We rarely stop to notice that ‘eating pizza with a friend’ could (but does not) mean that the friend fulfilled the same function as the knife and fork in ‘eating pizza with a knife and fork’, or as the glass of wine in ‘with a glass of wine’. The pervasiveness of ambiguity during sentence processing does not always pass us by, however. Occasionally we choose an interpretation that is not the one intended by the speaker or, in printed text, the writer. A sentence such as (1) below is grammatical but, more often than not, interpreted as ungrammatical:

(1) The horse raced past the crowd stumbled.

Commonly, people reach the word ‘stumbled’ in (1) and believe either that the sentence is ungrammatical, or that the sentence was supposed to be either: ‘The horse raced past the crowd and stumbled’ or ‘The horse raced past, and the crowd stumbled’. The problem in (1) is that the verb ‘raced’ tends to be interpreted as a main verb, which subsequently proves incompatible with the final word ‘stumbled’. In fact, the verb ‘raced’ is ambiguous between a main verb in the past tense and a past participle (see Glossary), and only the past participle version is compatible with the final continuation of this sentence. In (2) below, the verb ‘ridden’ can only be a past participle, and this sentence is therefore relatively unproblematic:

(2) The horse ridden past the crowd stumbled.

Other problematic cases include sentences such as the following:

(3) He will read the paper that he received tomorrow.

We tend to interpret the final adverb ‘tomorrow’ as saying something about the immediately preceding verb (‘received’) – yet the past tense of the verb is incompatible with an adverb that refers to the future. Instead, we should interpret the adverb as saying something about the earlier verb (that is, as saying something about when the reading will be done).

In some respects, sentences such as these might at first glance be considered oddities and, at best, unrepresentative of the language we normally encounter. But we can nonetheless ask: Why do readers of such sentences consistently misinterpret them? What is it about the grammatical structure of the language, or the structure and organization of our language faculty, that causes us to misanalyse consistently the grammatical structure of these sentences?

Syntactic explanations

The earliest attempts to explain these consistent misinterpretations were based on an analysis of the underlying syntactic structure of such sentences. John Kimball and subsequently Lyn Frazier pointed out that the interpretation of these ambiguities seemed to be determined by consistent differences in the syntactic structures that accompanied the alternative readings of each sentence. Frazier developed two principles to explain the behaviour of the ‘human sentence processing mechanism’ when faced with
In the box

processing has emerged that directly challenges this notion of

More recently, an alternative view of human sentence pro-

Multiple constraints in sentence processing

subsystem responsible for syntactic decision-making.

information because no other knowledge is available to the

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clause). A wide range of sentential ambiguities can be

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the clause currently being processed is kept ‘open’ as long

(see Fig. 2). Called ‘late closure’, this principle dictates that

principle dictates that the sentence processor adopts the

more branching points (‘nodes’) than the structure associ-

them. Such structures are often notated (see Figs 1 and 2).

Relative clause: a phrase that can be used to provide addi-

Referential context: a term used to refer to that aspect of

Subject: the grammatical subject of a sentence is, typically, the

argumentative approach to modelling

vastly different phenomena that amuse networks of interconecting units

whose activation levels can, by virtue of these interconnections,

influence the activation levels of their neighbours. Typically, information is encoded in the patterns of connectivity between

the unit, and the patterns of activation across these units in re-

sponse to an input reflect properties of the input (as defined by

the information already encoded within the network).

Event-related brain potential: electrical activity recorded at the scalp that changes in response to some (experimentally induced) event.

Interactive activation: a term used to refer to a class of model in which representations are activated to varying degrees (depend-

on the input), and in which the activation of one representation

can influence the activation of another (hence the interaction).

Intransitive: an intransitive verb requires only a subject, as in

‘he slept’. Intransitive verbs include those that can occur alone

in the passive, and those that can take a prepositional phrase, as in

‘the horse that lost the race’.

Syntactic structure: the organization of the words in a sentence into constituent phrases, and the relationships between

them. Such structures are often notated (see Figs 1 and 2).

Theme: a participant who is spatially displaced as a result of an

instigated event (cf. patient).

Transitive: a transitive verb requires both a subject and an object, as in

‘he ate the apple’.

syntactic ambiguities. The first of these, called ‘minimal at-

tachment’, was based on the observation that, for at least

one class of ambiguity, the structure associated with the

least interpreted interpretation is more complex – it contains more branching points (‘nodes’) than the structure associ-

ated with the preferred interpretation (see Fig. 1). This

principle dictates that the sentence processor adopts the

analysis that requires the simpler structure. In example (1)

given above, the preferred (but correct) reading requires more nodes in the corresponding syntactic structure.

The second principle applies to example (3) above, in

which each interpretation contains the same number of nodes

(see Fig. 2). Called ‘late closure’, this principle dictates that

the clause currently being processed is kept ‘open’ as long

as possible (with the consequence that incoming material

will be incorporated within the current, or more recent,

clause). A wide range of sentential ambiguities can be

analysed in terms of one or other of these principles. Both

were motivated, originally, in terms of reducing memory

load, although Frazier subsequently suggested, following

Fodor4, that the human sentence processing mechanism

consists of informationally encapsulated modules, with the

syntactic module being ‘informationally encapsulated’ from the

others (i.e. there is no non-syntactic influence on syn-

tactic decision-making)4,5 – in effect, decisions regarding

syntactic structure are made solely on the basis of syntactic

information because no other knowledge is available to the

subsystem responsible for syntactic decision-making.

Multiple constraints in sentence processing

More recently, an alternative view of human sentence pro-

cessing has emerged that directly challenges this notion of

informational encapsulation. It assumes instead that mul-

tiple sources of information interact, with each source of

information constraining the interpretation in a particular way4,5. An important aspect of this approach is that the dif-

ferent constraints (see below) are applied in parallel and are

probabilistic. This idea borrows much from findings in the

word-recognition literature. In particular, there are three

findings within that literature that motivate the constraint-

satisfaction approach to sentence processing:

(1) Multiple meanings of a single ambiguous word are

briefly activated6,7.

(2) The frequency (or probability) of occurrence of

each meaning in the language at large determines the rela-

tive degree of activation of the alternatives4,5

(3) Biasing contexts can increase the activation of one

or other of the alternatives (so that, for example, a less fre-

quent meaning can become activated to the same degree as a

more frequent meaning)4,5.

How do these findings relate to ambiguity in sentence processing? Consider again the first example:

(1) The horse raced past the cow ready staked.

Because the verb ‘raced’ is ambiguous, multiple repre-

sentations, corresponding to the meanings of the main verb

and past participle versions, will be activated. These repres-

entations will include information not simply about what

‘race’ means, but also about the syntactic (or argument) structures it can occur in (it can be Intransitive – taking just one argument, as in ‘he raced’, or Transitive – taking two arguments, as in ‘he raced the horse’). Whichever is the most frequent will be the more active4,5. However, the

frequency with which ‘raced’ occurs as a past participle or as

Glossary

Adverb: a word referring to some property of an event, such as

how or when the event happened (‘yesterday’) or how it happened.

Agent: the active instigator of an event (usually also the subject,

in English).

Argument: a participant (animate or otherwise) in an event

defined by a verb. The verb ‘put’ takes three ‘arguments’: he

put the ball in the box.

Argument structure: the information associated with a verb

regarding the syntactic context in which it should occur.

Connectionism: a computational approach to modelling

various phenomena that amuse networks of interconecting units

whose activation levels can, by virtue of these interconnections,

influence the activation levels of their neighbours. Typically, information is encoded in the patterns of connectivity between

the unit, and the patterns of activation across these units in re-

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Event-related brain potential: electrical activity recorded at the scalp that changes in response to some (experimentally induced) event.

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‘he slept’. Intransitive verbs include those that can occur alone

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Syntactic structure: the organization of the words in a sentence into constituent phrases, and the relationships between

them. Such structures are often notated (see Figs 1 and 2).

Theme: a participant who is spatially displaced as a result of an

instigated event (cf. patient).

Transitive: a transitive verb requires both a subject and an object, as in

‘he ate the apple’. 
A main verb is only one factor that will influence which meaning of ‘raced’ is the more activated. Another factor might be the frequency with which ‘raced’ is used in its intransitive form or its transitive forms. These two factors interact inasmuch as the passive past participle form is necessarily transitive, whereas the active main verb forms can be either. Different verbs will have different proprieties with respect to these factors (e.g. for ‘enjoyed’, the past tense form is more frequent than the past participle form; for ‘examined’, the two forms are equiprobable; for ‘received’ the past participle form is the more frequent – each case is determined by different factors). This means that a given sentence might be interpreted as both active and passive, although either the active or the passive interpretation tends to be more activated.

The context within which each verb occurs can also play a part. Take a sentence fragment, such as ‘The burglar arrested…’, the context of a verb ‘arrested’, a bad agent, but a good patient of theme. In ‘the cop arrested…’, the cop is likely to be doing the arresting, and is therefore a good agent (although, legitimately, the cop could be the person being arrested – perhaps with less likelihood). Thus, the plausibility with which the surface subject can fill one role (either as the thing doing the action referred to by the verb, or as the thing that the action is being done to) is another source of constraint. Each of the factors discussed so far has been shown, by a variety of means (for example, see Box 1), to have an independent influence on the initial choice of interpretation in cases like the ‘raced’ example. And because the influences are independent, they can on occasion conflict. The first sentence in the pair shown below should be entirely straightforward:

(4) The sofa scratched by the cat was badly damaged.
(5) The sofa that was scratched by the cat was badly damaged.

Sofas are more likely to be scratched than to scratch; yet ‘scratched’ is rarely used as a past participle. Indeed, analysis of the time taken to read ‘by the cat’ in sentence (4) compared with the unambiguous version in (5) reveals that ‘by the cat’ is unexpected in version (4) – it engenders longer reading times, which suggests that despite the implausibility of sofas scratching, the main verb interpretation is initially preferred.

An important feature of this constraint-based approach to syntactic ambiguity is that representations corresponding to alternative interpretations are activated, but that this activation is both graded and dynamically changing as the sentence unfolds, and as constraints continue to apply. Thus, it is not the case, according to such theories, that all possible interpretations are held in working memory, each equally accessible, until some decision process decides between them.

The role of extra-sentential context
Thus far, the only information we have considered that can influence the interpretation of sentential ambiguity has been information derived from within the sentence itself. However, a further source of information that can influence sentence interpretation is the context, linguistic or otherwise, in which the ambiguous sentence occurs. The following is another example of a sentence that is often initially perceived as ungrammatical:

(6) He told the journal that he had recently written it to hurry up and submit his piece.

Commonly, people interpret the sequence starting ‘that he had…’ as referring to what was told to the journalist, in which case the second ‘to’ appears ungrammatical. Instead, this sequence should be interpreted as a relative clause – that is, as telling us something about which journalist is being referred to, as in ‘He told the one whom he had recently written to hurry up with his piece’. Stephen Crain, working with children, has observed that children are often better able to process relative clauses when they are presented in a context that makes them necessary. For this last example, if the fragment ‘He told the journalist’ were

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Fig. 1 Two interpretations of ‘The burglar blew open the safe with the dynamite’.

(A) preferred, (B) unpreferred.
presented in a context that introduced two or more journalists, a relative clause would be required in order to specify which journalist was intended (that is, which journalist was being referred to): ‘the journalist that he had recently written to’. Crain and Steedman presented pilot data from adult studies suggesting that the problems normally encountered with sentences such as the one above could indeed be overcome in appropriate ‘referential contexts’. Several studies followed that supported this view. One recent study involved asking people in front of a table on which there were various objects, and monitoring their eye movements as they acted out various instructions, such as ‘Put the apple on the towel in the box’. In this case, the visual world, rather than a mental representation of the linguistic material, constituted the context. Ordinarily, ‘on the towel’ is initially interpreted as where the apple should be put (as predicted, in fact, by the earlier syntactic accounts of ambiguity resolution). However, the data demonstrate that if people are given this instruction when faced with two apples in front of them, just one of which is on a towel, they immediately interpret ‘on the towel’ as indicating which apple is being referred to, and not as indicating where it should be put. It was found, in this study, that the eyes would move, on hearing ‘on the…’, to the apple that was on the towel, as opposed to either the other apple or a second (empty) towel that could be a potential target location.

How do such contextual factors interact with the more local constraints described earlier? According to the constraint-satisfaction approach to sentence processing, the availability of alternative structures will be graded (according to the probabilistic effects of frequency, plausibility and so on), and this differential availability determines the extent to which any single constraint can influence the interpretive process. Thus, the stronger one kind of constraint (for example, the high frequency of occurrence of one argument structure rather than another), the weaker the potential influence of others. We saw an example of this with the ‘sofa scratched’ example earlier – there, the frequency of occurrence of ‘scratched’ as an active main verb is more influential than the implausibility (or untypicality) of sofa scratching. Exactly the same kind of trade-off has been observed with context: the stronger the local constraint (frequency of occurrence of one structure over another), the weaker the influence of contextual constraints.

The accumulation of evidence in favour of a constraint-based approach to sentence processing has led proponents of the earlier ‘syntactic’ accounts to modify their theories so as to incorporate the possibility of non-syntactic influences on the initial processing of ambiguities. One such account, termed ‘construal’, maintains nonetheless that there are restricted cases where non-syntactic influences are ruled out. For example, this account maintains that in a sentence such as ‘he put the apple on the towel…’, syntactic principles dictate that the phrase ‘on the towel’ must be interpreted as an argument of ‘put’ – indicating the location of the putting. Such an account is clearly at odds with the earlier finding that, in appropriate contexts, ‘on the towel’ is not interpreted as an argument of ‘put’.

**Fig. 2 Two interpretations of ‘He read the paper that he received yesterday’**. In (A), the adverb is associated with the lower (more recent) verb phrase, and hence refers to when the more recent action (the receiving) happened. In (B), the adverb is associated with the higher (earlier) verb phrase, and hence refers to when that action (the reading) happened. 

**Sentence**: He read the paper that he received yesterday. 

**NP** = noun phrase; VP = verb phrase; det = determiner; N = noun; V = verb; Adv = adverb; relp = relative pronoun; e = null element (the object of the relative clause, ‘the paper’).

**Activation and decay during sentence processing**

The constraint-satisfaction view of sentence processing does more than simply propose that there exist constraints on sentence processing; it proposes also that these constraints are applied within a framework of ‘interactive activation’, as exemplified by the connectionist approach to cognitive modelling. In that approach, interconnecting units increase and decrease in activation as a function of the inputs they receive across their connections. Recently, a number of computational models have been developed, using such
systems, that successfully capture the interplay of the different constraints25,26. Within the original formulation of the constraint-satisfaction approach it has been suggested that certain preferences of interpretation are due not to probabilistic constraints of the kind outlined thus far, but to the way in which a pattern of activity across those interconnecting units will gradually decay with time. Thus, whereas the constraints we have seen so far are due to the encoding of probabilistic information across those interconnecting units (encoded in the pattern of ‘connectivity’ between the units), other constraints are due, in effect, to the physical properties of the system (its ‘architecture’). An example of this latter kind of constraint is embodied in sentence (7) below [similar to sentence (3) above], in which the final adverb (‘yesterday’) can be associated, in principle, with either of the two verbs that precede it:

(7) He read the paper that he received yesterday.

People tend to associate the word ‘yesterday’ with the more recent verb. If one assumes that the representations corresponding to the argument structures of each verb become activated when that verb is encountered, then gradually decay over time, it follows that the representation associated with the more recent verb will have decayed less than the representation associated with the earlier one. Consequently, if incoming words are incorporated within the most active representation, there will be a preference to associate the final adverb, in examples such as this last one, with the more recent verb (in essence, this is simply a re-statement of the ‘late closure’ preference, but cast in activation terms).

Recently, it has been shown that even this preference can be reversed in appropriate contexts – if the context includes, for example, a phrase such as ‘they wondered when he read the paper that he received’, it is as easy in (7) to assume the final adverb with the earlier verb as it is to associate it with the more recent one. This is because the context serves to keep the representation associated with ‘read’ active – the question focuses attention on that verb. Interestingly, if some additional words are inserted between ‘received’ and ‘yesterday’, it becomes easier to associate the adverb with the earlier verb: (8) He read the paper that he received from the journal yesterday.

The finding that contextual information can influence the interpretation of semantic ambiguity is clearly relevant insofar as it represents another source of constraint that can be applied during sentence processing. However, we need also to explain what it means to say that a representation ‘receives contextual support’? What is the mechanism of such support?

Sentence interpretation as a predictive process

To explain the contextual effects observed with the last two examples, it has been proposed that the context (‘they wondered when he would read the paper…’) sets up predictive expectations regarding where, within the subsequent sentence, the relevant information may be found. As that sentence unfolds, the reader will expect the adverb to occur only in very specific locations. In representational terms,
and why the complexities required are apparently beyond statistics. The challenge is to explore what else is required, is not to say that language is nothing more than complex sensitivity to predictive contingencies that we possess. This acquisition which things in the infant's environment? This acquisition different sounds refer, in combination with which others, to the sounds of a language and the world to which human language processing. Thus, they are better consid-
tures encode, and acquire, linguistic structures in equivalent ways. Connectionist systems are not fully implemented can induce internal representations that are analogous to can acquire, encode and realize certain predictive contingencies that hold between relative clauses and the contexts (introducing multiple entities) within which those relative clauses are used. Of course, the claim that structure can be predictively acquired in this way, and that this acquisition supports the subsequent integration of the information corresponding to the structure that is activated, is just the same as the claim that representations corresponding to argument structures are acquired in response to each verb that is encountered. An argument structure is nothing more than the set of pre-
dictive contingencies that hold between a verb and the sen-
tential structures within which that verb can occur. (The nature of such contingencies necessarily makes them sensi-
tive to factors like frequency of occurrence, and necessarily encodes factors like typicality or plausibility.) These contin-
gencies 'support integration' insofar as the meaning of a verb, or indeed of any word, is, broadly speaking, little more than the encoding of the predictive contingencies that hold between that word and the context within which it can be experienced. Simple artificial neural networks can be built that are able to encode such contingencies, and in so doing can induce internal representations that are analogous to linguistic structures. However, it remains an empirical and (to an extent) theoretical issue whether human neural struc-
tures encode, and acquire, linguistic structures in equivalent ways. Connectionist systems are not fully implemented models of sentence processing – rather, they are small-scale implementations of fragments of the language system that are designed to capture principles believed to be shared with human language processing. Thus, they are better consid-
ered as a framework within which to cast theories of such processing.

Ambiguity in language is part of the legacy we inherit through having to acquire a language. The relationship be-
 tween the sounds of a language and the world to which those sounds refer is inherently ambiguous – which of the
different sounds refer, in combination with which others, to which things in the infant’s environment? This acquisition problem is solved, in part at least, by the extraordinary sensitivity to predictive contingencies that we possess. This is not to say that language is nothing more than complex statistics. The challenge is to explore what else is required, and why the complexities required are apparently beyond the sensitivities of other species. Research into ambiguity resolution during sentence processing is just one of many fields of study that should inform this exploration.

References


Cerebral asymmetry: motorizing on
Michael C. Corballis

Perhaps the major quantum confronting research on cerebral asymmetry is whether it will survive into the new millennium. The early wave that began with Broca’s discoveries in the 1860s faded after the turn of the century. Interest was revived in the 1960s following Sperry’s work on the split brain, and has continued more or less unabated into the 1990s. However, as in the late 19th century, much of the theorizing about the dual brain is fanciful, even exploitative, and one wonders if it will once again fade through want of credibility, or perhaps from a sheer surfeit of information, much of which is confusing and contradictory. Indeed its death has already been announced. Yet, there are signs that we might be moving towards a more realistic and biologically based understanding of what cerebral asymmetry is really about.

Empirical research has overwhelmingly stressed asymmetry at the perceptual level. Efron is more damning, suggesting that the perceptual world is largely in-