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PROSODIC BOUNDARIES AND THE GARDEN-PATH EFFECT IN COMBINATORY CATEGORIAL GRAMMAR

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ABSTRACT: This paper argues that Combinatory Categorial Grammar can be a good theory for showing how clear intonational boundaries and contours can help prevent the mental parser from being led up the garden path or even induce a garden path effect. With the analysis of the sentence "The horse raced past the barn fell", we show how a CCG derivation can effectively use information structure and prosodic cues (when present) in order to induce or avoid a garden path effect, predicted to occur in that sentence mostly for syntactic reasons in the psycholinguistic literature.
KEYWORDS: garden-path effect; combinatory categorial grammar; prosody.

INTRODUCTION

This article's main claim is that the presence and the position of clear prosodic boundaries in the so-called garden-path sentences may help disambiguating such sentences. The psycholinguistics literature in general defines the garden path effect in two general ways: for the so-called Garden Path Theorists (Frazier and Fodor (1978), Frazier (1978), Frazier and Clifton (1996), among others following the work of Bever (1970) and Kimball (1973)), a garden path effect occurs when there is need for reanalysis of a sentence because the prediction of occurrence of the general processing principles such as Minimal Attachment and Late Closure is incompatible with the actual input sentence. For another group of theories, such as those presented by Marcus (1980), Marcus (1987), Gorrell (1995) and Gorrell (1998), other processing factors define the term garden path: the mental parser works deterministically, and, upon reanalysis, certain kinds of deletion of previously stated structural information is responsible for the failure of the human mental parser in assigning structure to the input sentence. We assume the second view to be the definition of garden path that we

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will use when we discuss another theory, that takes in consideration syntactic, semantic and intonational information in the processing of sentences (CCG), in order to decide whether there is syntactic garden path in spoken sentences with clear and informative prosodic contours and boundaries. Our claim is that, following the theories developed in Steedman (1991), Steedman (2002a) and Steedman (2002b), other factors may induce or eliminate the mentioned effect, not only general parsing principles or a deterministic restriction on reanalysis.

1. LOCAL AMBIGUITIES AND THE GARDEN-PATH PHENOMENON

The garden path effect is said to occur with locally ambiguous sentences, because the parser, during the processing of a sentence, has to make a choice in a point where there is a local ambiguity. After making the wrong choice, it goes on processing until it cannot assign a grammatical structure to the rest of the input data anymore. So, we have different kinds of structural ambiguities: global ambiguities, local ambiguities that do not lead the parser up the garden path and local ambiguities that do lead the parser up the garden path.

Examples of global ambiguities are like the following:

(1) She saw the man with the telescope.

a. She saw the man that was with the telescope.

b. She used a telescope to see the man.

In this case, the ambiguous readings remain accessible after the complete processing of the sentence, since one can understand the sentence either as (1.a) or as (1.b).

Locally ambiguous sentences that don't lead the parser up the garden path are exemplified below:

(2) He gave her earrings yesterday.

(3) He gave her earrings to Mary.

Even though we will explain the local ambiguity of (2) and (3) in terms of the Structural Determinism proposed by Gorrell (1995) later, the explanation for the local ambiguity in sentences like these is this: during incremental processing, the parser computes

structure until *gave* and then finds *her*. At this point, it can either interpret *her* as the first NP-object or it can interpret *her* as a possessive pronoun that modifies something that comes later. Then, if the parser chooses the first option, it then processes *earrings* as a second NP-object. If the sentence turns out to be (2), no problems occur. If the sentence is (3), though, reanalysis is required, because the interpretation of *her* as a full NP is not adequate and the rest of the sentence cannot be parsed. Later we will see why this kind of local ambiguities do not lead the parser up the garden path in a model enhanced with prosodic information, while the next examples do.

(4) Ian put the candy on the table in his mouth.
(5) The horse raced past the barn fell.
(6) While she was mending the sock fell.

(4), (5) and (6) are locally ambiguous sentences that lead the parser up the garden path because they violate Gorrel's Structural Determinism and the Garden Path theorists' general parsing principles, and they do it in a way that demands conscious effort in reanalyzing the sentences, even though they are perfectly grammatical.

We will see next why the last three sentences are more costly for the reader than the locally ambiguous sentences in (2) and (3).

2. PRIMACY OF SYNTAX: GORRELL'S (1995) PARSER

We can explain the way Gorrel's model of the human sentence processing mechanism works with the three components below:

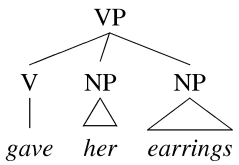
- Structure builder: responsible for the construction of the tree descriptions, based on what he calls primary relations: dominance and precedence.
- Structure interpreter: responsible for ensuring that secondary relations (government, case assignment, theta assignment, binding, etc.) hold between the nodes of the tree description generated by the structure builder.
- Structural determinism: upon reanalysis, information stated by the structure builder should not be disregarded - i.e., if new nodes are created, the primary relations stated in the first analysis must still hold. Otherwise, the garden-path effect occurs.

So Gorrell's parser has two main components: the structure builder and the structure interpreter. The first one is responsible for the construction of the tree representations, by stating information regarding dominance and precedence. The second component is responsible for assigning the rest of the grammatical information to the nodes already built by the structure builder.

The structural determinism, then, ensures that, when reanalysis is necessary, only information stated by the structure interpreter can be deleted. Otherwise, the parser is led up the garden path. This means that whenever information has to be deleted, it cannot be information of dominance and precedence. If this happens, the garden path effect occurs.

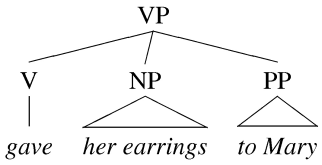
Let us see how Gorrell's parser deals with different kinds of local ambiguities: If the parser computes a structure such as (7), it can come across, for example, *yesterday* or *to Mary* (as it happens in sentences (2) and (3) after the processing of *earrings*).

(7)



When the parser has to process *yesterday*, reanalysis is not required, because the two complements of *gave* are already computed. However, if a PP such as *to Mary* is to be computed, a reanalysis is required and we have the structure in (8):

(8)



From (7) to (8), structural determinism still holds, because the position of *earrings* in the second analysis is still dominated by VP and is still preceded by *her*. That is to say, only secondary relations, such as government, have to be reformulated, and although this has a cost for the computation, it does not lead to irrecoverable failure. It is also clear that new

information of dominance and precedence has to be stated, but this does not violate structural determinism, since the information previously stated by the structure builder still remains.

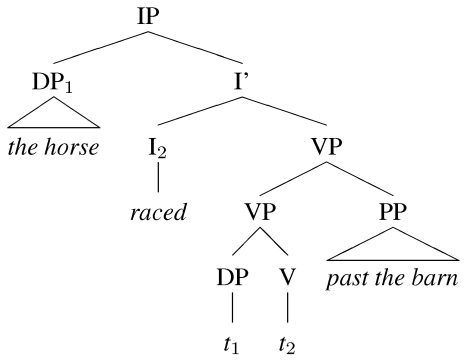
In the case of garden-path sentences, after reanalysis, the principle of structural determinism is violated. Let us see how this works with (5), represented below partially as (9) and completely as (10):

(9) The horse raced past the barn.

(10) The horse raced past the barn fell.

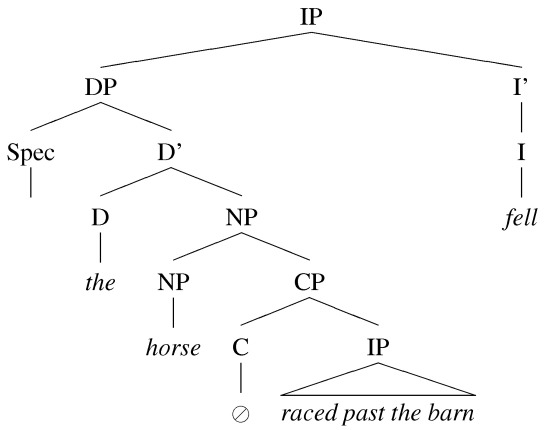
When the parser computes *raced*, it can be interpreted either as the simple past tense of the verb *to race* or as the past participle of the same verb. If the parser finishes the processing of the sentence when *barn* is computed in sentence (9), the local ambiguity created by *raced* is solved, and only the simple past reading is allowed. This is represented in (11).

(11)



However, if the parser has to compute a sentence such as (10), before the word *fell* is encountered, we have the structure represented in (11). Upon the processing of *fell*, (12) is the structure that should be built, after reanalysis, to result in a grammatical sentence. But this does not happen, because the parser is led up the garden path. It is so because structural determinism is violated when the I node in the first reading, for example, dominates the DP, while in the second, after reanalysis, it is dominated by it (it is inside the IP dominated by the CP, in (12)).

(12)



3. PROSODIC BOUNDARIES IN CCG AND DISAMBIGUATION OF GARDEN-PATH SENTENCES

Our claim is that, when spoken, sentence (9) has a different prosodic structure than (10). Considering information structure (as discussed in Steedman (2002a), Steedman (2002b) and Steedman (2002c)), we can even have different surface structures for (9) and (10), exemplified by the following contextual pairs of questions and answers:

(13) a. Who raced past the barn?

b. (The HORSE) (raced past the BARN)

H* L L+H* LH%

Rheme Theme

(14) a. What did the horse do?

b. (The HORSE) (raced past the BARN)

L+H* LH% H* LL%

Theme Rheme

(15) a. Which horse fell?

b. (The horse raced past the BARN) (FELL)

H* L L+H* LH%

Rheme Theme

(16) a. What happened to the horse that raced past the barn?

b. (The horse raced past the BARN) (FELL)

L+H* LH% H* LL%

Theme Rheme

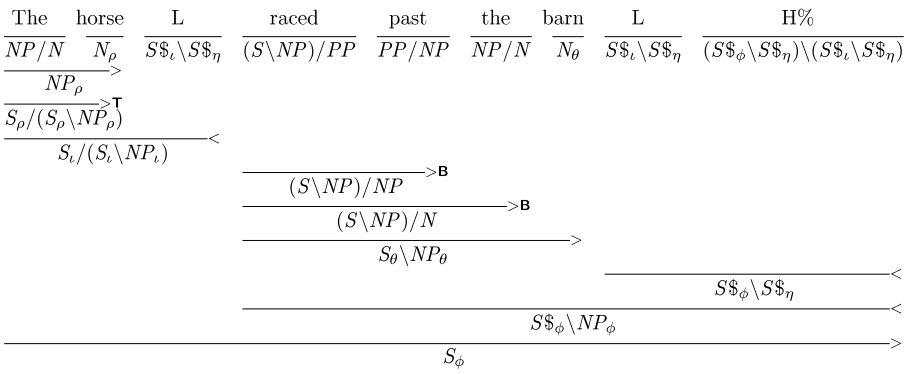
Clearly these are not the only possible intonational bracketings for these two sentences, nor these boundaries and information structures are necessarily clear. For example, Steedman assumes that themes can very often be unmarked, and that boundaries many times are not easily distinguishable. But through his combinatory prosody, once the bracketings are very clear in contexts where intonational boundaries are clearly present, like the ones presented roughly above, the mental parser should not be led up the garden path, because there would be enough information (prosodic and contextual, at least) for the parser to arrive at the correct derivations[2]. Let us see how this works through the CCG derivations below.

But, before we present them, the following explanations about the categories are necessary: The subscripts θ and ρ are values of the INFORMATION feature and correspond to theme and rheme, respectively. A category marked with a θ value unifies only with another category marked with a θ or with a η (for "eme", or, more clearly, something that can be either *th*eme or *rh*eme) to result in a category marked with a θ. The same happens with the categories marked with ρ - they combine only with ρ- or η-marked categories, to produce a ρ-marked category. The categories without any explicit INFORMATION feature value as a subscript Greek letter are the default-marked categories: their feature value is always η. The values ι and φ are the values that correspond to the *intermediate phrase* and to the *phonological phrase*, that is, ι- and φ-marked constituents only combine with ι- or φ-marked constituents. The symbol S$ (the dollar convention (Steedman, 2002a), (Steedman, 2002b)) is an abbreviated category that ranges over a set that includes S, S\NP "and all verbs and type-raised arguments of verbs, but not nouns and the like" (Steedman, 2002b, p. 112). The boundary categories are functors looking for S$ marked with either θ or ρ to result in the same category, in which the θ or ρ are replaced by the ι feature. As we have seen above, once a category is marked with the value ι, it is considered an intermediate prosodic phrase (Pierrehumbert and Hirschberg (1990) *apud* Steedman (2002b)), and thus can combine only with another ι-marked constituent or with a φ-marked constituent. The feature value φ marks a constituent as a phrasal constituent (a major intonational phrase), and can only combine with

[2] It is important to emphasize that it is not always that intonation disambiguates structure. We present the claim for these sentences, but further research with CCG, processing and prosody is required to investigate what are the limits to this claim. Thanks to Mark Steedman (personal communication) for comments on that.

another intonational phrase (marked with ι or φ). These characteristics of the unification of the INFORMATION feature turn the boundaries into very important "constituents", and show how their position influences the processing of the sentences. Let us see how the sentences (13.b), (14.b), (15.b) and (16.b) can be processed with CCG below:

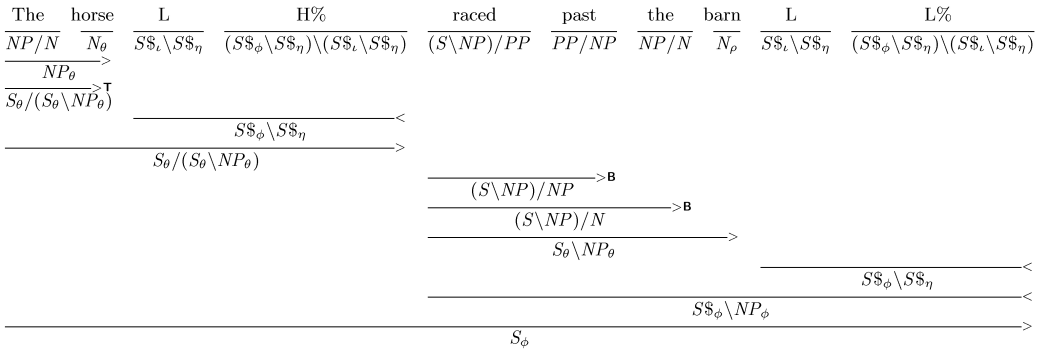
(13.a)



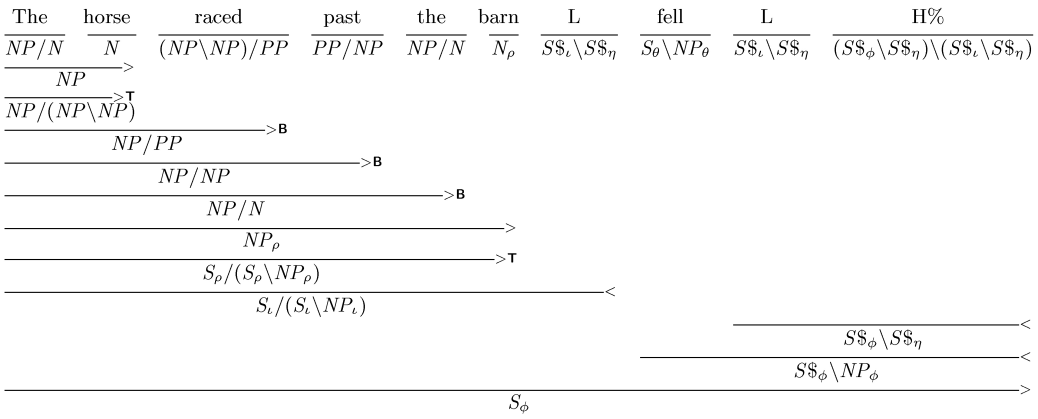
The analysis starts with the functional application from left to right of *the* and *horse*, followed by a type-raising rule applied to the constituent. Then, the boundary *L* takes the $S_\rho/(S_\rho\backslash NP_\rho)$ to the left and assigns the ι feature to the constituent, closing the first boundary. Then, we have a sequences of functional applications from left to right in the constituent *raced past the barn*, which is then marked with the category $S_\theta\backslash NP_\theta$. Then we have the closing boundaries, first the intermediate *L*, then the final one, *H%*, which takes the *L* category and results in a $S\$_\varphi\backslash S\$_\eta$, that is, a category that takes a *S$* of any kind and results in a $S\$_\varphi$. Then, a backwards application takes the $S_\theta\backslash NP_\theta$ to the left and turns it to $S\$_\varphi\backslash NP_\varphi$. Now the first constituent takes the second one as argument and results in an *S* category marked with a φ, closing the syntactic and the intonational derivation in a full grammatical sentence.

These steps can be followed in the next three derivations.

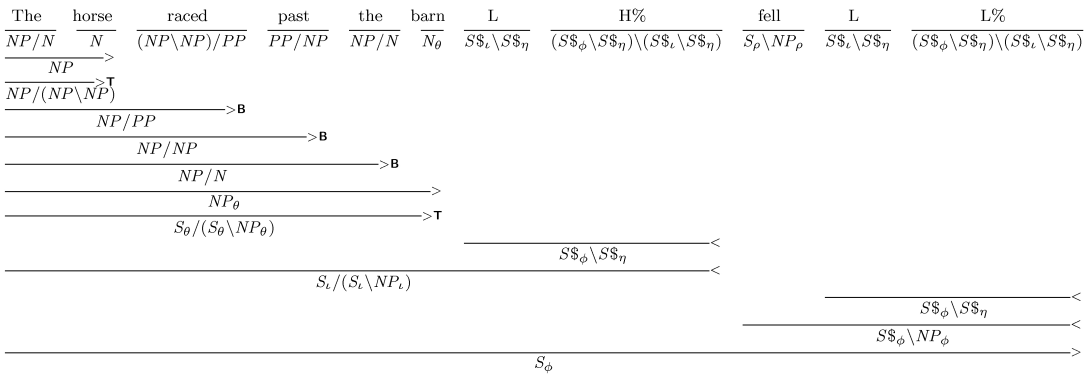
(14.b)



(15.b)



(16.b)



As we can see, the presence and position of the prosodic boundaries enable the derivation to be performed incrementally and according to the information structure of each sentence. Incoherence may result from several reasons. For example, if we exchange the

intonational contours that convey thematic/rhematic information in each pair of sentences, we get strange results, like the following:

(17) a. Who raced past the barn?

b. *(The HORSE) (raced past the BARN)

L+H* LH% H* LL%

Theme Rheme

(18) a. What did the horse do?

b. *(The HORSE) (raced past the BARN)

H* L L+H* LH%

Rheme Theme

(19) a. Which horse fell?

b. (The horse raced past the BARN) (FELL)

L+H* LH% H* LL%

Theme Rheme

(20) a. What happened to the horse that raced past the barn?

b. (The horse raced past the BARN) (FELL)

H* L L+H* LH%

Rheme Theme

Also, a prosodic boundary after *horse* in sentences like (15.b) and (16.b) would lead to serious incoherence, enabling (or even inducing) the occurrence the garden path effect. The CCG derivations for sentences like (21.b) and (22.b) would not be possible, causing the need for reanalysis of the whole string:

(21) a. Which horse fell?

b. *(The horse) (raced past the barn fell)

(22) a. What happened to the horse that raced past the barn?

b. *(The horse) (raced past the barn fell)

4. CONCLUSION

Intonation contours and prosodic boundaries are sometimes responsible for the disambiguation of locally or globally ambiguous sentences. In this article we tried to show how the so-called garden-path sentences may be parsed normally using a CCG formalism, which is able to cope with syntax, semantics, intonation structure and information structure at the same time.

For sentences like (6) (repeated as (23) below), for example,

(23) While she was mending the sock fell.

the idea that prosodic boundaries help the parser in assigning structure is even more plausible than with sentences like (10), as we have tried to show. In (23), a prosodic break (together with proper intonational contour and information structure) before *the sock* (sometimes represented in writing by a comma) is enough to make it easier for the parser to assign syntactic structure incrementally with no garden path effect at all.

Our claim, then, is that for some kinds of sentences that are considered to be garden-paths, a spoken version with proper information regarding information structure and intonation does not present the same structural difficulty than that predicted by the psycholinguistics literature for the written versions used in most experiments (cf. Gonçalves, 2004 for more details on the psycholinguistic experiments on garden-path sentences).

The claim is not new, though. Shari Speer and her colleagues have been working with the idea that the garden path is not necessarily present in spoken sentences, and Ilse Lehise, in the 1970's, had already published important papers claiming that intonation could solve ambiguities in natural language. Recently, Janet D. Fodor, Marcus Bader and colleagues have been publishing papers about the need for psycholinguistics to recognize prosody as an important factor in order to model more correctly the way the human mental parser works. Those are only some of the many scholars who have already proposed that prosody is important in sentence disambiguation and processing, but the point of this paper is that a Combinatory Categorial Grammar as that presented in Mark Steedman's recent works is the best framework to test the intuition that spoken sentences do not present the same ambiguities as written sentences do, because CCG is able to cope at the same time with syntax, semantics, intonation and information structure incrementally, which seems to be a very plausible way by which human brain works when processing sentences.

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RESUMO: Neste artigo, argumentamos que a Gramática Categorial Combinatória pode ser uma boa teoria para demonstrar de que modo a presença de fronteiras e contornos entoacionais claros podem auxiliar o processador mental de linguagem a evitar o chamado efeito labirinto, ou mesmo induzi-lo. A partir da análise da sentença "The horse raced past the barn fell", mostramos que as derivações da GCC podem fazer uso de informações prosódicas e da estrutura informacional do enunciado a fim de induzir ou evitar o efeito labirinto, tratado na literatura psicolinguística como um fenômeno fundamentalmente sintático.
PALAVRAS-CHAVE: efeito labirinto; gramática categorial combinatória; prosódia.

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