Prosodic Evidence for Recursion?

Michael Wagner

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Department of Linguistics

Cornell University ML216

Ithaca, NY 14850

chael@cornell.edu

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Abstract

The prosody of a linguistic expression, like its meaning, reflects its internal compositional structure. Two kinds of potential prosodic evidence for syntactic recursion are distinguished: A generalization about a prosodic property could be recursive in that it requires a recursive evaluation of the internal structure of a complex expression; more direct evidence for recursion could consist of a prosodic property that can encode indefinitely many degrees of syntactic embedding. Generalizations about prominence *and* boundary strength *are argued to be recursive in nature in the first sense, and thus indirectly reflect syntactic recursion; it is less clear, however, to what extent they can distinguish degrees of syntactic embedding and thus be recursive in the second sense.*

Keywords: prosody, stress, boundary strength, recursion, incremental production

1. Two Kinds of Prosodic Evidence for Syntactic Recursion

A language can be called recursive if well-formed expressions can be used as compositional building blocks in even bigger expressions. In the case of formal languages, there are often recursive definitions of what counts as a well-formed expression. For example, the convention $if a, b \in L, then\ a \wedge b \in L$ allows for recursively constructing more and more nested coordinate structures. To recycle an output in this way in order to build more complex expressions is to take what can be called a *recursive step*.[2].

One way of telling whether a natural language is recursive in this sense and employs recursive steps is to look out for the nesting of constituents of equal syntactic type. In a re-write

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[2]An overview of the various characterizations of recursion in the linguistic literature is given in Tomalin (2007)

grammar, building these expressions would require the application of the same re-write rule twice in such a way that the output of one is identical to (as in 1a) or at least contained in (as in 1b) the input of the other:

(1) a. NP → NP and NP: (Stan and Laurel) and Harold.

b. NP → NP PP: The man with the hat with the hole.

The claim that these expressions are built up using a recursive step can be made plausible by virtue of the fact that the constituents contribute to the overall meaning in a transparent compositional way. The semantic interpretation that the grammar assigns to a well-formed expression is standardly used as a window into its internal structure. An analysis that does not exploit the recursive internal structure would be cumbersome, since it would require positing more and more complex phrase structure rules and correspondingly complex rules for their interpretation.

In addition to assigning a meaning to every well-formed expression, the grammar also determines their pronunciation. If the prosody of a complex expression is compositional in the same way as its meaning, we might expect that prosody gives evidence for recursion as well. This article considers two empirical domains in order to evaluate whether it does: sentential stress and boundary strength.

There could be two kinds of evidence for recursion from prosody. The first kind of evidence would consist of a prosodic generalization that can be stated only in reference to the internal compositional structure of an expression. For example, the answer to the question *In any given expression, which word is most prominent?* or *In any given expression, which word precedes the strongest boundary?* might necessitate a recursive statement that cannot be replaced by a hard-fast rule that does not refer to recursive phrase structure, such as *The one that's rightmost* or *The one that precedes a clause boundary*. For this to be the case, the prosodic property itself need not be recursive, nor does it have to reflect different degrees of embeddedness; it must simply necessitate a *recursive generalization*.

The second kind of potential evidence would be to show that prosody directly distinguishes different degrees of embeddedness. It is conceivable, e.g., that relative prominence and/or relative boundary strengths reflect various levels of nesting. A prosodic representation could in principle reflect indefinitely many degrees of embeddedness. This could be achieved by gradient features that correlate with embeddedness, e.g., the numerical stress value feature of Chomsky and Halle (1968), which can assume any integer value; or by positing that prosodic structure itself is a layered recursive representation, e.g., a bracketing metrical grid (Halle and Vergnaud 1987). I will call either kind of representation a *recursive representation*, since it directly reflects the traces of syntactic recursion.

(2) Two types of Prosodic Evidence

a. *Recursive Generalization:* A generalization about a property of elements within some domain that has to be stated recursively and can't be replaced by a hard-and-fast generalization.

b. *Recursive Representation:* A representation that directly encodes different degrees of syntactic embeddedness.

In the recent literature on the relation between syntax and prosody, positing recursive generalizations about prominence and/or boundary strength (Halle and Vergnaud 1987, Cinque 1993, Arregi 2002, i.a.) usually goes hand in hand with assuming a recursive representation, following the idea of a purely relational metrical representation in Liberman (1975); analyses that have tried to formulate hard-and-fast non-recursive generalizations (Selkirk 1986, Truckenbrodt 1995, Kratzer and Selkirk 2007, i.a.) have usually assumed a flatter non-recursive structure, similar to the representation that is assumed in the ToBI convention of transcribing intonation (Beckman et al. 2005).

This article presents evidence that it is fruitful to keep the two notions separate, and argues that, while generalizations about prominence and boundary strength are indeed recursive in nature

and therefore give indirect evidence for the recursive structure of natural language, it remains an open empirical question to what extent prosody can distinguish different levels of embedding and thus encode recursive nesting more directly.

2. Nuclear Stress

In Chomsky and Halle (1968), the unique syllable that is judged to be most prominent is said to carry the 'nuclear stress' of an expression. The relative prominence of syllables is directly encoded in the form of a feature that can take any integer value, with '1' being the nuclear stress of an expression, and higher numbers reflecting lesser degrees of prominence.

Truckenbrodt (1995) and Wagner (2005b) interpret prominence as a more derivative notion and have defined a notion of the nuclear stress of an expression as the location of the last accented syllable, adapting an idea from Newman (1946). The advantage of this definition is that judgments about the location of the last accent are fairly robust and correlate with measurable phonetic cues, while judgments about prominence vary across speakers. For example, many people do not share the intuition that the last conjunct in a coordinate structure is more prominent than the first, and in fact Newman (1946) analyzed them as carrying one nuclear stress each:

(3) I invited Jóhn and Máry.

Which syllable in a sentence carries the nuclear stress? Usually, if a word carries an accent, it aligns with the main word stress, so this question boils down to the question of *which word* in a sentence carries the nuclear stress. The generalization about the location of nuclear stress in Germanic languages turns out to be recursive in nature.

2.1. A Recursive Generalization

Since a complete treatment of nuclear stress would go beyond the scope of this article, I will target one domain of facts which illustrates the recursive nature of the generalization straightforwardly, namely sequences of elements that can be analyzed as recursively nested functor-argument pairs. Furthermore, I will only discuss sentences in which no constituent is marked as 'given' or 'focused.' For a discussion of how focus- and givenness marking interacts with the facts presented here, and relevant references see Wagner (2005b, 2007a). Consider the following example:

(4) English: Last Accent Final

that he wanted$_1$ to help$_2$ to páint$_3$.

In this sentence, 'to paint' is the argument of the functor 'help' and the entire expression 'to help to paint' is the argument of the functor 'wanted.' The observation about nuclear stress in such nested functor-argument pairs is that *the argument of the deepest functor carries the nuclear stress*. The last accent falls on a different word only if the deepest argument is constructed as given, usually because it was mentioned in the context.

A look across neighboring languages shows that this characterization in terms of embedding is the right one. In Dutch, where the relative order between predicates is similar to the one in English, nuclear stress is also on the last word of the sequence:

(5) Dutch Predicate Cluster: Final Stress

... dat hij wilde$_1$ helpen$_2$ vérven$_3$.
that he wanted.to help.to paint

In German however, where the order of the three predicates is reversed, the nuclear stress falls on the *first* predicate:

(6) German Predicate Cluster: Initial Stress

...dass er málen$_3$ helfen$_2$ wollte$_1$.
...that he paint help want.

For those word orders that are shared by Dutch and German, the nuclear stress falls on the same predicate, so it is not the case that nuclear stress is generally rightmost in Dutch predicate sequences and left-most in German:

(7) a. Dutch, b. German

a. ...dat Ján Maríe$_{given}$ kan$_1$ gezíen$_3$ hebben$_2$.
that Jan Mary could seen have
'...that he can$_1$ have$_2$ seen$_3$ her'

b. ...weil sie ihn hat$_1$ málen$_3$ wollen$_2$.
because she him has paint wanted
'...that she has$_1$ wanted$_2$ to paint$_3$ him.'

Nuclear stress is not construction-specific: Often several word orders are possible in the same language, and nuclear stress falls as expected on the deepest argument, irrespective of re-ordering, unless of course some predicates are marked as given:

(8) '...because he promised$_1$ to try$_2$ to be silent$_3$.'

a. ...weil er versprach$_1$ zu versuchen$_2$ zu schwéigen$_3$.

b. ...weil er versprach$_1$ zu schwéigen$_3$ zu versuchen$_2$.

c. ...weil er zu schwéigen$_3$ zu versuchen$_2$ versprach$_1$.

That speakers have indeed internalized a very abstract recursive generalization and not some hard-and-fast rules for particular word orders can be tested by asking them to pronounce structures with word orders that only occur in dialects other than their own. The following word orders are from a dialect described in Bech (1955/57). Many speakers of German do not consider these part of their vernacular, and yet they know where to put the nuclear stress:

(9) 'that one will be able$_1$ to let$_2$ him stay$_3$ lýing$_4$ here.'

a. dass man ihn hier líegen$_4$ bleiben$_3$ lassen$_2$ kann$_1$.

b. → dass man ihn hier kann$_1$ lassen$_2$ líegen$_4$ bleiben$_3$.

c. → man wird ihn hier können$_1$ líegen$_4$ bleiben$_3$ lassen$_2$.

The same generalization arguably holds for English, but this is harder to test because of the strict word order of predicates relative to each other. Predicates are invariably ordered according to their sequence of embedding. In order to see that English is no exception among the Germanic languages, we have to look at DP complement and their prosody relative to the predicates that select them. The position of DP complements is a bit more flexible in English, and sometimes even 'internal' arguments precede the predicate that selects them. Consider:

(10) a. ...dat hij een múur$_4$ wilde$_1$ helpen$_2$ verven$_3$.
that he a wall want allow can help paint

b. ...dass er eine Wánd$_4$ streichen$_3$ helfen$_2$ wollte$_1$.
that he a wall paint help wanted

In English nested functor-argument pairs as well, nuclear stress falls on the complement of the deepest predicate irrespective of word order, as long as the argument is not given:

(11) Did she like the new place?

a. She wants$_1$ to paint$_2$ the wálls$_3$.

b. She wánts$_1$ to have$_2$ the wálls$_4$ painted$_3$.

The same observation can be made about intransitive sentences. The following example controls information structure by using a verb of coming into existence. Their subject cannot be construed as discourse given, since its referent only arises as a result of the described event (Wagner 2007b):[3]

[3]Shifting the stress is possible only if there is an antecedent with an alternative predicate that licences a contrast:

(12) - A rásh formed? - No, a rash disappéared!

(13) a. After taking this medication you might get a fever or feel nauseated, and a rásh$_4$ could$_1$ start$_2$ to emerge$_3$.

b. # After taking this medication you might get a fever or feel nauseated, and a rash$_4$ could$_1$ start$_2$ to emérge$_3$.

We can state the following descriptive generalization:[4]

(14) *Recursive Generalization:* In nested functor-argument pairs, the last Accent ('nuclear stress') falls on the argument of the lowest predicate.

This generalization is sensitive to the entire internal structure of the expression; it is not possible to restate it in terms of 'left-most' or 'right-most,' or any other notion that does not in itself reflect the internal structure. That nuclear stress placement is directly related to embeddedness was first proposed in Cinque (1993).

It is important to note though that the generalization observed in Germanic does not hold crosslinguistically, contrary to claims in Cinque (1993), Kahnemuyipour (2004) and Kratzer and Selkirk (2007) that prominence universally falls on the object rather than on the verb in 'OV'-like structures. That languages do indeed differ with respect to the nuclear stress generalization can be illustrated by the fact that, while in all Germanic languages that I have so far tested for constructions like (15), nuclear stress falls on the argument and the predicate is prosodically subordinated, the same is not true in Romance languages (at least Spanish, French, Brazilian Portuguese and Italian), where the predicate happily bears an accent. This difference between Romance and Germanic was observed for in Ortiz-Lira (1995) (for Spanish) and in Ladd (1996) (for Italian). Consider the following French example:

(15) a. I have some shópping to do.

[4]Wagner (2005b) presents evidence that, in fact, predicates are pitch reduced even if only part of the deepest complement precedes, suggesting that the generalization is better stated as a condition under which predicates are prosodically subordinated, rather than as a claim about where nuclear stress falls.

b. J'ai des courses a fáire.
I have some shopping to do

In Germanic, nuclear stress, and correlating with it relative prominence, encodes the embeddedness of the word that carries it.

2.2. Capturing the Generalization

The insight that the generalization about nuclear stress is recursive in nature goes back at least to Chomsky et al. (1957) and Chomsky and Halle (1968), who propose an algorithm that recursively derives a phonological representation: the transformational cycle.

Vanderslice and Ladefoged (1972) noted that the phonetic facts do not warrant indefinitely many levels of prominence, as they were used in Chomsky and Halle (1968), and proposed a 'flatter' representation that only distinguished four levels of stress. They maintained the transformational cycle in order to compute which syllables receive which degree of prominence. They thus kept the insight of the recursive generalization about stress placement but abandoned a recursive representation of stress.

The precise nuclear stress rule proposed in Chomsky and Halle (1968) assigns highest prominence to the rightmost constituent at each phrasal node. Since the expressions discussed here do not all have rightmost stress, they obviously cannot be accounted for by this rule. One way to fix this is to postulate that at some point in the derivation the deepest constituent *is* rightmost, and stress is assigned then, before a subsequent reordering takes place. This line of argument is taken in Bresnan (1971), and more recently in Legate (2001).

Other approaches have formulated principles that do not assign prominence to the rightmost constituent at every node, but are sensitive as to whether or not a constituent is a functor or an argument (Schmerling 1976, Gussenhoven 1983, Jacobs 1992). This approach is further supported by close parallels in the prosody of predicates and that of modifiers observed in Wagner (2005a). The prosodic asymmetry between functor and argument was argued to correlate with syntactic

projection in Arregi (2002) and Wagner (2005a). The way any of the mentioned approaches can capture the generalization under consideration here is that the principle that assures that predicates following their complement are not accented must be applied recursively. To be sure, the approaches differ widely in how exactly the idea is implemented and prosody is represented.

A second kind of approach to explain the generalization could be called the 'indirect approach,' in which the mapping principles are not applied recursively, but are sensitive to representational aspects of syntactic structure that in turn reflect recursion. A popular instance is the theory of edge-alignment, which phrases an output string into prosodic categories based on conventions that map certain types of syntactic constituents into certain types of prosodic constituents, e.g via XP-Edge Marking (Chen 1987, Selkirk 1986) or XP-Alignment (Selkirk 1995b, Truckenbrodt 1995, 1999). The account of the generalization in Germanic would have to be that the left edge of XPs aligns with the left edge of phonological phrases. The trick is that the location of rightmost left edge is sensitive to the recursive structure of the expression, so the mapping principle itself need not be stated recursively.

(16) a. Syntax: [$_{XP}$ Mary [$_{XP}$ wanted [$_{XP}$ to try [$_{XP}$ to paint]]].
Phonology: (Mary)$_{\phi}$ (wanted)$_{\phi}$ (to try)$_{\phi}$ (to paint)$_{\phi}$.

b. Syntax: [$_{XP}$ Maria] [$_{XP}$ hat [$_{XP}$ [$_{XP}$ [$_{XP}$ malen] helfen] wollen].
Phonology: (Maria)$_{\phi}$ (hat)$_{\phi}$ (malen helfen wollen)$_{\phi}$.

The edge-alignment approach faces several challenges. First, the approach does not actually predict the location of stress *within* the prosodic domain, and thus does not by itself capture the generalization outlined here. Stress within the phonological phrase must in addition be assumed to be leftmost. Moreover, the analysis is tied to a syntactic concept that has fallen out of fashion, and in fact it is not obvious that the generalization about what counts as an XP can be motivated on syntactic grounds at all (cf. discussion in Wagner 2005b, Kratzer and Selkirk 2007).

More recently, Kahnemuyipour (2003) proposed a principle that exploits the notion of

phase from Chomsky (2001) and assigns phrase stress on the highest phrase within a phase. This analysis was adopted in Kratzer and Selkirk (2007) and argued to account for the placement of nuclear stress in German and English. But how can a generalization that places nuclear stress on the highest constituent account for the generalization in (14)?

For the data discussed above in which stress is not rightmost, either the constituent bearing nuclear stress must be the highest in the lowest phase, or some other factor must play a role. The first option is undesirable since it would require an analysis of predicate sequences in Germanic that posits that the predicate lowest in the selectional chain, i.e., the semantic argument of the deepest functor-argument pair, is always constructed as syntactically highest in the first phase, i.e., all other predicates must be either lower or added at higher phases, which seems rather cumbersome and unlikely to be correct.

The line taken in Kratzer and Selkirk (2007) is that the nuclear stress principle is sensitive to whether or not a constituent is *phrasal*, importing the phrase/non-phrase distinction from earlier syntactic theories, and is thus in essence an updated version of the Edge-based theory. It is not clear what to do with the examples in which the deepest argument is itself a predicate and not an XP, since stipulating that the lowest predicate always must be in its own XP seems arbitrary. In fact, Kratzer and Selkirk (2007) would need a different set of principles that negotiates stress in predicate clusters. In light of the fact that nuclear stress falls on the deepest complement in the selectional sequence, irrespective of whether or not it consists of a head or a DP, this constitutes a significant loss of generalization. In other words, it remains unclear why generalization (14) should be true.

A further issue is that the analysis is empirically contentful only to the extent that criteria are given for what is a *phase* and also what counts as a *phrase* that are independent of nuclear stress, but converge exactly on the same domains, a premise whose validity yet awaits to be investigated.

Both indirect approaches to capturing the generalization in (14) are similar in that they attempt to explain the placement of nuclear stress by a hard-and-fast generalization rather than

by a principle that is recursively applied. However, since the proposed generalizations refer to a notion that itself reflects the recursive structure of an expression (*rightmost left XP boundary*, *highest element in first phase*), they in fact do not contradict the claim that the generalization about nuclear stress is recursive in nature; they differ only in the way this insight is captured.

2.3. Recursive Representation?

We observed that in Dutch, the predicates in a cluster are usually ordered according to their embedding, with the highest predicate first and the lowest predicate last. In pronouncing such clusters, one can place additional accents on words carrying secondary stress. Does the distribution of these stresses encode further information about the relative embedding of the other predicates?

It is instructive to look at the distribution of secondary stress in nested functor-argument pairs. A secondary accent in (17a) can fall on the first and least embedded predicate, but not on the second and more embedded predicate. However, if a preposition that is unaccented separates the last two predicates, then a secondary accent is placed on the second predicate (17b):

(17) Rhythmic Effects:

'That he wanted to help to paint.' (Dutch:)

a. ... dát hij wìlde$_1$ helpen$_2$ vérven$_3$

b. ... dát hij wilde$_1$ hèlpen$_2$ met vérven$_3$

It seems that the distribution of secondary stresses is guided by rhythmic principles such as clash avoidance rather than syntactic considerations. This is further confirmed by longer predicate clusters, where secondary accents are placed to avoid clashes between two adjacent accented predicates:

(18) 'He says that he wants to be allowed to be able to help to paint.'

Hij zèi dat hij...

a. ...vérf de.

b. ...wil de$_1$ vérv en$_2$.

...that he wanted to paint

c. ...wìl de$_1$ helpen$_2$ vérv en$_3$.

...that he wanted to helpt to paint

d. ...wìl de$_1$ kunnen$_2$ helpen$_3$ vérv en$_4$.

..that he wanted to be able to help to paint

e. ... wìl de$_1$ kunnen$_2$ mò gen$_3$ helpen$_4$ vérv en$_5$.

... wìl de kunnen mogen helpen vérv en.

that he want be.allowed can help paint

Similarly, intuitions about secondary stresses in German are rhythmic in nature, and not related to the relative embedding of predicates. The only difference from Dutch is that secondary stresses cannot be accompanied with pitch accents, since that would mean that the nuclear stress is shifted, which is possible only in cases where the deepest predicate is given.

(19) ‘He says that he wants to be allowed to be able to help to paint.’

Er sag te dass er...

a. ... m’al te.

b. ... mál en$_2$ wollte$_1$..

c. ... mál en$_3$ helfen$_2$ wòllte$_1$

d. ... mál en$_4$ helfen$_3$ können$_2$ wòllte$_1$.

e. ... mál en$_5$ helfen$_4$ kòennen$_3$ dürfen$_2$ wòllte$_1$.

that he want be.allowed can help paint

Of course, a sentence might contain several domains, each of which contains a nuclear stress. An example would be a sentence that involves a subject that itself is complex, e.g., where the subject might itself contain nested predicate-argument pairs. The intuition that the nuclear stress within the subject is less prominent than the sentence final stress can be attributed to Newman's generalization.

(20) [Die Vorstellung ein Búch lesen zu wollen] [erschien Maria suspékt.]
the thought a book read to want seemed Maria suspicious
Mary found the thought that someone would want to read a book suspicious.

To summarize, within each domain that contains a nuclear stress, the distribution of secondary stress reveals patterns that are rhythmic in nature, and do not reflect the relative embedding of predicates. The prosodic representation does not need to distinguish many degrees of stress, but it suffices to distinguish nuclear stress from secondary stress, and to distinguish post-nuclear secondary stress from pre-nuclear secondary stress in their ability to carry accents. Further structural relations between predicates that do not receive nuclear stress are not prosodically encoded. Therefore, based on these facts, it seems that *the prosodic representation or prominence can be fairly flat*, and degrees of embeddedness are not encoded; yet the distribution of nuclear stress itself is recursive in nature and encodes the location of the deepest constituent in the selectional chain.

3. Boundary Strength

We can often distinguish boundaries of different strength between the words of a sentence that reflect syntactic (or at least prosodic) grouping (Lehiste 1973). The percept of boundaries correlates with phonetic measures such as pre-boundary lengthening (cf. Price et al. 1991, Wightman et al. 1992, Kim et al. 2004, Yoon et al. 2007), the lengthening of onsets following the boundary (Keating to appear), the relative tonal scaling of pitch accents on words (Ladd 1988, Féry and Truckenbrodt 2004), and also with more categorical distinctions such as the presence/absence of a

boundary tone or a pause (Price et al. 1991, Kim et al. 2004, Yoon et al. 2007).

This part of the article looks at the generalization about which word(s) in a sentence is/are followed by the strongest boundary(ies), and the argument is that the answer calls for a recursive generalization. Since a comprehensive treatment of boundary strength is impossible in the confines of this article, I will again focus on one particular domain, this time coordinate structures involving only proper names and *and* and *or*.

3.1. A Recursive Generalization

The use of boundary strength in coordinate structures in natural language is similar to the use of parentheses in logical notation. The formulas (21a,b) are well-formed as they are, while the formula (21c) seems incomplete.

(21) a. $A \vee B \vee C$

b. $A \wedge B \wedge C$

c. $A \vee B \wedge C$

The reason is of course that *and* and *or* are associative operators. We can define a notion of associativity between linguistic elements more generally as a domain in which any rebracketing leaving linear order constant does not affect meaning:

(22) ASSOCIATIVITY

$[[\ [[x]][[yz]]\ ]] = [[\ [[xy]][[z]]\ ]]$

Non-Associative coordinate structures in natural language are usually prosodically articulated, and require the use of prosodic boundaries of different strength (boundary strength is indicated by the number of pipes). Consider the following examples, where it is clear that two people

must have been given an apple jointly, so the associative reading would not give an appropriate answer:

(23) Two apples were given out, but I don't know to whom. Who was given an apple?

a. Lysander | and Demetrius || and Hermia (respectively).

b. Lysander || and Demetrius | and Hermia (respectively).

c. # Lysander | (and) Demetrius | and Hermia (respectively).

Similarly, certain predicates interact with coordinate structures, and whenever the grouping makes a difference it is encoded (Lasersohn 1995, Winter 2001):

(24) Altogether, Lysander, Demetrius and Hermia weigh 400 lbs.

a. Lysander | and Demetrius || and Hermia weigh 200 lbs (respectively).

b. Lysander || and Demetrius | and Hermia weigh 200 lbs (respectively).

c. ?* Lysander | (and) Demetrius | and Hermia weigh 200 lbs (respectively).

The adverb 'both' can be used to force a sub-grouping, and again prosodic articulation becomes obligatory (Lasersohn 1995, Winter 2001):

(25) a. Both Lysander || and (Hermia | and Demetrius).

b. Both (Lysander | and Hermia) || and Demetrius.

c. * Both Lysander, | (and) Hermia, | and Demetrius.

Finally, Min (1996) observes that it is odd to alternate *and* and *or* without indicating the intended bracketing prosodically:

(26) a. Lysander | and Helena || or Demetrius.

b. Lysander || and Helena | or Demetrius.

c. ?? Lysander | and Helena | or Demetrius.

The generalization about prosody in coordinate structures is:

(27) Recursive Generalization about Boundary Strength in Coordinate Structures

a. In an associative structure, elements are separated by boundaries of equal strength.

b. In a non-associative structure, constituents that are more deeply embedded are separated from each other by weaker boundaries than constituents that are less deeply embedded.

The statement makes reference to the syntactic structure in that embeddedness is reflected in degrees of boundary strength. While any given utterance might not actually fully realize many different degrees of boundary strength, the generalization about the location of the *strongest* boundary cannot be stated without looking at the entire structure if (27) is true. Consider the boundaries separating the conjuncts in the following structure, which are of equal strength:

(28) Lysander | and Hermia | and Demetrius.

In the following two structures, there is a distinction between stronger and weaker boundaries, but evaluating whether the boundary following Lysander is one of the strongest or not is possible only by considering the entire structure:

(29) a. Lysander || and Hermia || and (Demetrius | or Helena)

b. (Lysander | and Hermia | and Demetrius) || or Helena

It is not possible to assign part of the structure a prosodic realization without considering the rest of the structure. For example, a typical rendition of (28) does not involve intonational boundaries. However, the presence of a weaker boundary within the third coordinate makes it more likely that an IP will separate *Lysander* and *and Hermia* (and less likely that *Demetrius* and *or Helena* will be separated by one).

That such generalizations about prosody need to be stated in these relational terms and not in absolute ones was also observed by Taglicht (1998, 192), who proposed similar constraints on the prosody of coordinate structures.

3.2. Capturing the Generalization

Articulated prosodic structures in coordinate structures are unexpected in theories that operate with hard-and-fast rules for boundary assignment. Consider again the approach in terms of XP-edge-marking, in which designated syntactic categories aligh with the edges of certain prosodic domains (e.g., Φ) (Selkirk 1986, Chen 1987, Selkirk 1995b, Truckenbrodt 1995). The predicted prosody for all coordinate structures would be one in which all constituents are separated by boundaries of equal strength:

(30) (Lysander)$_{\Phi}$ (and Hermia)$_{\Phi}$ (or Demetrius.)$_{\Phi}$

The generalization about boundary strength is clearly sensitive to the internal recursive structure of an expression. One possible line of explanation is positing principles of syntax-to-phonology mapping that assign boundary strength based on syntactic constituent structure, as in Gee and Grosjean (i.a. 1983), Cooper and Paccia-Cooper (i.a. 1980), Wagner (i.a. 2005b); a second possibility is positing a more indirect processing-related explanation as in Watson and Arnold (2005), which correlate boundary strength with constituent size and the associated processing cost for planning and recovery. Both approaches, however, presuppose a syntactic representation and thus employ the recursive structure of syntactic expressions to capture the generalization.

3.3. Recursive Representation?

If the generalization about the placement of the strongest boundary is recursive in nature and related to embedding, we can ask whether recursive degrees of embedding are encoded by finer grained differences in boundary strength.

A typical utterance only distinguishes very few different boundary strengths, and highly nested structures seem to be dispreferred. The syntax of many natural languages feature various strategies of 'restructuring,' e.g., extraposition, which turns structures into lists and reduces the degree of embedding (Wagner 2005b, and references therein), maybe for processing reasons, as was already hypothesized in Chomsky (1965) and Lieberman (1967). So one reason many utterances do not show many degrees of embedding signaled in their prosody might be that their syntax does not actually involve much nesting.

Under the rare circumstances that there is a highly nested syntactic structure, we can ask the question to what extend the nesting is directly reflected in prosody. The dominant theory or prosodic representation since the eighties has been the theory of the prosodic hierarchy, which assumes a very limited and rather flat prosodic representation and disallows recursion of prosodic categories.[5] The number of distinct boundary strengths would be predicted to be identical to the number of different prosodic labels.

More recently, however, experimental evidence has accumulated that boundary strength is a more gradient and relative notion. Evidence for gradient distinctions in relative boundary strength in production was presented in Ladd (1990), Price et al. (1991), Wightman et al. (1992), Keating (to appear) and Wagner (2005b). Evidence for a hierarchical organization above and beyond that allowed for by the prosodic hierarchy was given based on pitch scaling in Ladd (1986, 1988), van den Berg et al. (1992), Ladd (1996), Féry and Truckenbrodt (2004), Dilley (2005). Studies have also found evidence for a relative *interpretation* of phonetic cues when perceiving speech, e.g., in Price et al. (1991), Carlson et al. (2001) and Clifton et al. (2002).

Taken together, the evidence from recent studies makes it quite likely that boundary strength can be used to encode several layers of nesting in coordinate structures, although the degree to which this information can be reliably retrieved from the signal remains to be estab-

[5]Evidence in favor of recursion within categories defined by the prosodic hierarchy was discussed in Dresher (1994). Selkirk (1995a) and Truckenbrodt (1995, 1999) weaken the restriction against recursion by turning it into a violable constraint, and allow for limited forms of recursive prosodic structures under special circumstances.

lished.

One reason that it would make sense for a language that obeys the generalization in (27) to operate with a relative rather than an absolute notion of boundary strength is the incrementality of language production. Imagine one has to articulate the structures in (31a,b):

(31) a. A || or B || or || (C | and D)

b. (A | or B | or C) || and D

If boundary strength is relative, then one can begin articulating (31a,b) without planning out the entire utterance and place a boundary of identical strength after A in both cases. It is then crucial to articulate the boundary preceding the last conjunct as either stronger or weaker *relative to earlier produced boundaries*. If, on the other hand, the grammar would require that a particular strength would need to be used to make the boundary after A strong or weak, then articulating (31a,b) would necessarily require planning out the entire utterance beforehand.

If the generalization about boundary strength is recursive along the lines of (27), then a prosodic representation that can encode relative boundary strength and degrees of embedding rather than absolute boundary strength may be desirable.

4. Conclusion

The goal of this article was to discuss potential prosodic evidence for syntactic recursion. The two empirical domains examined were prominence and boundary strength. It was argued that the generalizations about highest prominence and about highest boundary strength are recursive in nature. The prosody of an expression, like its meaning, reflects its compositional make-up. The extent to which prosody is able to encode degrees of embedding and thus more directly represent recursion is less clear, and an answer to this question will require more experimental research. An issue that was not addressed in this article is to what extent phonology itself is a recursive system

above and beyond the traces of recursiveness that are parasitic on syntax. This issue is discussed in Ladd (this volume).

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