimal attachment structure but (38) is not. In (38) the phrase “in the museum” must be formed into a noun phrase with “paintings”; in (39) the phrase “in the night” must be formed into a verb phrase with “stole.” The noun phrase attachment in (38) produces a grammatically more complex structure than the verb phrase attachment in (39). Nevertheless, Taraban and McClelland found that (38) is read faster than (39). They argued that this is because all the words up to “museum” and “night” create a semantic bias for the non-minimal interpretation. They concluded that violations of the purely syntactic process of the attachment of words to the developing structural representation do not slow down reading, but violations of the semantic process of assigning words to thematic roles do. Taraban and McClelland also concluded that previous studies that had appeared to support minimal attachment had in fact confounded syntactic simplicity with semantic bias.

Why do we find garden-pathing on some occasions but not others? Milne (1982) was one of the first to argue that semantic factors rather than syntactic factors lead us up the garden path. Consider the three sentences (40)–(42). Only (40) causes difficulty, because it sets up semantic expectancies that are then violated:

(40) The granite rocks during the earthquake.
(41) The granite rocks were by the seashore.
(42) The table rocks during the earthquake.

How can semantic factors explain our difficulty with reduced relatives?

Crain and Steedman (1985) used a speeded grammaticality judgment task to show that an appropriate semantic context can eliminate syntactic garden paths. In this task, participants see a string of words and have to decide as quickly as possible whether the string is grammatical or not. Participants in this task on the whole are more likely to misidentify garden path sentences as non-grammatical than non-garden path sentences. Sentence (43) was incorrectly judged ungrammatical far more often than the structurally identical but semantically more plausible sentence (44):

(43) The teachers taught by the Berlitz method passed the test.
(44) The children taught by the Berlitz method passed the test.

Crain and Steedman argued that there is no such thing as a truly neutral semantic context. Even when semantic context is apparently absent from the sentence, participants bring prior knowledge and expectations to the experiment. They argued that all syntactic parsing preferences can be explained semantically. All syntactic alternatives are considered in parallel, and semantic considerations then rapidly select among them. Semantic difficulty is based on the amount of information that has to be assumed: The more assumptions that have to be made, the harder the sentence is to process. Hence sentences such as (45) are difficult compared with (46), where the existence of only one horse is assumed. This assumption is incompatible with the semantic representation needed to understand (45)—that there are a number of horses but it was the one that was raced past the barn that was the one that fell. That is, if the processor encounters a definite noun phrase in the absence of any context, only one entity (e.g., one horse) is postulated, and therefore no modifier is necessary. If one is present, processing difficulty ensues.

(45) The horse raced past the barn fell.
(46) The horse raced past the barn quickly.

Altmann and Steedman (1988) measured reading times on sentences such as (47) and (48):

(47) The burglar blew open the safe with the dynamite and made off with the loot.
(48) The burglar blew open the safe with the new lock and made off with the loot.

These sentences are ambiguous: the prepositional phrases "with the dynamite" and "with the new lock" can modify either the noun phrase "the safe" or the verb phrase "blew open the safe." Altmann and Steedman presented the participants with prior discourse context that disambiguated the sentences. A prior context sentence referred to either one or two safes. ("Once inside he saw that there was a safe with a new lock and a strongbox with an old lock" versus "Once inside he saw that there was a safe with a new lock and a safe with an old lock.") If the context sentence mentioned only one safe, then the complex noun phrase "the safe with the new lock" is redundant, and causes extra processing difficulty. Hence the prepositional phrase in (48) took relatively longer to read. If the context sentence mentioned two safes, then the simple noun phrase "the safe" in (47) fails to identify a particular safe, so the prepositional phrase "with the dynamite" in (47) took relatively longer to read.

Altmann and Steedman (1988) emphasized that the processor constructs a syntactic representation incrementally, on a word-by-word basis. At each word, alternative syntactic interpretations are generated in parallel, and then a decision is made using context. Altmann and Steedman called this "weak" interaction, as opposed to strong interaction, where context actually guides the parsing process so that only one alternative is generated. This approach is called the referential theory of parsing. The processor constructs analyses in parallel and uses discourse context to disambiguate them immediately. It is the immediate nature of this disambiguation that distinguishes the referential theory from garden path models. As many factors guide parsing, it must be semantic considerations that in this case must lead us up the garden path.

Is it possible to distinguish between the referential and the constraint-based theories? The theories are similar in that each denies that parsing is restricted to using syntactic information. In constraint-based theories, all sources of semantic information, including general world knowledge, are used to disambiguate, but in referential theory only referential complexity within the discourse model is important. Ni, Crain, and Shankweiler (1996) tried to separate the effects of these different types of knowledge by studying reading times and eye movements when reading ambiguous sentences. The results suggested that semantic-referential information is used immediately, but more general world knowledge takes longer to become available. Furthermore, world knowledge was dependent on working memory capacity, whereas use of semantic-referential principles was not. (In general, people with larger working memory spans are better able to maintain multiple syntactic representations and therefore will be more effective at processing ambiguous sentences; see MacDonald, Just, & Carpenter, 1992; Pearlmutter & MacDonald, 1995.) Ni et al. argued that the focus operator "only" presupposes the existence of more than one vampire (in this example), and therefore a modifier is needed to select one of them. Consider (49) and (50):

(49) The vampires loaned money at low interest were told to record their expenses.
(50) Only vampires loaned money at low interest were told to record their expenses.

Sentence (49) provokes a garden path effect but (50) does not. Analysis suggested that these referential principles were used immediately to resolve ambiguity. Information about semantic plausibility of interpretations was used later. However, as Pickering (1999) noted, referential theory cannot be a complete account of parsing, because it can only be applied to ambiguities involving simple and complex noun phrases. There is also more to context than discourse analysis. Referential theory was an early version of a constraint-based theory, applied to a limited type of syntactic structure. Nevertheless, the idea that discourse information can be used to influence parsing decisions is one essential component of constraint-based theories.

Altmann, Garnham, and Dennis (1992) used eye-movement measures to investigate how context affects garden pathing. Consider sentence (51):

(51) The fireman told the man that he had risked his life for to install a smoke detector.

Garden path theory predicts that (51) should always lead to a garden path. We always start to parse "the man" as a simple noun phrase because this has a simpler structure than the alternative (which turns out to be the correct analysis), in which the noun is the head of a complex noun phrase. According to referential theory, the resolution of ambiguities in context depends on whether a unique referent can be found. The context can bias the processor towards or away from garden-pathing. The null context induces a garden path in (51). However, some contexts will bias the processor towards a relative clause interpretation and prevent garden-pathing. Such a biasing context can be obtained by preceding the ambiguous relative structure with a relative-supporting referential context. One way of doing this is to provide more than one possible referent for "the man." (For example, "A fireman braved a dangerous fire in a hotel. He rescued one of the guests at great danger to himself. A crowd of men gathered around him.") Eye-movement measurements verified this prediction. Measurements of difficulty associated with garden-pathing were reflected in longer average reading times per character in the ambiguity region, and an increased probability of regressive eye movements. When syntactic information leads to ambiguity and a garden path is possible, then the processor proceeds to construct a syntactic representation on the basis of the best semantic bet.

Further evidence for constraint-based models comes from the finding that thematic information can be used to eliminate the garden path effect in these reduced relative sentences (MacDonald et al., 1994a; Trueswell & Tanenhaus, 1994; Trueswell et al., 1994). For example, consider the ambiguous sentence fragments (52) and (53):

(52) The fossil examined –
(53) The archeologist examined –

The fragments are ambiguous because they are consistent with two sentence constructions: the most frequent order, the unreduced structure, where the first NP is the agent (e.g., "The archeologist examined the fossil"), and with a reduced relative clause ("The fossil examined by the archeologist was important"). However, consider the thematic roles associated with the verb "examine." It has the roles of agent, best fitted by an animate entity, and a theme, best fitted by an inanimate object (Trueswell & Tanenhaus, 1994). So semantic considerations associated with thematic roles suggest that (52) is likely to be a reduced relative structure, and (53) a simple sentence structure. Difficulty ensues if subsequent material conflicts with these interpretations, or if the context provided by the nouns is not sufficiently biasing. Trueswell et al. (1994) examined eye movements to investigate how people understood sentences such as (52) and (53). They found that if semantic constraints were sufficiently strong, reduced relative clauses were no more difficult than the unreduced constructions.

Remember that, in contrast, Ferreira and Clifton (1986) found evidence of increased difficulty with very similar materials, (26) and (27). Why is there a discrepancy? Trueswell et al. argued that the semantic bias in Ferreira and Clifton's experiment was too weak. If the semantic constraint is not strong enough, we will be garden-pathed. McRae, Spivey-Knowlton, and Tanenhaus (1998) found that strong plausibility can also overcome garden-pathing. On the other side of the coin, people are reluctant to abandon plausible analyses in favor of implausible ones, even when the plausible analysis is turning out to be wrong (Pickering & Traxler, 1998).

An important idea in constraint-based models is that of verb bias (Garnsey et al., 1997; Trueswell et al., 1993). This is the idea that although some verbs can appear in a number of syntactic structures, some of their syntactic structures are more common than others. The relative frequencies of alternative interpretations of verbs predict whether or not people have difficulty in understanding reduced relatives (MacDonald, 1994; Trueswell, 1996). Hence, although the verb "read" can appear with sentence complements ("the ghost read the book had been burned"), it is most commonly followed by a direct object (as in simply, "the ghost read the book during the plane journey"). Direct-object verbs are those where the most frequent continuation is the direct object; sentence-complement verbs are those where the most frequent continuation is the sentence complement.

According to constraint-based models, verb-bias information becomes available immediately the verb is recognized. Trueswell et al. (1993) found evidence for the immediate availability of verb-bias information across a range of tasks (priming, self-paced reading, and eye movements). They found that verbs with a sentence-complement bias did not cause processing difficulty, whereas verbs with direct-object bias did. Furthermore, the more frequently a sentence complement verb appears in the language without a complementizer ("that"), the less likely it is to lead to processing difficulty in sentence-complement constructions. Using a carefully controlled set of materials combined with eye-movement and self-paced reading analyses, Garnsey et al. (1997) also found that people's prior experience with particular verbs guides their interpretation of temporary ambiguity. Verb bias guides readers to a sentence-complement interpretation with sentence-complement verbs. This information is available very quickly (certainly by the word following the verb). Furthermore, verb-bias information interacts with how plausible the temporarily ambiguous noun is as a direct object. For example, "the decision" is more plausible as a direct object than "the reporter." This result is best explained by constraint-based models, as according to the garden path model there should be no early effect of plausibility and verb bias.

Note though that there is controversy over whether verb-bias effects are real: Some studies have found no effect of verb-frequency information. For example, using an eye-tracking methodology, Pickering, Traxler, and Crocker (2000) found that readers experienced difficulty with temporarily ambiguous sentence-complement clauses even when the verbs were biased towards that analysis. Consider the sentence beginning (54).

(54) The young athlete realized her potential –

There are now two possible analyses: the object analysis (simply, "The young athlete realized her potential"), and the sentence-complement analysis (as in "The young athlete realized her potential might one day make her a world class athlete"). The sentence-complement analysis is the most common for the verb "realized," so readers should adopt that and not the object analysis. However, they do not. People preferred to attach noun phrases as arguments of verbs, regardless of whether or not this analysis was likely to be correct. Kennison (2001) similarly found that ambiguous structures caused difficulty regardless of the verb bias. Pickering and van Gompel (2006) concluded that verb-bias information has some influence on syntactic processing, but often not enough to prevent us having difficulty with temporally ambiguous sentences.

In constraint-based models, syntactic ambiguity is eventually resolved by competition (MacDonald et al., 1994a, 1994b). The constraints activate different analyses to differing degrees; if two or more analyses are highly activated, competition is strong and there are severe processing difficulties. Tabor and Tanenhaus (1999; see also Tabor, Juliano, & Tanenhaus, 1997) proposed that the competition is resolved by settling into a basin of attraction in an attractor network similar to those postulated to account for word recognition (Hinton & Shallice, 1991; see Chapter 7). Along similar lines, McRae et al. (1998) proposed a connectionist-like model of ambiguity resolution called competition-integration. Competition between alternative structures plays a central role in a parsing process that essentially checks its preferred structure after each new word. Evidence for parallel competition models comes from studies that show that the more committed people become to a parsing choice, the more difficult it is for them to recover, an effect called digging-in (Tabor & Hutchins, 2004). For example, increasing the gap between the ambiguity and the disambiguating information causes the comprehenders to "dig in" as they become more committed to the wrong analysis (e.g., (55) is easier than (56); materials from Ferreira & Henderson, 1991). Once they have dug in, alternative interpretations (including the correct one) become less activated.

(55) After the Martians invaded the town was evacuated.
(56) After the Martians invaded the town that the city bordered was evacuated.

Another important aspect of constraint-based models is that syntactic and lexical ambiguity are resolved in similar ways because of the importance of lexical constraints in parsing (MacDonald et al., 1994a, 1994b). Syntactic ambiguities arise because of ambiguities at the lexical level. For example, "raced" is an ambiguous word, with one sense of a past tense, and another of a past participle. In (57), only the past tense sense is consistent with the preceding context. This information eventually constrains the processor to a particular syntactic interpretation. But in (58), both senses are consistent with the context. Although contextual constraints are rarely strong enough to restrict activation to the appropriate alternative, they provide useful information for distinguishing between alternative candidates. In this type of approach, a syntactic representation of a sentence is computed through links between items in a rich lexicon (MacDonald et al., 1994a).

(57) The horse who raced –
(58) The horse raced –

Part of the difficulty in distinguishing between the autonomous and interactive constraint-based theories is in obtaining evidence about what is happening in the earliest stages of comprehension. Tanenhaus et al. (1995) examined the eye movements of participants who were following instructions to manipulate real objects. Analysis of the eye movements suggested that people processed the instructions incrementally, making eye movements to objects immediately after the relevant instruction. People typically made an eye movement to the target object 250 ms after the end of the word that uniquely specified the object. With more complex instructions, participants' eyes moved around the array looking for possible referents.

The best evidence for the independence of parsing comes from reading studies of sentences with brief syntactic ambiguities, where listeners have clear preferences for particular interpretations, even when the preceding linguistic context supports the alternative interpretation. Tanenhaus et al. pointed out that in this sort of experiment the context may not be immediately available because it has to be retrieved from memory. They examined the interpretation of temporarily ambiguous sentences in the context of a visual array so that information is immediately available. They auditorily presented participants with the sentence (59) with one of two visual contexts.

(59) Put the apple on the towel in the box.

In the one-referent condition there was just one apple on a towel and another towel without an apple on it. In the two-referent condition there were two possible referents for the apple, one on a towel and one on a napkin. According to modular theories, "on the towel" should always be initially interpreted as the destination (where the apple should be put, because this is structurally simplest). However, analysis of the eye movements across the scene showed that "on the towel" was initially interpreted as the destination only in the one-referent condition. In the two-referent condition, "on the towel" was interpreted as the modifier of "apple." In the one-referent condition, participants looked at the incorrect destination (the irrelevant towel) 55% of the time; in the two-referent condition, they rarely did so. This experiment is strong evidence that people use contextual information immediately to establish reference and to process temporarily ambiguous sentences.

A similar experiment by Sedivy, Tanenhaus, Chambers, and Carlson (1999) showed that people very quickly take context into account when interpreting adjectives. On the basis of these findings, Sedivy et al. argued that syntactic processing is incremental—that is, a semantic representation is constructed with very little lag following the input. People immediately try to integrate adjectives into a semantic model even when they do not have a stable core meaning (e.g., tall is a scalar object—it is a relative term and depends on the noun it is modifying; tall in "a tall glass" means something different from in "a tall building"). They do this by establishing contrasts between possible referents in the visual array (or memory).

Brain-imaging fMRI studies show that the brain processes ambiguous and unambiguous sentences differently (Mason, Just, Keller, & Carpenter, 2003). Higher levels of brain activation are shown for ambiguous sentences, but also during reading more complex structures and unpreferred structures (those where the reduced relative reading is the correct one). Furthermore, and contrary to the reading time results, higher activation was shown while reading ambiguous sentences when the ambiguity was resolved in favor of the preferred syntactic construction. The higher workload was spread among the superior temporal gyrus (including Wernicke's area) and the inferior frontal gyrus (including Broca's area), hinting that multiple processes are involved in ambiguity resolution (see Figure 10.3). In particular, Broca's area might be involved in generating abstract syntactic frames, and Wernicke's in interpreting and elaborating them with semantic information. These findings are more consistent with parallel models where multiple parses are kept open at the same time.

There is also recent electrophysiological evidence that shows that people predict what is coming next (DeLong, Urbach, & Kutas, 2005; see also Kutas, DeLong, & Smith, 2011). DeLong et al. examined the phonological regularity in the English indefinite article ("a" before a consonant, "an" before a vowel) using ERP, and concluded that people pre-activate words in a graded fashion.

Cross-linguistic differences in attachment

A final point concerns the extent to which any parsing principles apply to languages other than English. Cuetos and Mitchell (1988) examined the extent to which speakers of English and Spanish used the late-closure strategy to interpret the same

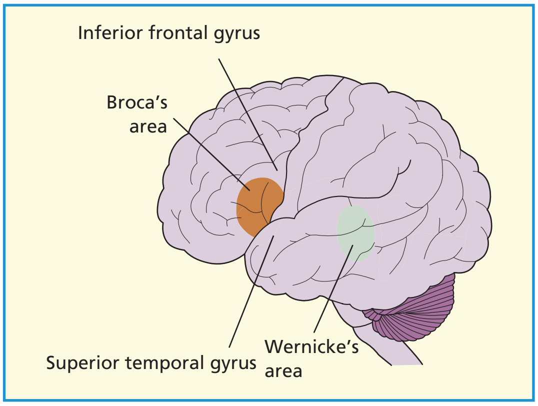

FIGURE 10.3

sorts of sentences. They found that although the interpretations of the English speakers could be accounted for by late closure, this was not true of the Spanish speakers. For example, given (60), English speakers prefer to attach the relative clause ("who had the accident") to "the colonel," because that is the phrase currently being processed. We can find this out simply by asking readers "Who had the accident?"

(60) The journalist interviewed the daughter of the colonel who had the accident.

Spanish speakers, on the other hand, given the equivalent sentence (61), seem to follow a strategy of early closure. That is, they attach the relative clause to the first noun phrase.

(61) El periodista entrevisto a la hija del coronel que tuvo el accidente.

Other languages also show a preference for attaching the relative clause to the first noun phrase, including French (Zagar, Pynte, & Rativeau, 1997) and Dutch (Brysbaert & Mitchell, 1996). These results suggest that late closure may not be a general strategy common to all languages. Instead, the parsing preferences may reflect the frequency of different structures within a language (Mitchell, Cuetos, Corley, & Brysbaert, 1995). These **cross-linguistic** differences question the idea that late closure is a process-generated principle that confers advantages on the comprehender, such as minimizing processing load. Frazier (1987b) proposed that late closure is advantageous because if a constituent is kept open as long as possible, it avoids the processing cost incurred by closing it, opening it, and closing it again.

The results of this study can be explained in one of three ways. First, late closure may not originate because of processing advantages, and the choice of strategy (early versus late closure) is essentially an arbitrary choice in different languages. Second, late closure may have a processing advantage and may be the usual strategy, but in some languages, in some circumstances, other strategies may dominate (Cuetos & Mitchell, 1988). Third, as constraint-based models advocate, parsing does not make use of linguistic principles at all. The results of interpretation depend on the interaction of many constraints that are relevant in sentence processing. Whatever the answer, it is clear that if we limit our studies of parsing to English then we miss out on a great deal of potentially important data.

Constraint-based models contain a probabilistic element in that the most strongly activated analysis can vary depending on the circumstances. Another example of a probabilistic model is the tuning hypothesis (Brysbaert & Mitchell, 1996; Mitchell, 1994; Mitchell et al., 1995). The tuning hypothesis emphasizes the role of exposure to language. Parsing decisions are influenced by the frequency with which alternative analyses are used. Put another way, people resolve ambiguities in a way that has been successful in the past (Sturt, Costa, Lombardo, & Frasconi, 2003). Given the reasonable assumption that people vary in their exposure to different analyses, then their preferred initial attachments will also vary. Attachment preferences may vary from language to language, and from person to person, and indeed might even vary within a person across time. Brysbaert and Mitchell (1996) used a questionnaire to examine attachment preferences in Dutch speakers, and found individual differences in these preferences.

Comparison of garden path and constraint-based theories

When do syntax and semantics interact in parsing? This has proved to be the central question in parsing, as well as one of the most difficult to answer. In serial two-stage models, such as the garden path model, the initial analysis is constrained by using only syntactic information and preferences, and a second stage using semantic information. In parallel constraint-based models, multiple analyses are active from the beginning, and both syntactic and non-syntactic information is used in combination to activate alternative representations. Unfortunately, there is little consensus about which model gives the better account. Different techniques seem to give different answers, and the results are sensitive to the materials used. Proponents of the garden path model argue that the effects that are claimed to support constraint-based models arise because the second stage of parsing begins very quickly, and that many experiments that are supposed to be looking at the first stage are in fact looking at the second stage of parsing. Any interaction observed is occurring at this second stage, which starts very early in processing. They argue that experiments supporting constraint-based models are methodologically flawed, and that constraint-based models fail to account for the full range of data (Frazier, 1995). On the other hand, proponents of the constraint-based models argue that researchers favoring the garden path model use techniques that are not sensitive enough to detect the interactions involved, or that the non-syntactic constraints used are too weak.

Other models of parsing

Is there any way out of this dilemma? Alternative approaches to garden path and constraint-based theories have recently come to the fore.

The first alternative may be called the unrestricted-race model. To understand the basis of this model, we must consider exactly how syntactic ambiguity is resolved. We also need to distinguish between models that always adopt the same analysis of a particular ambiguity and those that do not (van Gompel, Pickering, & Traxler, 2000, 2001).

The garden path model can be described as a fixed-choice two-stage model. It is fixed choice in that it has no probabilistic element in its decision making. Given a particular structure, the same syntactic structure will always be generated on the basis of late closure and minimal attachment. Either the correct analysis is chosen on syntactic grounds from the beginning, or, if the initial syntactic analysis becomes implausible, reanalysis is needed.

Constraint-based models are variable-choice one-stage models. In constraint-based models, syntactic ambiguity is resolved by competition. When there are alternative analyses of similar activation, competition is particularly intense, causing considerable processing difficulty. Competition might continue for a long time. In the competition-integration model (McRae et al., 1998; Spivey & Tanenhaus, 1998), competition is long-lasting but decreases as the sentence unfolds.

So do we resolve ambiguity by reanalysis or competition? Van Gompel et al. (2001) examined how we resolve ambiguity. They constructed sentences such as (62) to (64):

(62) The hunter killed only the poacher with the rifle not long after sunset.
(63) The hunter killed only the leopard with the rifle not long after sunset.
(64) The hunter killed only the leopard with the scars not long after sunset.

The prepositional phrase ("with the rifle/scars") can be attached either to "killed" (a VP **attachment** analysis: the hunter killed with the rifle/scars) or to "poacher/leopard" (an NP attachment: the poacher/leopard had the rifle/scars). In (63), only the VP attachment is plausible (that the hunter killed with the rifle, rather than that the leopard had the rifle); this is the VP condition. In (64), only the NP attachment is plausible (that the leopard had the scars, as you cannot kill with scars); this is the NP condition. In (62), both the VP and NP attachments are plausible; this is called the ambiguous condition.

What do the different theories predict? The garden path model (an example of a fixed-choice two-stage model where ambiguity is resolved by reanalysis) predicts, on the basis of minimal attachment, that the processor will always initially adopt the VP analysis, because this generates the simpler structure. (It creates a structure with fewer nodes than the NP analysis; see Chapter 2.) The processor only reanalyzes if the VP attachment turns out subsequently to be implausible. Hence (62) should be as difficult as (63), but (64) should cause more difficulty. Constraint-based theories predict little competition in (64), because plausibility supports only the NP interpretation. In (63) there should be little competition, because the semantic plausibility information supports only the VP analysis. Crucially, in this experiment there was no syntactic preference for VP or NP attachment. The ambiguity was balanced (usually

VP/NP ambiguities are biased towards VP attachment). In (62), however, there should be competition because both interpretations are plausible. In summary, garden path theory predicts that (62) and (63) should be equally easy, but (64) should be difficult; constraint-based theory predicts that (63) and (64) should be easy, but (62) should be difficult.

Van Gompel et al. examined readers' eye movements to discover when these sentences caused difficulty. They found that an inspection of reading difficulty favored neither pattern of results. Instead, they found that the ambiguous condition was easier to read than the two disambiguated ones. That is, (64) was easy but (62) and (63) were difficult.

Neither garden path nor constraint-based theories seem able to explain this pattern of results. Van Gompel et al. argue that only a variable-choice two-stage model can account for this pattern of results. The unrestricted race is such a model (Traxler, Pickering, & Clifton, 1998; van Gompel et al., 2000, 2001). As in constraint-based models, all sources of information, both syntactic and semantic, are used to select among alternative syntactic structures (hence it is unrestricted). The alternatives are constructed in parallel and engaged in a race. The winner is the analysis that is constructed fastest, and this is adopted as the syntactic interpretation of the fragment. So in contrast to constraint-based theories, only one analysis is adopted at a time. If this analysis is inconsistent with later information, the processor has to reanalyze, at considerable cost; hence it is also a two-stage model. It is also a variable-choice model, as the initial analysis is affected by the particular characteristics of the sentence fragment (as well as by individual differences resulting from differences in experience).

Let us consider how the unrestricted-race model accounts for these data. Because there is no particular bias for NP or VP in (62)–(64), people will adopt one of these as their initial preference on about half the trials. In (62), people will never have to reanalyze, because either preference turns out to be plausible, but (63) and (64) will both cause difficulty on those occasions when the initial preference turns out to be wrong, and the processor will be forced to reanalyze. The critical and surprising finding that only a variable-choice two-stage model such as the unrestricted-race model seems able to explain is that sometimes ambiguous sentences cause less difficulty than disambiguated sentences.

Need detailed syntactic processing necessarily precede semantic analysis? In a second alternative approach Bever, Sanz, and Townsend (1998) suggest that semantics comes first. In an extension of the idea that probabilistic, statistical considerations play an important role in comprehension, Bever et al. argue that statistically based strategies are used to propose an initial semantic representation. This then constrains the detailed computation of the syntactic representation. They argued that the frequency with which syntactic representations occur constrains the initial stage of syntactic processing. At any one time, the processor assigns the statistically most likely interpretation to the incoming material. Bever et al. argued that a principle such as minimal attachment cannot explain why we find reduced relatives so very difficult, but the statistical rarity of this sort of construction can (just because they are so rare). On this account, the role of the processor is reduced to checking that everything is accounted for, and that the initial semantic representation indeed corresponds with the detailed syntactic representation.

Do we always construct a complete, idealized syntactic structure? Christianson, Hollingworth, Halliwell, and Ferreira (2001) argue that we do not. They focus on what people understand after they have read garden path sentences such as "While the man hunted the deer ran into the woods." This emphasis on comprehension—for example, asking people what they thought were the subjects, objects, and actions of clauses, and how confident they were about these judgments—is different from that of most of the other studies we have looked at, which emphasize on-line measures of what is happening when we process individual words while looking at garden path sentences. They found that people do not always completely reanalyze sentences, and often retain a mistaken interpretation derived from the initial misanalysis. They concluded that people do not strive towards perfect analyses, but instead are happy with interpretations that seem to work; they settle for "good enough." In a return related to the early idea of surface cues, some researchers now think that people use simple heuristics when processing language, in addition to detailed and complete syntactic processing (Ferreira, 2003). Comprehenders start out with the assumption that a sentence is in canonical, NVN form, and sentences that violate this heuristic (e.g., passives) are more difficult to understand.

A different approach is taken by McKoon and Ratcliff (2002, 2003). They argue that syntactic constructions themselves carry meaning, beyond the meaning of their constituent words. A passive sentence provides a different emphasis from its corresponding active, and therefore has a different meaning. Sentences (65) and (66), although superficially similar, convey different meanings.

(65) Boris loaded the truck with hay.
(66) Boris loaded hay onto the truck.

Here, sentence (65) conveys the notion that the truck is completely full of hay, but (66) does not. A difference in syntax conveys a difference in meaning. Reduced relative constructions convey a particular meaning. McKoon and Ratcliff argue that this meaning means that it can only be combined with particular sorts of nouns and verbs. The reduced relative can only be used to talk about particular sorts of things: The main noun participates in an event caused by some force or other entity external to itself. The main verb has to convey this sense of external participation. A sentence such as (67) satisfies this constraint, but a sentence such as (68) does not.

(67) Cars and trucks abandoned in a terrifying scramble for safety.
(68) The horse raced past the barn fell.

"Abandoned" conveys this sense of external causation ("something caused cars and trucks to be abandoned"), but "raced" does not (because it is the horse itself that is doing the racing). McKoon and Ratcliff propose that reduced relatives with verbs denoting internally caused events really are ungrammatical, which is why people have so much difficulty with them. A study of a large corpus of natural speech confirms that people only produce reduced relatives with these external-causation verbs. With verbs where the control is internal, in real life speakers use non-reduced constructions ("the horse that was raced past the barn fell").

McKoon and Ratcliff call this approach, where syntactic constructions convey particular meanings that restrict what sorts of nouns and verbs can be used with them, and particularly what sort of verb-argument structures can be used, meaning through syntax (MTS). They further argue that the MTS conflicts with constraint-based theories. According to constraint-based theories, the language processor knows about statistics of usage, not meanings and rules, whereas according to MTS, the language processor knows about meanings and rules, but not statistics. McKoon and Ratcliff found that statistical information about verbs derived from an actual corpus of speech does not predict reading times of sentences containing those verbs.

The MTS approach is criticized by McRae, Hare, and Tanenhaus (2005), who argue that the difficulty of reduced relatives is best accounted for not by the internal–external distinction, but by temporary processing difficulty resulting from ambiguity. Furthermore, the syntactic constructions can on occasion force, or coerce, a particular interpretation regardless of the meaning of the verb: We can still understand a sentence such as "Boris sneezed the tissue off the table" even though "sneezed" does not normally imply causation. Sentence constructions do carry meaning independently of their constituent verbs. In summary, it is difficult to see how the MTS approach can replace alternative theories of parsing difficulty. Indeed, instead of replacing constraint-based theories, the internal–external causation distinction may be just one more constraint.

Processing syntactic-category ambiguity

One type of lexical ambiguity that is of particular importance for processing syntax is lexical-category ambiguity, where a word can be from more than one syntactic category (e.g., a noun or a verb, as in "trains" or "watches"). This type of ambiguity provides a useful test of the idea that lexical and syntactic ambiguity are aspects of the same thing and are processed in similar ways.

According to serial-stage models such as garden path theory, lexical and syntactic ambiguity are quite distinct, because lexical representations are already computed but syntactic representations must be computed (Frazier & Rayner, 1987). According to Frazier (1989), distinct mechanisms are needed to resolve lexical-semantic, syntactic, and lexical-category ambiguity. Lexical-semantic ambiguity is resolved in the manner described in Chapter 6: The alternative semantic interpretations are generated in parallel, and one meaning is rapidly chosen on the basis of context and meaning frequency. Syntactic ambiguity is dealt with by the garden path model in that only one analysis is constructed at any one time; if this turns out to be incorrect, then reanalysis is necessary. Lexical-category ambiguity is dealt with by a delay mechanism. When we encounter a syntactically ambiguous word, the alternative meanings are accessed in parallel, but no alternative is chosen immediately. Instead, the processor delays selection until definitive disambiguating information is encountered later in the sentence. The advantage of the delay strategy is that it saves extensive computation because usually the word following a lexical-category ambiguity provides sufficient disambiguating information.

Frazier and Rayner (1987) provided some experimental support for the delay strategy. They examined how we process two-word phrases containing lexical-category ambiguities, such as "desert trains." After the word "desert," two interpretations are possible. The first noun can either be a noun to be followed by a verb (in which case "desert" will be the subject of the verb "trains"—this is the NV interpretation), or it can be a modifier noun that precedes a head noun (in which case "desert" will be the modifying noun and "trains" the head noun—this is the NN interpretation). Frazier and Rayner examined eye movements in ambiguous and unambiguous sentences. The ambiguous sentences started with "the" ("the desert trains"), which permits both NV and NN interpretations, and the unambiguous controls started with "this" (giving "this desert trains" for an unambiguous NV interpretation) or with "these" (giving "these desert trains" for an unambiguous NN interpretation). The rest of the sentence provided disambiguating information, as shown in the full sentences (69) and (70):

(69) I know that the desert trains young people to be especially tough.

(70) I know that the desert trains are especially tough on young people.

Frazier and Rayner found that reading times in the critical, ambiguous region ("desert trains") were shorter in the ambiguous ("the") condition than the unambiguous ("this"/"these") conditions. However, in the ambiguous condition, reading times were longer in the disambiguating material later in the sentence. They proposed that when the processor encounters the initial ambiguity, very little analysis takes place. Instead, processing is delayed until subsequent disambiguating information is reached, when additional work is necessary.

According to constraint-based theories, there is no real difference between lexical-semantic ambiguity and lexical-category ambiguity. In each case, alternatives are activated in parallel depending on the strength of support they receive from multiple sources of information. Hence multiple factors, such as context and the syntactic bias of the ambiguous word (that is, whether it is more frequently encountered as a noun or a verb), immediately affect interpretation.

How can constraint-based theories account for Frazier and Rayner's findings that we seem to delay processing lexical-category ambiguities until the disambiguating region is reached? MacDonald (1993) suggested that the control condition in their experiment provided an unsuitable baseline, in that they introduced an additional factor. The determiners "this" and "these" serve a deictic function, in that they point the comprehender to a previously mentioned discourse entity. When there is no previous entity, they sound quite odd. Hence Frazier and Rayner's control sentences (71) and (72) in isolation read awkwardly:

(71) I know that this desert trains young people to be especially tough.
(72) I know that these desert trains are especially tough on young people.

Therefore, MacDonald suggested, the relatively fast reading times in the ambiguous region of the experimental condition arose because the comparable reading times in the control condition were quite slow, as readers were taken aback by the infelicitous use of "this" and "these." MacDonald therefore used an additional type of control sentence. Rather than using different determiners, she used the unambiguous phrases "deserted trains" and "desert trained." She found that "this" and "these" did indeed slow down processing, even in the unambiguous version ("I know that these deserted trains could resupply the camp" compared with "I know that the deserted trains could resupply the camp").

MacDonald went on to test the effects of the semantic bias of the categorically ambiguous word. The semantic bias is the interpretation that people give to the ambiguity in isolation. It can turn out either to be correct if it is supported by the context, such as in (73), which normally has a noun–verb interpretation, or to be incorrect if it is not, as in (74), where "warehouse fires" normally has a noun–noun interpretation:

(73) The union told reporters that the corporation fires many workers each spring without giving them notice.
(74) The union told reporters that the warehouse fires many workers each spring without giving them notice.

According to the delay model, even a strong semantic bias should not affect initial resolution, because all decisions are delayed until the disambiguation region: Reading times should be the same whether the bias is supported or not. According to the constraint-based model, a strong semantic bias should have an immediate effect. If the interpretation favored by the semantic bias turns out to be correct, ambiguous reading times should not differ from the unambiguous control condition. It is only when the interpretation favored by the semantic bias turns out to be incorrect that reading times of the ambiguous sentence should increase. The pattern of results favored the constraint-based model. Semantic bias has an immediate effect.

(75) She saw her duck –

What happens when we encounter an ambiguous fragment such as (75)? In this situation, the continuation using "duck" in its sense as a verb (e.g., "She saw her duck and run") is statistically more likely than that as a noun (e.g., "She saw her duck and chickens"). It is possible to bias the interpretation with a preceding context sentence (e.g., "As they walked round, Agnes looked at all of Doris's pets"). Boland (1997), using analysis of reading times, showed that whereas probabilistic lexical information is used immediately to influence the generation of syntactic structures, background information is used later to guide the selection of the appropriate structure. These findings support the constraint-based approach: When we identify a word, we do not just access its syntactic category, we activate other knowledge that plays an immediate role in parsing, such as the knowledge about the frequency of alternative syntactic structures. However, the finding that context sometimes has a later effect requires modification of standard constraint-based theories.

GAPS, TRACES, AND UNBOUNDED DEPENDENCIES

Syntactic analysis of sentences suggests that sometimes constituents have been deleted or moved. Compare (76) and (77):

(76) Vlad was selling and Agnes was buying.
(77) Vlad was selling and Agnes_buying.

Sentence (77) is perfectly grammatically well formed. The verb ("was") has been deleted to avoid repetition, but it is still there, implicitly. Its deletion has left a **gap** in the location marked.

Parts of a sentence can be moved elsewhere in the sentence. When they are moved they leave a special type of gap called a trace. There is no trace in (78), but in (79) "sharpen" is a transitive verb demanding an object; the object "sword" has been moved, leaving a trace (indicated by t). This type of structure is called an unbounded dependency, because closely associated constituents are separated from each other (and can, in principle, be infinitely far apart).

(78) Which sword is sharpest?
(79) Which sword did Vlad sharpen [t] yesterday?

Gaps and traces may be important in the syntactic analysis of sentences, but is there any evidence that they affect parsing? If so, the gap has to be located and then filled with an appropriate **filler** (here "the sword").

There is some evidence that we fill gaps when we encounter them. First, traces place a strain on memory: The dislocated constituent has to be held in memory until the trace is reached. Second, processing of the trace can be detected in measurements of the brain's electrical activity (Garnsey, Tanenhaus, & Chapman, 1989; Kluender & Kutas, 1993), although it is difficult to disentangle the additional effects of plausibility and working memory load in these studies. Third, all languages seem to employ a recent filler strategy, whereby in cases of ambiguity a gap is filled with the most recent grammatically plausible filler. For example, Frazier, Clifton, and Randall (1983) noted that sentences of the form of (80) are understood 100 ms faster (as measured by reading times) than sentences such as (81):

(80) This is the girl the teacher wanted [t_1] to talk to [t_2].
(81) This is the girl the teacher wanted [t] to talk.

One possibility is that when the processor detects a gap it fills it with the most active item, and is prepared to reanalyze if necessary. This is the active-filler strategy (Frazier & Flores d'Arcais, 1989). Another possibility is that the processor detects a gap, and fills it with a filler, that is, the most recent potential dislocated constituent. This is the recent-filler strategy. This leads to the correct outcome in (80): Here the constituent "the teacher" goes into the gap t_1, leaving "the girl" to go into t_2. In (81), however, it is "the girl" that should go into the gap t, and not the most recent constituent ("the teacher"). This delays processing, leading to the slower reading times. These two strategies can be quite difficult to distinguish, but in each case trace-detection plays an important role in parsing.

Finally, at first sight some of the strongest evidence for the processing importance of traces is the finding that traces appear able to prime the recognition of the dislocated constituents or antecedents with which they are associated. That is, the filler of the gap becomes semantically reactivated at the point of the gap. There is significant priming of the NP filler at the gap (Nicol, 1993; Nicol & Swinney, 1989). In a sentence such as (82), the NP "astute lawyer" is the antecedent of the trace [t], as the "astute lawyer" is the underlying subject who is going to argue during the trial (Bever & McElree, 1988). In the superficially similar control sentence (83) no constituent has been moved, and therefore there is no trace.

(82) The astute lawyer, who faced the female judge, was certain [t] to argue during the trial.
(83) The astute lawyer, who faced the female judge, hated the long speeches during the trial.

We find that the gap in (82) does indeed facilitate the recognition of a probe word from the antecedent (e.g., "astute"). The control sentence (83) produces no such facilitation. Hence, when we find a trace, we appear to retrieve its associated antecedent—a process known as binding the dislocated constituent to the trace, thereby making it more accessible.

On the other hand, there is other research suggesting that traces are not important in online processing. McKoon, Ratcliff, and Ward (1994) failed to replicate the studies that show wh- traces (traces formed by a question formation) can prime their antecedents (e.g., Nicol & Swinney, 1989). Although unable to point to any conclusive theoretical reasons why it should be the case, they found that the choice of control words in the lexical decision was very important; a choice of different words could obliterate the effect. They found no priming when the control words were chosen from the same set of words as the test words, yet priming was reinstated when the control words were from a different set of words than the test words. In addition, when they found priming, they found it for locations both after and before the verb. This should not be expected if the trace is reinstating the antecedent, as the trace is only activated by the verb. Clearly what is happening here is poorly understood.

An alternative view to the idea that we activate fillers when we come to a gap is that interpretation is driven by the verbs rather than the detection of the gaps, so that we postulate expected arguments to a verb as soon as we reach it (Boland, Tanenhaus, Carlson, & Garnsey, 1989). In the earlier sentences where there was evidence of semantic reactivation, the traces were adjacent to the verbs, so the two approaches make the same prediction. What happens if they are separated? Consider sentence (84):

(84) Which bachelor did Boris grant the maternity leave to [t]?

This sentence is semantically anomalous, but when does it become implausible? If the process of gap postulation and filling is driven by the syntactic process of trace analysis, it should only become implausible when people reach the trace at the end of the sentence. The role of "bachelor" can only be assigned after the preposition "to." But if the process is verb-driven, the role of "bachelor" can be determined as soon as "maternity leave" is assigned to the role of the direct object of "grant"; hence "bachelor" is the recipient. So the anomaly will be apparent here. This is what Boland et al. found. Hence the postulation and filling of gaps are immediate and are driven by the verbs (for similar results see Altmann, 1999; Boland, Tanenhaus, Garnsey, & Carlson, 1995; Nicol, 1993; Pickering & Barry, 1991; Tanenhaus, Boland, Mauner, & Carlson, 1993). For example, consider (85) from Traxler and Pickering (1996):

(85) That is the very small pistol in which the heartless killer shot the hapless man [t] yesterday afternoon.

Clearly this sentence is implausible, but when do readers experience difficulty? Here the gap location is after "man" (because in the plausible version the word order should be the heartless killer shot the hapless man with the very small pistol yesterday afternoon), but the readers experience processing difficulty immediately on reading "shot." The unbounded dependency has been formed before the gap location is reached. The parsing mechanism seems to be using all sources of information to construct analyses as soon as possible.

Similarly, Tanenhaus et al. (1989) presented participants with sentences such as (86) and (87):

(86) The businessman knew which customer the secretary called [t] at home.

(87) The businessman knew which article the security called [t] at home.

At what point do people detect the anomaly in (87)? Analysis of reading times showed that participants detect the anomaly before the gap, when they encounter the verb "called." ERP studies confirm that the detection of the anomaly is associated with the verb (Garnsey et al., 1989).

In summary, the preponderance of evidence suggests that fillers are postulated by activating the argument structure of verbs.

THE NEUROSCIENCE OF PARSING

As we would expect of a complex process such as parsing, it can be disrupted as a consequence of brain damage. Deficits in parsing, however, might not always be apparent, because people can often rely on semantic cues to obtain meaning. The deficit becomes apparent when these cues are removed and the patient is forced to rely on syntactic processing.

There is some evidence that syntactic functions take place in specific, dedicated parts of the brain. The evidence includes the differing effects of brain damage to regions of the brain such as Broca's and Wernicke's areas (see Chapters 3 and 13), and studies of brain imaging (e.g., Dogil, Haider, Schaner-Wolles, & Husman, 1995; Friederici, 2002; Neville et al., 1991).

The comprehension abilities of agrammatic aphasics

The disorder of syntactic processing that follows damage to Broca's area is called **agrammatism**. The most obvious feature of agrammatism is impaired speech production (see Chapter 13), but many people with agrammatism also have difficulty in understanding syntactically complex sentences. The ability of people with agrammatism to match sentences to pictures when semantic cues are eliminated is impaired (Caramazza & Berndt, 1978; Caramazza & Zurif, 1976; Saffran, Schwartz, & Marin, 1980). These patients are particularly poor at understanding reversible passive constructions (e.g., "The dog was chased by the cat" compared with "The flowers were watered by the girl") and object relative constructions (e.g., "The cat that the dog chased was black" compared with "The flowers that the girl watered were lovely") in the absence of semantic cues.

One explanation for these people's difficulty is that brain damage has disrupted their parsing ability. One suggestion is that these patients are unable to access grammatical elements correctly (Pulvermüller, 1995). Another idea is that this difficulty arises because syntactic traces are not processed properly, and the terminal nodes in the parse trees that correspond to function words are not properly formed (Grodzinsky, 1989, 1990; Zurif & Grodzinsky, 1983). Grodzinsky (2000) spelled out the trace-deletion hypothesis. This hypothesis states that people with an agrammatic comprehension deficit have difficulty in computing the relation between elements of a sentence that have been moved by a grammatical transformation and their origin (trace), as well as in constructing the higher parts of the parse tree. One problem with this view is that, as we have seen, the evidence for the existence of traces in parsing is questionable.

Some evidence against the idea that people with agrammatism have some impairment in parsing comes from the grammaticality judgment task. This task simply involves asking people whether a string of words forms a proper grammatical sentence or not. Linebarger, Schwartz, and Saffran (1983) showed that the patients are much more sensitive to grammatical violations than one might expect from their performance on sentence comprehension tasks. They performed poorly in a few conditions containing structures that involve making comparisons across positions in the sentence (such as being insensitive to violations like "*the man dressed herself" and "*the people will arrive at eight o'clock didn't they?"). It appears, then, that these patients can compute the constituent structure of a sentence, but have difficulty using that information, both for the purposes of detecting certain kinds of violation as well as for thematic role assignment. Schwartz, Linebarger, Saffran, and Pate (1987) showed that agrammatic patients could isolate the arguments of the main verb in sentences that were padded with extraneous material, but had difficulty using the syntax for the purpose of thematic role assignment. These studies suggest that these patients have not necessarily lost syntactic knowledge, but are unable to use it properly. Instead, the mapping hypothesis is the idea that the comprehension impairment arises because although low-level parsing processes are intact, agrammatics are limited by what they can do with the results of these processes. In particular, they have difficulty with thematic role assignment (Linebarger, 1995; Linebarger et al., 1983). They compensate, at least in part, by making use of semantic constraints, although Saffran, Schwartz, and Linebarger (1998) have shown that reliance on these constraints may sometimes lead them astray. Thus these patients failed to detect anomalies such as "*The cheese ate the mouse" and "*The children were watched by the movie" approximately 50% of the time.

Some types of patient that we might expect to find have so far never been observed. In particular, no one has (yet) described a case of a person who knows the meaning of words but who is unable to assign them to thematic roles (Caplan, 1992; although Schwartz, Saffran, & Marin, 1980b, describe a patient who comes close).

A completely different approach emerged that postulated that the syntactic comprehension deficit results from an impairment of general memory. According to this idea, the pattern of impairment observed depends on the degree of reduction of language capacity, and the structural complexity of the sentence being processed (Miyake, Carpenter, & Just, 1994). (Somewhat confusingly, although Miyake et al. talk of a reduction in working memory capacity, they mean a reduction in the capacity of a component of the central executive of Baddeley's 1990 conception of working memory that serves language comprehension; see Just & Carpenter, 1992.) In particular, these limited computational resources mean that people with a syntactic comprehension deficit suffer from restricted availability of the materials. Miyake et al. simulated agrammatism in normal comprehenders with varying memory capacities by increasing computational demands using very rapid presentation of words (120 ms a word). Along similar lines, Blackwell and Bates (1995) created an agrammatic performance profile in normal participants who had to make grammaticality judgments about sentences while carrying a memory load. In other words, people with a syntactic comprehension deficit are just at one end of a continuum of central executive capacity compared with the normal population. Syntactic knowledge is still intact, but cannot be used properly because of this working memory impairment. Grammatical elements are not processed in dedicated parts of the brain, but are particularly vulnerable to a global reduction in computational resources. Further evidence for this idea comes from self-reports from aphasic patients suggesting that they have limited computational resources ("other people talk too fast"—Rolnick & Hoops, 1969) and conversely that slower speech facilitates syntactic comprehension in some aphasic patients (e.g., Blumstein, Katz, Goodglass, Shrier, & Dworetzky, 1985). Increased time provides more opportunity for using the limited resources of the central executive. Indeed, time shortage or the rapid decay of the results of syntactic processing might play a causal role in the syntactic comprehension deficit and in agrammatic production (Kolk, 1995).

This is an interesting idea that has provoked a good deal of debate. The extent to which the comprehension deficit is related to limited computational resources is debatable. For example, giving these patients unlimited time to process sentences does not lead to an improvement in processing (Martin, 1995; Martin & Feher, 1990). The degree to which Miyake et al. simulated aphasic performance has also been questioned (Caplan & Waters, 1995a). In particular, the performance of even their lowest-span participants was much better than that of the aphasic comprehenders. Caplan and Waters pointed out that rapid presentation might interfere with the perception of words rather than syntactic processing. Furthermore, patients with **Alzheimer's disease (AD)** with restricted working memory capacity show little effect of syntactic complexity, but do show large effects of semantic complexity (Rochon, Waters, & Caplan, 1994). Addressing these concerns, Dick et al. (2001) compared the syntactic comprehension abilities of agrammatic patients with college students working under a variety of stressful conditions (e.g., with the speech masked by noise, or by compressing the speech). The two groups then performed similarly.

Finally, if there is a reduction in processing capacity involved in syntactic comprehension deficits, it might be a reduction specifically in syntactic processing ability, rather than a reduction in general verbal memory capacity (Caplan, Baker, & Dehaut, 1985; Caplan & Hildebrandt, 1988; Caplan & Waters, 1999). The extent to which this is the case, or whether general verbal working memory is used in syntactic processing (the capacity theory), is still a hotly debated topic with few signs of settling on any agreement (Caplan & Waters, 1996, 1999; Just & Carpenter, 1992; Just, Carpenter, & Keller, 1996; Waters & Caplan, 1996; see also Chapter 15). On balance it looks as though a general reduction in working memory capacity cannot cause the syntactic deficit in agrammatism.

Are content and function words processed differently?

Remember that content words do the semantic work of the language and include nouns, verbs, adjectives, and most adverbs, while function words, which are normally short, common words, do the grammatical work of the language. Are content and function words processed in different parts of the brain?

Content words are sensitive to frequency in a lexical decision task, but function words are not. For a while it was thought that this pattern is not observed in patients with agrammatism (Bradley, Garrett, & Zurif, 1980). Instead, agrammatic patients are sensitive to the frequency of function words, as well as to the frequency of content words. This is because the brain damage means that function words can no longer be accessed by the special set of processes and have to be accessed as other content words. Perhaps the comprehension difficulties of these patients arise from difficulty in activating function words? Unfortunately, the exact interpretation of these results has proved very controversial, and the original studies have not been replicated (see, for example, Gordon & Caramazza, 1982; Swinney, Zurif, & Cutler, 1980). Caplan (1992) concluded that there is no clear neuropsychological evidence that function words are treated specially in parsing.

Is automatic or attentional processing impaired in agrammatism?

Most of the tasks used in the studies described so far (e.g., sentence–picture matching tasks, anomaly detection, and grammaticality judgment) are off-line, in that they do not tap parsing processes as they actually happen. Therefore, the results obtained might reflect the involvement of some later variable (such as memory). So do these impairments reflect deficits of automatic parsing processes, or deficits of some subsequent attentional process?

Tyler (1985) provided an indication that at least some deficits in some patients arise from a deficit of attentional processing. She examined aphasic comprehension of syntactic and semantic anomalies, comparing performance on an on-line measure (monitoring for a particular word) with that on an off-line measure (detecting an anomaly at the end of the sentence). She found patients who performed normally on the on-line task but very poorly on the off-line task. This suggests that the automatic parsing processes were intact, but the attentional processes were impaired.

This is a complex issue that has spawned a great deal of research (e.g., Friederici & Kilborn, 1989; Haarmann & Kolk, 1991; Martin, Wetzel, Blossom-Stach, & Feher, 1989; Milberg, Blumstein, & Dworetzky, 1987; Tyler, Ostrin, Cooke, & Moss, 1995). Clearly at least some of the deficits we observe arise from attentional factors: the question remaining is, how many?

Evaluation of work on the neuroscience of parsing

Although there has been a considerable amount of work on the neuropsychology of parsing, it is much more difficult to relate to the psychological processes involved in parsing. Much of the work is technical in nature and relates to linguistic theories of syntactic representation. It is also unlikely that there is a single cause for the range of deficits observed (Tyler et al., 1995).

Friederici (2002) describes a model of sentence processing where the left temporal regions identify sounds and words; the left frontal cortex is involved in sequencing and the formation of structural and semantic relations; and the right hemisphere is involved in identifying prosody (see Figure 10.4). She argues that imaging and electrophysiological data suggest that sentence processing takes place in three phases. In Phase 1 (100–300 ms) the initial syntactic structure is formed on the basis of information about word category. In Phase 2 (300–500 ms) lexical-syntactic processes take place, resulting in thematic role assignment. In Phase 3 (500–1,000 ms) the different types of information are integrated. She argues that syntactic and semantic processes only interact in Phase 3.

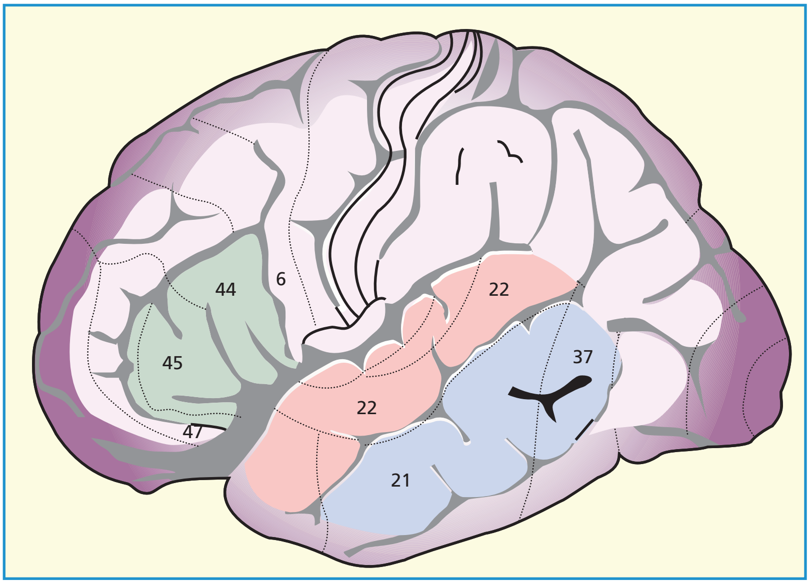

FIGURE 10.4 Brodmann areas in the left hemisphere. The inferior frontal gyrus (IFG) is shown in green, the superior temporal gyrus (STG) in red, and the middle temporal gyrus (MTG) in blue. From Friederici (2002).

SUMMARY

- The clause is an important unit of syntactic processing.
- In autonomous models, only syntactic information is used to construct and select among alternative syntactic structures; in interactive models non-syntactic information is used in the selection process.
- Psycholinguists have particularly studied how we understand ambiguous sentences, such as garden path constructions.
- One of the most studied types of garden path sentence is the reduced relative, as in the well-known sentence "The horse raced past the barn fell."
- Early models of parsing focused on parsing strategies using syntactic cues.
- Kimball proposed seven surface structure parsing strategies.
- The sausage machine of Frazier and Fodor comprised a limited window preliminary phrase packager (PPP) and a sentence structure supervisor (SSS).
- The principle of minimal attachment says that we prefer the simplest construction, where simple means the structure that creates the minimum number of syntactic nodes.
- The principle of late closure says that we prefer to attach incoming material to the clause or phrase currently being processed.
- Languages may differ in their attachment preferences.
- The garden path model of parsing is still a two-stage model, where only syntactic information can affect the first stage.
- The referential model of parsing explains the garden path effect in terms of discourse factors such as the number of entities presupposed by the alternative constructions.
- In constraint-based models, all types of information (e.g., thematic information about verbs) are used to select among alternative structures.

- The experimental evidence for and against the autonomous garden path and interactive constraint-based models is conflicting.
- In constraint-based models, lexical and syntactic ambiguity are considered to be fundamentally the same thing, and resolved by similar mechanisms.
- Statistical preferences may have some role in parsing.
- Some recent models have questioned whether syntax needs to precede semantic analysis.
- Gaps are filled by the semantic reactivation of their fillers.
- Gaps may be postulated as soon as we encounter particular verb forms.
- Verbs play a central role in parsing.
- ERP studies show that people try and predict what is coming next.
- Some aphasics show difficulties in parsing when they cannot rely on semantic information.
- There is no clear neuropsychological evidence that content and function words are processed differently in parsing.
- Some off-line techniques might be telling us more about memory limitations or semantic integration than about what is actually happening at the time of parsing.
- Electrophysiological and imaging data suggest that sentence comprehension takes place in three phases, and different components of processing are identifiable with distinct regions of the brain.

QUESTIONS TO THINK ABOUT

1. What does the evidence from the study of language development tell us about the relation between syntax and other language processes? (You may need to look at Chapters 2 and 3 again in order to be able to answer this question.)
2. What do studies of parsing tell us about some of the differences between good and poor readers?
3. Is the following statement true: “Syntax proposes, semantics disposes”?
4. How does the notion of “interaction” in parsing relate to the notion of “interaction” in word recognition?
5. Which experimental techniques discussed in this chapter are likely to give the best insight into what is happening at the time of parsing? How would you define “best”?

FURTHER READING

Fodor, Bever, and Garrett (1974) is the classic work on much of the early research on the possible application of Chomsky’s research to psycholinguistics, including deep structure and the derivational theory of complexity. Greene (1972) covers the early versions of Chomsky’s theory, and detailed coverage of early psycholinguistic experiments relating to it. See Clark and Clark (1977) for a detailed description of surface structure parsing cues. Johnson-Laird (1983) discusses different types of parsing systems with special reference to garden path sentences.

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For reviews on parsing work see Pickering and van Gompel (2006) and van Gompel and Pickering (2007). For a model based on a rational analysis of what parsing involves, see Hale (2010).

As Mitchell (1994) pointed out, most of the work in parsing has examined a single language. There are exceptions, including work on Dutch (Frazier, 1987b; Frazier, Flores d'Arcais, & Coolen, 1993; Mitchell, Brysbaert, Grondelaers, & Swanepoel, 2000), French (Holmes & O'Reagan, 1981), East Asian languages (Special Issue of *Language and Cognitive Processes*, 1999, volume 14, parts 5 and 6), German (Bach, Brown, & Marslen-Wilson, 1986; Hemforth & Konieczny, 1999), Hungarian (MacWhinney & Pleh, 1988), Japanese (Mazuka, 1991), and Spanish (Cuetos & Mitchell, 1988), but the great preponderance of the work has been on English alone. It is possible that this is giving us at best a restricted view of parsing, and at worst a misleading view.

See Caplan (1992; the paperback edition is 1996) for a detailed review of work on the neuropsychology of parsing. See Haarmann, Just, and Carpenter (1997) for a computer simulation of the resource-deficit model of syntactic comprehension deficits.