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Disfluencies and human language comprehension

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Spoken language contains disfluencies, which include editing terms such as *uh* and *um* as well as repeats and corrections. In less than ten years the question of how disfluencies are handled by the human sentence comprehension system has gone from virtually ignored to a topic of major interest in computational linguistics and psycholinguistics. We discuss relevant empirical findings and describe a computational model that captures how disfluencies influence parsing and comprehension. The research reviewed shows that the parser, which presumably evolved to handle conversations, deals with disfluencies in a way that is efficient and linguistically principled. The success of this research program reinforces the current trend in cognitive science to view cognitive mechanisms as adaptations to real-world constraints and challenges.

Consider this utterance: "*That Vermeer – uh where is 'The Love Letter' um what museum is it is it in?*" The goal of psycholinguistic research is to understand how people understand and produce language, but until recently, investigations have focused almost exclusively on sentences written in 'citation' form and not on spoken utterances like this example [1–3]. This approach has been productive and has yielded important insights into the nature of comprehension and especially of PARSING (see Glossary), but the picture is incomplete. What is missing from consideration is that when people talk, they produce sentences that contain DISFLUENCIES (see Glossary, and Figure 1). Conversation would be impossible if efficient mechanisms for dealing with *uh*s, *um*s, repeats and repairs were not a basic part of the architecture of the human comprehension system. There has been some work examining the influence of PROSODIC 'cues' on comprehension, but even in these approaches the goal is to evaluate the use of prosody during SYNTACTIC operations [4–6]. Moreover, studies of prosody have not considered utterances containing mistakes and misarticulations, even though they are part of the input the comprehension system routinely processes.

Why study disfluencies?

The last five years or so have seen a large shift in attitudes towards the study of disfluencies, with many investigators now exploring how mechanisms for processing them operate in the context of a comprehension system that builds linguistic representations incrementally. One reason for this topic being of general interest to cognitive scientists working on language is that disfluencies are a normal part of human speech, and occur at the rate of about six to 10 per 100 words [7,8]. Another reason disfluencies are important is that those that introduce lexical content – repeats, abandonments and repairs (all of which occur in the introductory example) – create an ungrammatical utterance. The string '*what museum is it is it in*' from the first example is literally ungrammatical because the second '*is it*' is syntactically unlicensed. Clearly though, the human parser does not simply crash when it encounters these sequences, suggesting that it has some means for distinguishing disfluencies from the rest of the input.

A third reason is that understanding the parser's mechanisms for handling disfluencies could shed light on the basic comprehension architecture in which those mechanisms are embedded. Consider a repair, such as '*You will put – you should drop the ball*'. At a descriptive level, we know the parser integrates '*you will put*' as part of the clause, and then the ungrammaticality of the sequence '*you will put you should drop*' is treated as evidence for the presence of a disfluency (as has been proposed for computer speech parsing [9]). The sequence '*you will put*' would then be expunged from the structure, leaving just '*you should drop*'. This description of the relevant processes is reminiscent of what has been proposed for the reanalysis of so-called garden-path sentences [10–12]. Garden-path sentences contain a temporary syntactic ambiguity which causes the parser to build an incorrect syntactic analysis and then try to revise it upon encountering a word that cannot be integrated into that structure. This similarity raises the possibility that the processes that perform garden-path reanalysis and those that engage in disfluency repair are similar [13] (K.G.D. Bailey, unpublished).

Finally, cognitive scientists should be intrigued by this growing body of work on disfluencies, because it is part of

Glossary

Parsing: The process by which the human brain or a machine assigns syntactic structure to a sequence of words.
Syntax: The component of the grammar that describes how words may be combined to form phrases and sentences.
Prosody: The component of the grammar that describes the sounds patterns of language, focusing especially on intonation, stress, and syllable timing.
Disfluency: Any deviation in speech from ideal delivery.

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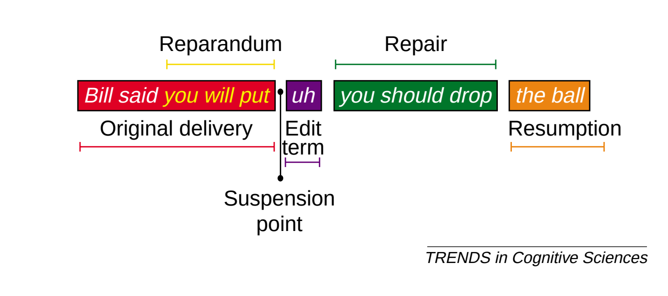

Figure 1. A disfluent utterance divided into parts. The region shown in red is the original delivery, the portion prior to the point of difficulty. The disfluency begins when the original delivery is suspended (the suspension point). An editing term such as *uh* or *um* (shown in purple) optionally occurs at the suspension point. The repair (shown in green) replaces the undesired segment of the original delivery, referred to as the reparandum (shown in yellow text). The resumption (in orange) marks the return to fluent delivery.

an emerging trend in the field to view cognitive mechanisms as adaptations to real-world constraints and challenges [14–16]. If we think about the human comprehension system from the perspective of what it evolved to do, it seems reasonable to assume that it developed tools for handling 'dirty' input easily and efficiently. A great deal of progress has been made in psycholinguistics by focusing on 'standard' sentences, but it is now time to take on the challenge of understanding the processing of the real input in all its complexity. The most exciting research programs will put these two lines of research together so that what emerges is an understanding of how linguistic structures are created in real time for realistic, spoken utterances [17].

Why filtering won't work

One intuitively appealing solution to the problem of understanding how disfluencies are handled during comprehension is to assume that the parser ignores them because they are not linguistic items and are therefore irrelevant to the task of building an interpretation. One problem with this suggestion lies in the assumption that disfluencies are non-linguistic, an idea that is far from uncontroversial [3]. But setting aside this concern, the problem with the proposal that disfluencies are ignored is that this amounts to 'filtering'. Filtering assumes that the parser must remove disfluencies so that it can then operate on sanitized input consisting of only words and prosodically licensed acoustic cues [18]. This solution is unlikely to work because the language comprehension system is known to operate incrementally: Input is interpreted as it is received [19–23], and the system even tries to predict words and structure [22,23]. Therefore, it cannot be true that the parser begins to build constituents only once the input has been cleansed of disfluencies. In addition, consider again the earlier example: "*That Vermeer – uh where is 'The Love Letter' um what museum is it is it in*". Notice that the pronoun *it* in the repair must find its antecedent *The Love Letter* in the reparandum, the part of the utterance that was spoken in error. If filtering were the correct solution, the pronoun would not have an antecedent, but clearly people interpret the utterance as if it does. It follows, then, that the parser processes disfluencies as part of the normal task of building interpretations. It is important to know, then, how the mechanisms for creating structure and handling disfluencies are coordinated.

Corpus analyses of disfluencies

Through examination of large corpora of utterances, computational linguists have developed tools for identifying disfluencies [24], predicting their locations [25], and even for using them as information. Prosodic analyses of speech have revealed that reparanda are not acoustically marked, but often the repair portion of a disfluency is spoken with distinctive acoustic features [26]. This means that the parser receives no prosodic warning of a disfluency, and therefore as the reparandum is processed, the parser cannot yet label it as such because it appears to be a standard linguistic sequence; the prosodic cues that are available occur in the repair. Therefore, the parser receives this combination of cues indicating that it must engage in 'disfluency reanalysis': distinctive prosody, together with aberrant syntactic structures.

Disfluencies and pragmatic interpretation

Psycholinguists have examined how disfluencies influence high-level meaning. They have discovered that disfluencies are useful for dividing referents in a discourse into those that are *given*, or already established in the discourse, and those that are *new* [2]. Some work has examined what disfluencies reveal about speakers' confidence in their utterances [27,28]. Further evidence suggests that people have less trouble understanding utterances with filled pauses and repeats than those with repairs [8], and that the difficulty of handling a repair is greater when the speaker produces an incorrect word in its entirety rather than truncating it [29]. Only very recently have psycholinguists begun to address how disfluencies affect constituent building operations performed by humans in real time. We examine this topic here, following a brief overview of what is known about human parsing. The final section of the article presents a model of disfluency processing.

Disfluencies and human parsing

Basic findings in human parsing

There is much debate about the basic architecture of the sentence comprehension system. Nevertheless, it is generally agreed that there are three essential findings that any model must explain. First, the parser keeps track of information that is correlated with structural types [30,31]. Second, the parser sometimes pursues an incorrect syntactic analysis, as shown in the example '*Bush spoke to Blair and the media reported the story*'. In general, people tend to interpret '*and the media*' as part of the object of '*spoke to*' (Figure 2), an analysis that must be abandoned at '*reported*' (the disambiguating word), because all verbs must have a subject. In these situations, the parser does not give up or simply start over from the very beginning; instead, it engages in structural reanalysis [32–35]. Reanalysis processes sometimes leave the comprehender with an interpretation of the sentence that merges the original and corrected structures (i.e. they believe that Bush spoke to Blair and the media *and* that the media

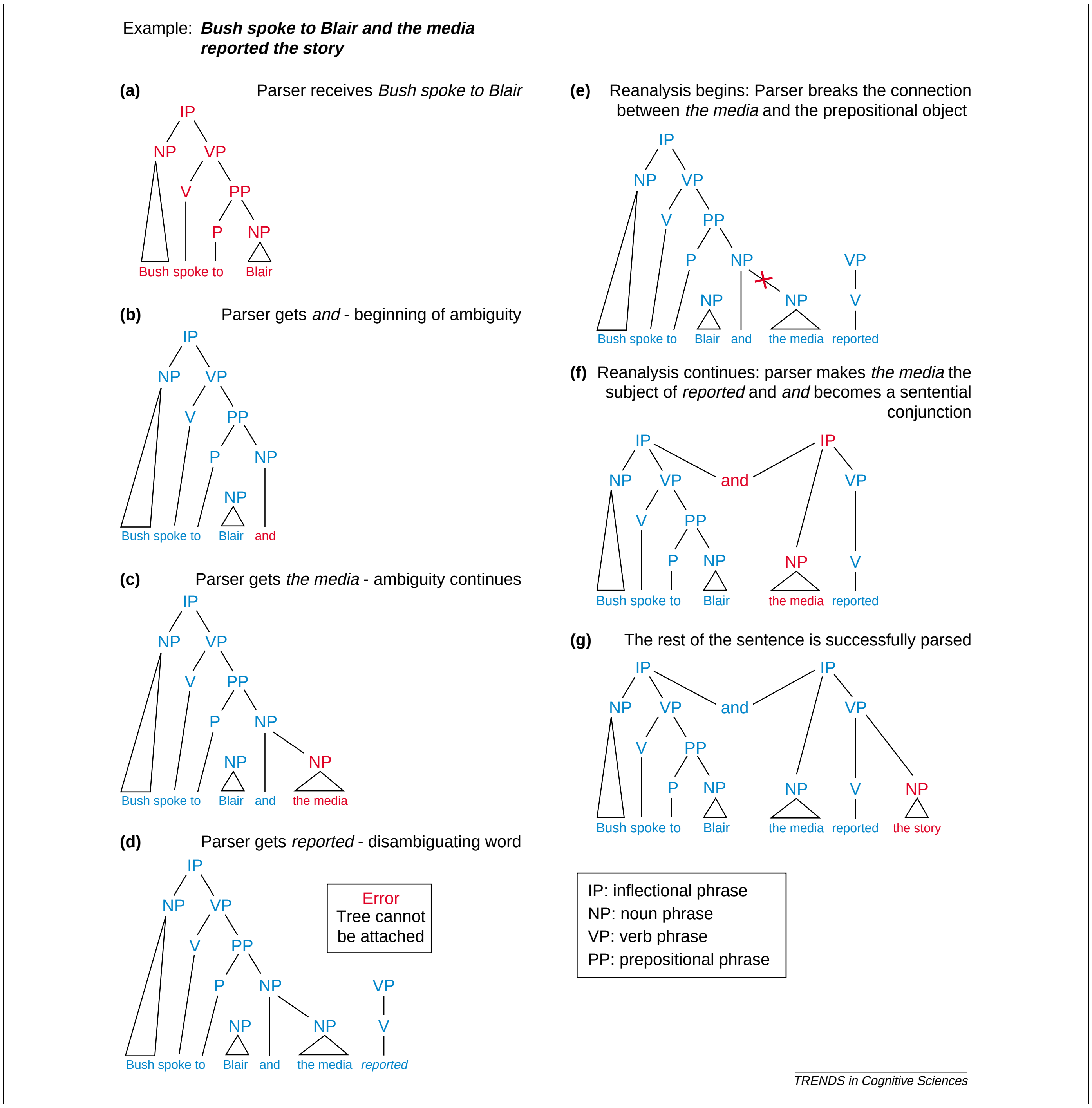

Figure 2. The process of building a syntactic tree incrementally (parsing) and repairing it when an error is encountered (reanalysis). **(a–c)** show structure building prior to parsing breakdown. **(d)** The point at which the ongoing parse fails. **(e,f)** Reanalysis of the structure. **(g)** The final, correct parse.

reported the story), demonstrating that the comprehension system does not always clean up all the semantic consequences of syntactic revision [36].

Third, although the parser is capable of performing garden-path repair, certain features of a sentence can make the process difficult. For example, the longer the parser has been committed to the wrong analysis, the more trouble it has recovering the right one [1,37]. More specifically, reanalysis is made more difficult the greater the distance between the disambiguating word and the head of the misanalyzed phrase. Thus, '*Bush spoke to Blair and the media reported the story*' and '*Bush spoke to Blair and the European media reported the story*' are equivalently easy to reanalyze; but '*Bush spoke to Blair and the media from Europe reported the story*' is much more difficult, because *media* (the head of the ambiguous phrase) and *reported* are separated by two words. These findings come from studies of reading but as we will see, examination of disfluencies reveals that this Head Position Effect (HPE) occurs because of the temporal processing dynamics associated with building and rebuilding structure, and this principle generalizes to spoken language.

In recent work these three findings concerning parsing

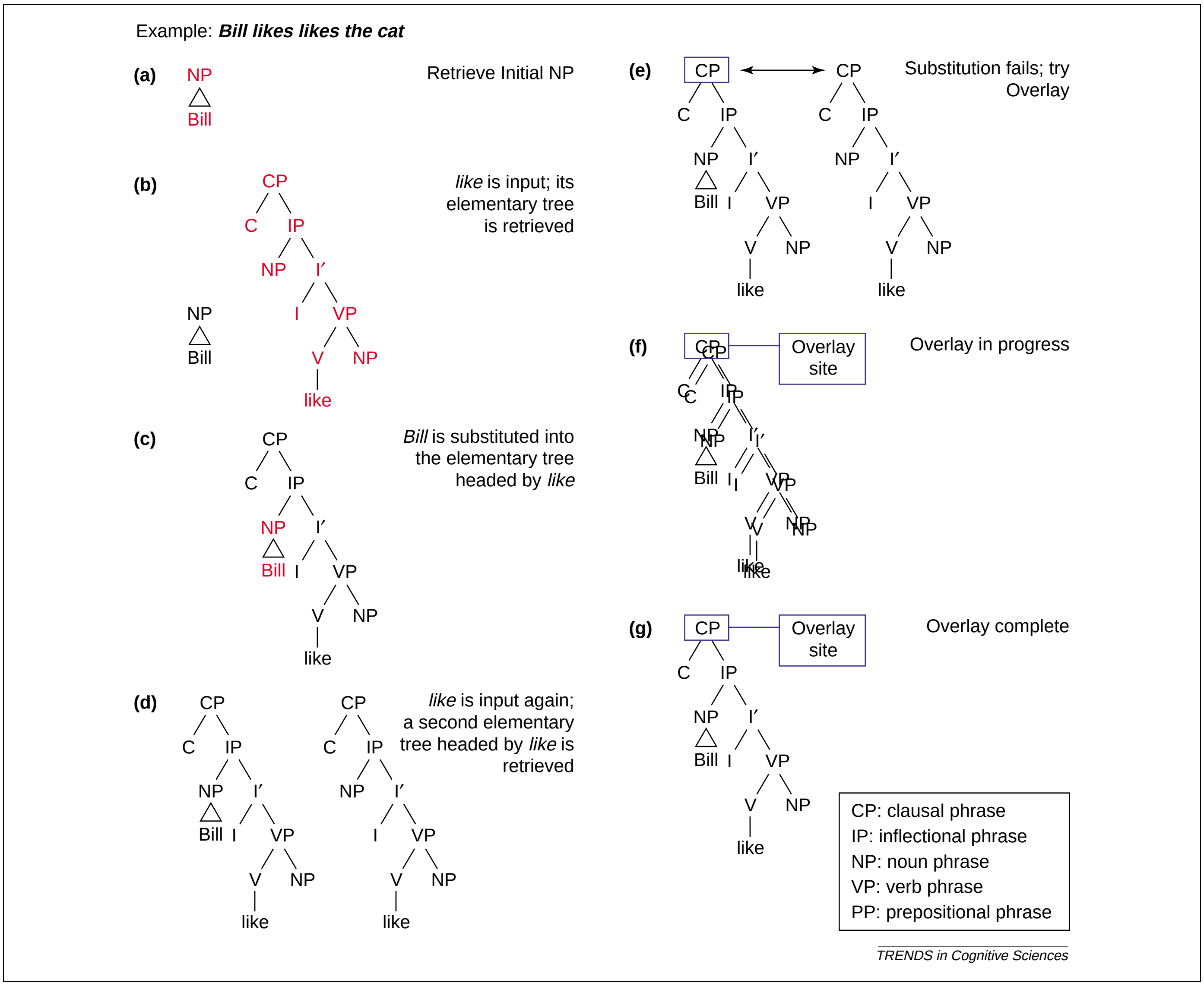

Figure 3. How 'Overlay' handles repeats during parsing (see text). **(a–c)** show regular structure building. In **(d)**, the verb repetition is encountered. **(e)** The tree headed by the repeated verb cannot be integrated into the structure build up to that point. **(f)** The parser therefore attempts Overlay, putting the two trees on top of each other at their root nodes. **(g)** The final structure, which is identical to one that would have been built had no repeat occurred.

have been directly related to the processing of sentences containing disfluencies. We turn to this research next.

Use of information about the co-occurrence of disfluencies and structures

Analyses of spoken corpora have revealed that speakers tend to be disfluent in particular syntactic locations [38–40]. For example, filled pauses and repeated words are most common at the beginnings of clauses and other complex constituents [38]. In many garden-path sentences, the parser must choose between a simple and a more complex structure (see Figure 2). If the parser can make use of co-occurrence information involving disfluencies, then the presence of an *uh* or a repeated word could serve as a cue to choose the more complex alternative. This prediction has been supported in recent work. A comprehender who hears '*Bush spoke to Blair and uh the media reported the story*' is more likely to take '*the media*' to be the subject of a new clause than one who hears the same sentence without a disfluency at all or with a disfluency in a non-diagnostic location (such as before '*reported*') [1]. This effect occurs because *uh* precedes a noun phrase (NP), and that NP is playing a role that is temporarily ambiguous: It is either the end of the object of '*spoke to*' or the start of a new clause. The disfluency cues the latter analysis because disfluencies tend to precede the beginnings of clauses, and so the parser has a cue to the correct structure. The parser, then, appears to use disfluencies as information.

Reanalysis of structural commitments induced by reparanda

A word or series of words that is produced in error and then repaired could well cause problems for comprehension, because the parser receives no warning of the mistake (recall that any prosodic cues to disfluency are not in the reparandum but rather in the repair). Consider a simple example such as '*Mary will put – throw the ball*'. The word recognition system would retrieve *put*, which would activate the structures associated with *put* (an object and a location) [22]. But the rest of the utterance makes clear that *put* was said in error, and the intended verb is *throw*. Ideally, the system would remove all traces of *put* and its constituents from the processing record, leaving only *throw* and its associated arguments. But this is not what happens. Recent evidence suggests that the information associated with the reparandum is only partially deactivated [13].

People judge a sentence like '*Mary will put – throw the ball*' to be less acceptable than one with no disfluency ('*Mary will throw the ball*'), but they also like '*Mary will throw – put the ball*' better than they like the same utterance with no disfluency ('*Mary will put the ball*'). These effects arise because the verb in the reparandum biases the interpretation of the verb in the repair. For the '*put–throw*' sequence, the effect is harmful, because *put* requires a prepositional phrase (PP), which the sentence does not contain. By contrast, for the '*throw–put*' sequence, the effect is salutary, because *throw* does not need a PP, and as a result *put*'s need for one is reduced. For the same reason, a disfluency can make a garden-path sentence easier to understand. A sentence such as '*The girl chosen – uh selected for the role celebrated with her parents*' is easier to understand than the same sentence with no disfluency or with a reparandum verb such as *picked* – '*The girl picked selected for the role celebrated with her parents*'. The idea is that *chosen* activates the correct passive, relative clause structure for the sentence, and that structure lingers for the remainder of the utterance, making this notoriously difficult garden-path sentence easy to understand (*picked* does not have the same effect because its potential active sense is as ambiguous as *selected*).

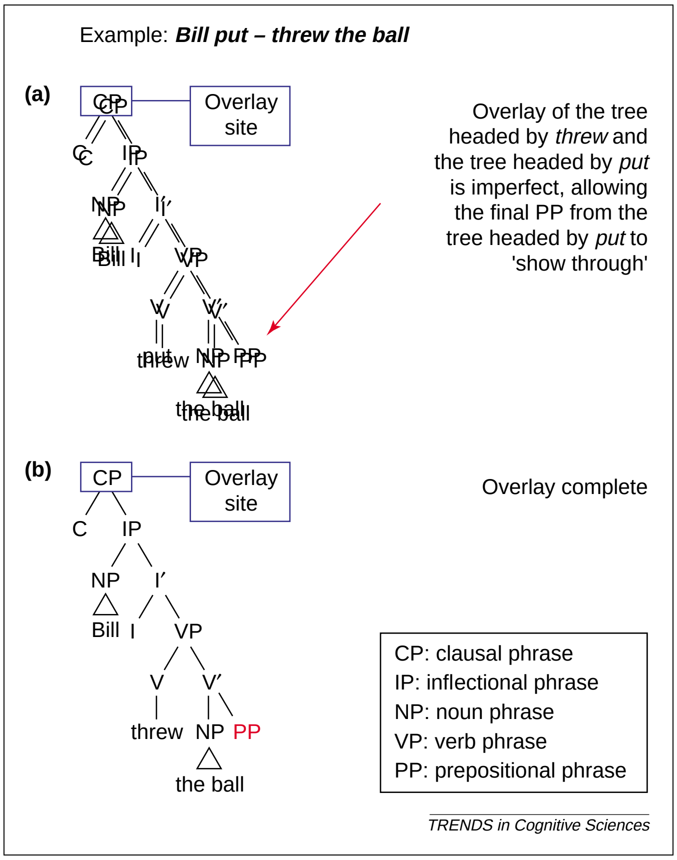

Figure 4. How Overlay handles a sequence of reparandum (*put*) plus repair (*threw*). **(a)** The two structures are Overlayed at their root nodes. **(b)** Even when the alignment is complete, the result is imperfect: the prepositional phrase (shown in red) associated with *put* remains visible in the final tree, thus influencing the interpretation of the utterance.

Disfluencies and temporal processing dynamics during parsing

Filled-pause disfluencies might affect parsing because their status as non-words means that the parser cannot integrate them into the tree under construction. The parser must sit in a holding pattern during an *uh* or an *um*, waiting for the disfluency to end and the next word to arrive. While the parser waits, the structure under consideration might gain strength at the expense of alternatives. If so, then a disfluency that separates the head of the ambiguous phrase from the disambiguating word should produce the HPE mentioned earlier – it should exaggerate any garden-path effect, because the incorrect structural commitment would be maintained longer. This prediction has indeed been supported [1]: a sentence such as '*Bush spoke to Blair and the uh uh media reported the story*' is as easy to process a sentence without any disfluencies at all, but '*Bush spoke to Blair and the media uh uh reported the story*' is much more difficult than either. In fact, the same pattern of results holds for disfluencies as was found previously for modifiers. It appears that the HPE occurs because disfluencies and modifiers both affect temporal processing dynamics and thus the availability of structural alternatives during parsing.

A model of disfluency processing

These results have motivated a model of the parsing of sentences with disfluencies. The model is based on a computational formalism called Tree-Adjoining Grammar (TAG), and in particular the lexicalized versions [41]. The fundamental idea is that every word of the language is associated with a mini-syntactic tree containing that word (the 'lexical anchor') and all the structures it licenses. For instance, retrieval of the word '*the*' yields a tree anchored by *the* and containing nodes for a NP. Activation of '*put*' leads to retrieval of a tree anchored by *put* and containing nodes for an entire clause consisting of a subject, an object, and a PP (the constituents associated with *put*). These bits of structure are called elementary trees, and they are combined using the simple operation of substitution, which allows two trees to be unified under certain conditions.

Let us begin with a disfluency involving a repeated word, as in '*Bill likes likes the cat*' (Figure 3). The string-initial word *Bill* anchors an elementary NP tree, so the word and tree are retrieved together. The NP then waits for a structure into which it can be substituted. That structure becomes available at the first '*likes*', which provides positions for both a subject and an object. (Of course, *likes* anchors a clausal tree consisting of a subject and an infinitival complement. For purposes of simplicity, we will focus on the former structure because given the frequency of the two alternatives as well as syntactic simplicity, it is likely to be considered first.) Because language processing is incremental, *Bill* substitutes into the subject position. So far, the parser has '*Bill likes*', with a slot for the obligatory object. But now the second occurrence of *likes* is the input, and so an elementary tree identical to the one initially retrieved for *likes* becomes available. Substitution is impossible, because the verb *like* does not license a tensed clause. In this situation, the parser engages in what we call 'Overlay'. Overlay works as follows: when the parser retrieves any new tree, it first looks for a substitution site. But if no such site can be found (as will occur when an utterance contains a repeat or other type of disfluency with lexical content), then the parser looks for root node identities and attempts to overlay the trees on top of each other, anchored at the roots. In repeats, the trees will be identical, resulting in perfect overlap, and the tree for the entire utterance will look essentially the way it would had no disfluency occurred.

But now let us consider a repair such as '*Bill put – threw the ball*'. As in the '*likes–likes*' case, the parser would Overlay two trees: one anchored by *threw* and another anchored by *put*. The result, though, is imperfect overlap (see Figure 4). Consequently, the argument structure of the reparandum verb influences processing, and even interpretation, because the tree anchored by *put* is visible 'underneath' the *threw*-tree. More precisely, the PP argument of *put* is visible, and this causes the parser to expect a PP. Therefore, even though a PP is optional for *threw* [42], the parser will have at least a mild tendency to expect one because the misarticulated verb *put* and its elementary tree lurk in the background.

This model of parsing with disfluencies can also account for the effects of filled pauses (*uh*, *um*). Because these items cannot anchor elementary trees, when the parser encounters them it must wait for lexical input to continue parsing. This delay will affect the parser's commitment to its ongoing analysis if we assume that phrases are substituted once their heads are located. For example, if the parser received '*Mary saw the uh…*', it could not attach the NP that includes *the* until the disfluency stopped and the head noun arrived. The effect of *uh* would therefore be to shorten the parser's commitment to the direct object interpretation of the verb, which would make it easier to recover a sentential complement interpretation if the sentence turned out to require reanalysis, as in '*Mary saw the uh cat eat the tuna*'. By contrast, if the disfluency occurred after the word *cat* in this same sentence, the disfluency would prolong the parser's commitment to the incorrect direct object interpretation, making it more difficult to recover the sentential complement analysis. In this way, disfluencies affect ease of recovery from garden-path structures.

Conclusions

Theories of human language comprehension must provide a mechanistic account of how people understand sentences with disfluencies. Indeed, the processes are so efficient that often people are not consciously aware that a disfluency occurred [43,44]. It is clear that disfluencies affect parsing, and the mechanisms proposed within a TAG framework explain how they are handled. An intriguing possibility is that these same mechanisms handle more 'standard' phenomena, such as repair of garden-path sentences. This remains a topic for future investigation (see also Box 1). What is clear is that the parser, which presumably evolved to handle naturalistic, interactive conversations, deals with disfluencies in a way that is efficient and linguistically principled.

Box 1. Questions for future research

- What cues does the human parser use to detect disfluencies?
- In what ways does the comprehension system make use of information contained in the reparandum?
- How does the parser distinguish between repetition for emphasis and disfluent repetition?
- What contribution do prosody and prosodic disruption make to disfluency processing?
- Can an operation like Overlay generalize to other repair processes such as reanalysis?
- What is the linguistic relationship between Overlay and the theoretical idea of three dimensional syntactic trees for coordination?
- Can a grammar of 'dirty speech' be generated to allow for automatic parsing of speech by machine?

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