Abstract

This paper provides a constraint-based account of information-prosody correspondence within the HPSG framework. The starting point of the paper is Klein's (2000) account of prosodic constituency in HPSG. However, it departs from the standard syntactocentric architecture of grammar, and adopts a grammar design in which syntax, phonology, and information structure are generated in parallel, with all three applying to a common list of domain objects. It is shown that this theoretical architecture elegantly captures many of the various constraints that have been shown to hold in classical views of grammar.

1 Introduction[1]

For several years, the main preoccupation of researchers working in constraint-based theories of grammar such as HPSG has been syntax and to some extent semantics. It is only in the past few years that we find work being done within phonology and its interfaces with other components of the theory. Some notable examples of such work in the HPSG framework are (Asudeh and Mikkelsen, 2000; Bird, 1990, 1995; Bird and Klein, 1991; Höhle, 1999; Klein, 2000; Yoshimoto, 2000). It has been shown that unification-based approaches are not only compatible with work in phonology as well as grammatical interfaces, but also at times they are better alternatives to derivational frameworks. Thus, it seems only natural that one would want to pursue this line of inquiry in order to explore its potential rewards to the field.

Recently, proponents of Combinatory Categorial Grammar (CCG) (Steedman, 1991, 2000b; Prevost and Steedman, 1994; Prevost, 1995) have been promoting an approach relying on the premise that surface structure is isomorphic to prosodic structure. A central claim of CCG is that by making use of elaborate type-raising and abstraction operators in a single component, one arrives at a theory that is simpler and more restricted than a multi-partite theory whose layers interact at interfaces. Although CCG can make very interesting predictions, its implications for cross-linguistic data, especially from non-configurational languages have not yet been explored and thus are largely unknown. In addition, more modular linguistic theories have been argued to model human language and other cognitive faculties more closely. Jackendoff (1997, 2002), for example, argues for a tripartite architecture of grammar where phonological, morpho-syntactic and semantic components work in parallel and only meet at interface levels.

Moreover, there are also practical reasons that it is important to do research in grammatical interfaces in constraint-based and multi-partite frameworks. A modular theory is easier for the researcher to work with. A grammar written in this ap-

[1] I would like to thank Elizabeth Cowper, Dave McKercher, and Gerald Penn for their valuable comments and discussions. I am also grateful to three anonymous reviewers for the 10th International Conference on Head-Driven Phrase Structure Grammar for their useful comments and their suggested references. Any oversights or shortcomings, however, are solely my responsibility.

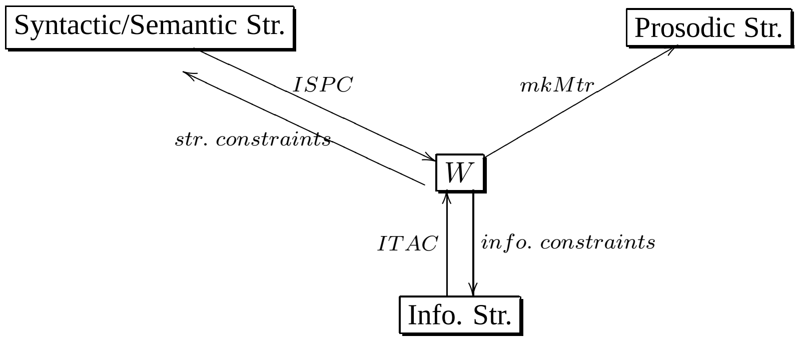


Figure 1: Architecture of the information-based model of prosodic constituency

proach is certainly more readable and more convenient to maintain. Furthermore, with the emergence of large-scale HPSG grammars a modular approach becomes more significant to promote code readability and reuse.

From a computational standpoint the significance of the interactions between phonology and other components of grammar is becoming more and more evident to the computational linguistics community as we observe a shift of focus from text-to-speech (TTS) to concept-to-speech (CTS) system. A predictable intonation created based on syntactic criteria no longer seems to fully meet the conversational needs of a dialogue system. More natural-sounding systems are being sought that adapt their intonation to their context.

This paper lays down the groundwork for a unification-based model of prosody that is sensitive to the syntax and information structure of the sentence. The approach adopted is a more modular one in the spirit discussed above. The theory developed here derives syntactic and prosodic structures at different layers interacting at interfaces only. The model of prosodic constituency laid out here is nolonger syntax-driven. Prosodic structure is defined in parallel with syntactic structure over a list of domain objects[2] commonly accessed from syntax, phonology, and information structure. The architecture of this information-based and modular model of prosody is depicted in Figure 1. According to this model, the syntactic/semantic, prosodic and information structures are all constructed from a unique list of lexical items, W. The arrows pointing from W to various structures represent well-formedness constraints on those structures. The arrows that point back to W represent constraints on the features of the members of W imposed by those structures. Structural constraints are basically those found in standard HPSG literature such as the rule schemata and the like. Informational constraints define well-formed information structures. We do not discuss these in this paper. ISPC, ITAC and mkMtr are discussed in detail in section 3 where the formal account of the data is presented.

[2]Domain objects in this paper are assumed to be lexical items as a starting point. Therefore, they differ from the domain objects introduced by Kathol (1995, 2000); Reape (1994). However, the exact nature of the domain objects in this approach is an open question.

Further motivation for adopting the architecture presented in Figure 1 comes from the myriad mismatches observed between syntactic and prosodic structures. As Zwicky (1982) puts it, "[t]he divergence between the syntactic and phonological organizations of the same material has long been recognized as a problem in analysis and a challenge to theorizing, finding recognition in works as diverse as Kahane and Beym (1948); Pulgram (1970); Bing (1970); Cooper and Paccia-Cooper (1980) and the writing of the 'metrical phonologists', in particular Selkirk (1981)." Basically, the mainstream literature assumes that the prosodic structure mirrors syntactic structure unless otherwise specified in order to satisfy certain phonological constraints. These constraints, however, render virtually every prosodic structure different from the syntactic structure of the same sentence. For example, invariably in every Det, Adj, N sequence, the Adj gets "promoted" to the sister of Det giving rise to the following prosodic structure [[Det Adj] N] which is different from the syntactic structure [Det [Adj N]]. The modular model proposed in this paper accounts for the phenomena that Butt and King (1998) call "prosodic promotion", and "prosodic flattening" straightforwardly without having to manipulate syntactic structures. In addition, information structure-prosody correspondence is handled elegantly in a modular fashion without recourse to unnecessary and *ad hoc* operations and/or levels of representation. This approach allows for the extension of the model to straightforwardly account for word-order variations as well.

As it stands, this paper can be thought of as a response to the CCG claim that modular theories are overly complicated and unconstrained. It is our claim that by making use of sufficient constraints on each module, we *can* have a theory with very simple sub-components that are more readable, extensible, and maintainable. The analysis here builds on ideas proposed in Klein (2000), but departs from the syntactocentric approach adopted in that work.

Section 2 goes over the data that is to be accounted for. As mentioned earlier, section 3 presents a formal account of the data. For some backgound information on the issues discussed here, refer to Klein (2000); Selkirk (1984); Zwicky (1982) and the references therein.

2 Data

Let us go over some examples to illustrate the empirical coverage of Klein's interface model. Starting with (1), we can see how the application of mkMtr results in a correct derivation of a prosodic tree.

(1) I want to begin to try to write a play.

Stepping into the derivation bottom-up and right-to-left, we can easily trace the working of mkMtr. For example, *a play* is a *hd-spr-cx* and thus also of type *ext-pr*, which employs $\mathsf{mkMtr}_{\mathrm{LA}}$ according to Klein (2000). As shown in (2), the application of $\mathsf{mkMtr}_{\mathrm{LA}}$ to *a play* results in a metrical tree of type *mtr(lnr)*.

(2) $\mathsf{mkMtr}_{\mathrm{LA}}(\langle \mathrm{a}, \mathrm{play}\rangle) = \mathsf{mkMtr}^{full}(\mathsf{mkMtr}^{lnr}(\langle \mathrm{a}, \mathrm{play}\rangle) \oplus \langle\quad\rangle) =$

$$\mathsf{mkMtr}^{full}\left(\left\langle\begin{bmatrix} \textit{mtr}\Big(\textit{lnr}\Big) & \\ \text{DOM} & \Big\langle \text{a}, \boxed{1}\ \text{play}\Big\rangle \\ \text{DTE} & \boxed{1} \end{bmatrix}\right\rangle\right) = \begin{bmatrix} \textit{mtr}\Big(\textit{lnr}\Big) & \\ \text{DOM} & \Big\langle \text{a}, \boxed{1}\ \text{play}\Big\rangle \\ \text{DTE} & \boxed{1} \end{bmatrix}$$

Going through the derivation procedurally in the same manner yields the result shown in (3). The following example is frequently mentioned by Steedman (e.g. Steedman, 2000b, 94) as one that needs to be accounted for by any theory that deals with syntax-phonology mismatches.

(3) [(I want) [(to begin) [(to try) [(to write) (a play)]]]]

(4) * [[I want to begin to][try to write a play]]

In this example a pause has been placed between a leaner and the prosodic word that it leans on. Clearly, a pause should not be allowed to intervene within leaner groups and we should make provisions in our theory to reject such ill-formed structures.

Klein's account incorrectly marks (5) ungrammatical as *I*, being a personal pronoun is considered a leaner in that model.

(5) [I] [want to begin to try to write a play].

The sentences in (5) and (6) appear in Steedman (2000b, 93). He suggests a model of syntax whose surface structures correspond directly to intonational contours. Thus, in these examples, all of the observed intonational contours correspond to alternate surface structures for the sentence in a CCG framework.

(6) a. [I want][to begin to try to write a play].
b. [I want to begin][to try to write a play].
c. [I want to begin to try][to write a play].
d. [I want to begin to try to write][a play].

In our framework, we would like to develop a model that not only is able to account for these alternate intonational contours and their corresponding semantics, but also maintains the modularity of its component theories as much as possible. Another example that Steedman (2000b), *inter alia*, discusses is (7).

(7) *[Three mathematicians] [in ten prefer margarine].

Selkirk (1984) attributes the ungrammaticality of (7) to the violation of the Sense Unit Condition, meaning that the prepositional phrase *in ten* and the verb phrase *prefer margarine* fail to form a sense unit as neither is a complement or modifier of the other. Steedman's CCG model accounts for this. Again, approaching the problem from our standpoint, we would like a multi-partite account for this fact. Another type of data that we want to account for here is:

(8) a. [Jane gave the book to Mary]
b. [Jane] [gave the book to Mary]
c. [Jane gave the book] [to Mary]
d. [Jane gave] [the book] [to Mary]
e. * [Jane] [gave] [the book to Mary]
f. * [Jane gave] [the book to Mary]
g. [Jane] [gave the book] [to Mary]
h. [Jane] [gave] [the book] [to Mary]

These data have been discussed in Selkirk (1984), and similar examples have been talked about in Steedman (2000a). Selkirk (1984) also attributes the ungrammaticality of (8e, f) to the violation of the Sense Unit Condition: The phrases *the book* and *to Mary* do not form a sense unit because neither is a complement or modifier of the other.

3 Analysis

3.1 Information Status and Intonation

Like Steedman, who adopts a Hallidayan tradition, we use the term *theme* to refer to given information and *rheme* to new information.[3] Steedman (2000b, 101), following Pierrehumbert (1980), attributes L+H* LH% intonation contour to theme and H*LL% to rheme. L+H* LH% and H*LL% are in Pierrehumbert's notation (Pierrehumbert, 1980), and respectively correspond to *rise-fall-rise* and *fall* intonation in British style (Ladd, 1996, 82). Going back to our example about writing a play (extended here as (9)), we can discuss some of the interaction between information structure and prosody. Hereafter, $_\theta$ stands for *theme* and $_\rho$ for *rheme*.

(9) a. $[\text{I}]_\theta$ [want [(to begin) [(to try) [(to write) (a play)]]]]$_\rho$
L+H* LH% H*LL%

b. [(I want)]$_\theta$ [(to begin) [(to try) [(to write) (a play)]]]$_\rho$
L+H* LH% H*LL%

c. [(I want) (to begin)]$_\theta$ [(to try) [(to write) (a play)]]$_\rho$
L+H* LH% H*LL%

d. [(I want) (to begin) (to try)]$_\theta$ [(to write) (a play)]$_\rho$
L+H* LH% H*LL%

[3] Other terms used in the partitioning of information include *(back)ground/focus*, and *topic/comment* among others. For the purposes of this paper, we assume that all of these correspond to *given/new* information. Steedman (2000b) makes a distinction between *background/focus* and *theme/rheme*. For him, *theme* or *rheme* can be partitioned into *background* and *focus*. In this account, the DTE can be thought of Steedman's *focus* and whatever that is not a DTE can be considered as *background*. For a survey of literature on information packaging, see Vallduví and Engdahl (1996).

e. [(I want) (to begin) (to try) (to write)]$_\theta$ [(a play)]$_\rho$
L+H* LH% H*LL%

f. [(I want) [(to begin) [(to try) [(to write) (a play)]]]]

In (9a–e), each sentence is marked with respect to its information structure; whereas (9f) is unmarked. Assuming that the correlation between information structure and intonation holds and ignoring the possibility of foregrounding items other than the last in an intonational phrase, we conclude that in (9a–e) the last prosodic word (i.e. the default DTE) in theme bears a L+H* LH% (rise-fall-rise) intonation and the last prosodic word in rheme bears a H*LL% (fall) intonation.

3.2 The Type Hierarchy and Constraints

Klein's model does not have provisions for relating the information status of the constituents in the sentence to prosody. It is clear, however, that in order for it to be able to return the correct intonational phrasing, such a correspondence is necessary. We need to make sure that themes and rhemes (when marked) bear the right intonation and do not occupy the same intonation phrase. Sensitivity to contextual information by the prosodic component entails modification in the feature appropriateness conditions in the prosodic type hierarchy as well as having new constraints introduced on them. Pollard and Sag (1994) assume the presence of a CONTEXT feature for SIGN|SYNSEM|LOCAL. It only seems natural to place information structure within context. However as Engdahl and Vallduví (1994) propose, placing information structure in *local* objects is problematic for a trace-based account of unbounded dependencies. It is exactly for this reason that De Kuthy (2002), in her theory of information structure, assumes that information structure is a feature appropriate to *sign* in par with PHON, and SYNSEM. This is another step towards a tripartite architecture of grammar and we are going to adopt it in this work as well. But unlike De Kuthy, we are not going to assume that the scope of information status is represented as a symbolic language with a model-theoretic interpretation. There are two reasons for this: Firstly, taking De Kuthy's approach requires adherence to one particular semantic theory. In this work, we would like to remain theory-neutral as much as possible when it comes to the internal structures of phonology and semantics. Secondly, linking semantics directly to information structure and in turn phonology adds to the syntactocentrism of the theory. In addition to Jackendoff (2002), a considerable body of work suggests that semantics, syntax, and phonology should be allowed to work separately while making sure that they constrain one another. For more information see Penn (1999a,b); Penn and Haji-Abdolhosseini (2003). What is assumed here is that phonology, syntax and information structure all operate as independently as possible while working on one common list of domain objects that we assume to be lexical items here for convenience. Thus, *sign* will have (at least) the following feature appropriateness constraint defined over it.

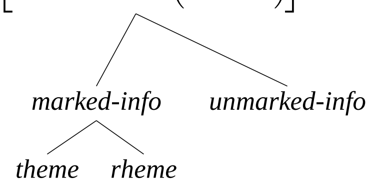
(10) **Appropriateness Constraint on *sign***

$$\begin{bmatrix} \textit{sign} & \\ \text{PHON} & \textit{pros} \\ \text{SYNSEM} & \textit{synsem} \\ \text{DOM} & \textit{list}\left(\textit{dom-obj}\right) \\ \text{INFO} & \textit{list}\left(\textit{info}\right) \end{bmatrix}$$

Type *info* has two subtypes: *marked-info* and *unmarked-info*. The type *marked-info* itself subsumes *theme* and *rheme*.

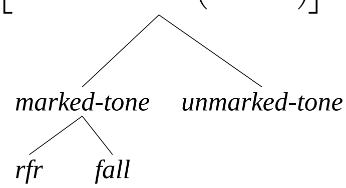
(11) **Informational Types:**

$$\begin{bmatrix} \textit{info} & \\ \text{INF-DOM} & \textit{list}\left(\textit{dom-obj}\right) \end{bmatrix}$$



(12) **Tonal Types:**

$$\begin{bmatrix} \textit{tone} & \\ \text{TONE-DOM} & \textit{list}\left(\textit{dom-obj}\right) \end{bmatrix}$$



In the prosody partition, we need a place to record the tonal information. Therefore, we add the feature TONE to *mtr(*τ*)*. Feature TONE takes as its value a list of *tone* objects, which have the following subtypes: *marked-tone* and *unmarked-tone*. The type *marked-tone* (at least) subsumes *rfr*, which stands for rise-fall-rise (L+H* LH%) intonation, and *fall*, which stands for falling (H*LL%) intonation (see (12)). Our revised prosodic type hierarchy takes the form shown in Figure 2.

Another point to discuss here is Klein's type hierarchy of phrases that cross-classify prosodic phrases under syntactic phrases. What that hierarchy assumes is that all syntactic phrases match some prosodic phrase in their yield. While this is a logical starting point since syntactic trees and prosodic trees often look very similar, even isomorphic in some cases, they clearly are not the same as we observe in the data above and in the literature. Sometimes prosodic phrases do not correspond to any syntactic constituent and vice versa. In our move towards a tripartite architecture, we should therefore treat these two types of constituency differently. Klein's approach is heavily syntax-driven and involves making prosodic trees by manipulating syntactic trees. What we need to do instead is to modify `mkMtr` such that it declaratively defines prosodic trees without the need to refer to syntax. This will also simplify `mkMtr` as we shall see shortly. What this means for the type hierarchy of *phrase* types is that phrases are no longer cross-classified with respect to the two dimensions headedness and prosody. Prosodic structure is defined over the list of domain objects as opposed to a list of partial prosodic structures. Figure 3 presents the type hierarchy of phrases that we assume in this paper.

A constraint is now required to associate the tones introduced in (12) with the information that they convey. This constraint has to be declared for any object of

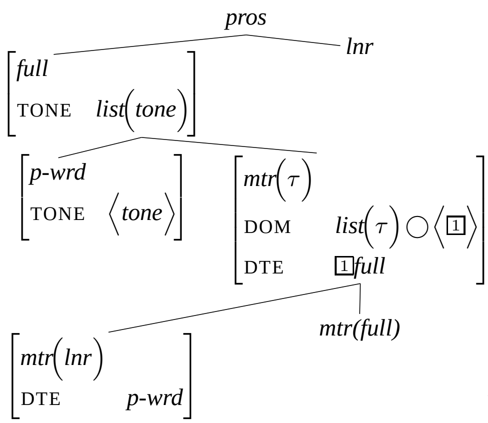


Figure 2: Prosodic Type Hierarchy

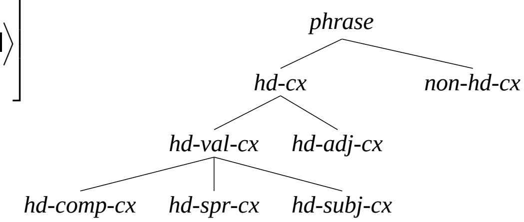


Figure 3: Type hierarchy of phrasal constructions

type *word*. This can be regarded as an interface point between conceptual structure and phonological structure in Jackendoff's terms. The constraint, which is called the *Information-Tone Association Constraint (ITAC)*, is formulated in Figure (4). The first disjunct in (4) relates theme with the *rise-fall-rise* (L+H* LH%) intonation. The second disjunct relates rheme with *falling* (H*LL%) intonation, and the third one is the default situation where lexical items are left unmarked with regard to their information status and tone. The last disjunct states that some *word* objects are prosodically leaners.

3.3 The mkMtr Function Revisited

We now need to revise the mkMtr function to handle the new formalism. Before we do that, however, let us go over the type of change that needs to be made. Take the examples in (13).

(13) a. [Jane [drank milk]]
b. [[Jane drank] milk]

In (13a), *Jane* is the theme and *drank milk* the rheme; whereas, in (13b), *Jane drank* is the theme and *milk* the rheme. (13a) is compatible with the Prosodic Isomorphism Hypothesis (PIH) but (13b) is not. *Jane* and *drank* form their own prosodic constituent because they both correspond to the theme of the sentence and *milk* belongs to a different prosodic constituent because its informational status is different. Therefore, what we want mkMtr to do is to relate prosodic structure and information structure. What this amounts to theoretically is that a weak form of PIH in this model holds for prosody and information structure as opposed to syntactic structure.

$$
\textit{word} \Rightarrow
\begin{bmatrix}
\text{PH} & \begin{bmatrix} \textit{p-wrd} & \\ \text{TONE} & \left\langle \begin{bmatrix} \textit{rfr} & \\ \text{T-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{DOM} & \left\langle \boxed{1} \right\rangle \\
\text{INFO} & \left\langle \begin{bmatrix} \textit{theme} & \\ \text{I-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle
\end{bmatrix}
\vee
\begin{bmatrix}
\text{PH} & \begin{bmatrix} \textit{p-wrd} & \\ \text{TONE} & \left\langle \begin{bmatrix} \textit{fall} & \\ \text{T-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{DOM} & \left\langle \boxed{1} \right\rangle \\
\text{INFO} & \left\langle \begin{bmatrix} \textit{rheme} & \\ \text{I-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle
\end{bmatrix}
\vee
$$

$$
\begin{bmatrix}
\text{PH} & \begin{bmatrix} \textit{p-wrd} & \\ \text{TONE} & \left\langle \begin{bmatrix} \textit{unmarked-tone} & \\ \text{T-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix} \\
\text{DOM} & \left\langle \boxed{1} \right\rangle \\
\text{INFO} & \left\langle \begin{bmatrix} \textit{unmarked-info} & \\ \text{I-DOM} & \left\langle \boxed{1} \right\rangle \end{bmatrix} \right\rangle
\end{bmatrix}
\vee
\begin{bmatrix} \text{PH} & \textit{lnr} \end{bmatrix}
$$

Figure 4: Information-Tone Association Constraint (ITAC)

(14) **The** mkMtr **Function (Revised)**

a. $\mathsf{mkMtr} : list(pros) \mapsto mtr(pros)$
$\mathsf{mkMtr}(\boxed{1}) = \mathsf{mkMtr}^{full}(mkAllLnrs(\boxed{1}))$

b. $\mathsf{mkMtr}^{\tau < pros} : list(pros) \mapsto mtr(\tau)$

$$
\mathsf{mkMtr}^{\tau}\left(\left\langle \begin{bmatrix} \text{PHON} & \boxed{1}\textit{pros} \end{bmatrix} \right\rangle\right) = \boxed{1}
$$

c. $\mathsf{mkMtr}^{lnr} : list(pros) \mapsto mtr(pros)$

$$
\mathsf{mkMtr}^{lnr}\left(\left\langle \boxed{2}\textit{lnr}, \ldots, \boxed{n}\textit{lnr}, \boxed{m}\begin{bmatrix} \textit{p-wrd} & \\ \text{TONE} & \boxed{3} \end{bmatrix} \right\rangle\right) =
\begin{bmatrix}
\textit{mtr}\big(\textit{lnr}\big) & \\
\text{DOM} & \left\langle \boxed{2}, \ldots, \boxed{n}, \boxed{m} \right\rangle \\
\text{DTE} & \boxed{m} \\
\text{TONE} & \left\langle \boxed{3} \right\rangle
\end{bmatrix}
$$

d. $\mathsf{mkMtr}^{full} : list(pros) \mapsto mtr(full)$

i. $$
\mathsf{mkMtr}^{full}\left(\left\langle \boxed{1}\begin{bmatrix} \text{TONE} \left\langle \boxed{3} \right\rangle \end{bmatrix}, \boxed{2}\begin{bmatrix} \text{TONE} \left\langle \boxed{3} \right\rangle \end{bmatrix}, \ldots, \boxed{n}\begin{bmatrix} \text{TONE} \left\langle \boxed{3} \right\rangle \end{bmatrix} \right\rangle\right) =
$$

$$
\begin{bmatrix}
\textit{mtr}\big(full\big) & \\
\text{DOM} & \left\langle \boxed{1}, \boxed{2}, \ldots, \boxed{n} \right\rangle \\
\text{DTE} & \boxed{n} \\
\text{TONE} & \left\langle \boxed{3} \right\rangle
\end{bmatrix}
$$

ii. $\mathsf{mkMtr}^{full}(\boxed{1} \oplus \boxed{2} \oplus \cdots \oplus \boxed{n}) = \begin{bmatrix} \textit{mtr}\big(\textit{full}\big) & \\ \text{DOM} & \big\langle \boxed{5}, \boxed{6}, \ldots, \boxed{o} \big\rangle \\ \text{DTE} & \boxed{o} \\ \text{TONE} & \big\langle \boxed{3}, \boxed{4}, \ldots, \boxed{m} \big\rangle \end{bmatrix} \wedge$

$\boxed{1} = \Big\langle \begin{bmatrix}\text{TONE} & \boxed{3}\end{bmatrix}, \ldots, \begin{bmatrix}\text{TONE} & \boxed{3}\end{bmatrix} \Big\rangle \wedge$

$\boxed{2} = \Big\langle \begin{bmatrix}\text{TONE} & \boxed{4}\end{bmatrix}, \ldots, \begin{bmatrix}\text{TONE} & \boxed{4}\end{bmatrix} \Big\rangle \wedge \cdots \wedge$

$\boxed{n} = \Big\langle \begin{bmatrix}\text{TONE} & \boxed{m}\end{bmatrix}, \ldots, \begin{bmatrix}\text{TONE} & \boxed{m}\end{bmatrix} \Big\rangle \wedge$

$\boxed{3} \neq \boxed{4} \neq \cdots \neq \boxed{m} \wedge$

$\mathsf{mkMtr}^{full}(\boxed{1}) = \boxed{5} \wedge \mathsf{mkMtr}^{full}(\boxed{2}) = \boxed{6} \wedge \cdots \wedge \mathsf{mkMtr}^{full}(\boxed{n}) = \boxed{o}$

The new mkMtr function is used in a constraint on *sign* objects as formalised in (16). The function *collect-phon* that is defined below in (15) and used in (16) takes a list of domain objects and returns a list of the PHON values of those objects. Theoretically, relations like *collect-phon* not only ensure the correct input type to other relations or modules of the grammar, they are also ideal in restricting access. In this case, *collect-phon* allows phonology to only see the phonological data inside DOM. Except for the interface constraints (such as ITAC, and ISPC), nothing from phonology can access the data in the syntactic/semantic, or information-structural modules.

We no longer make use of *base-pr* and *ext-pr*; rather, we let what has been described as prosodic flattening and prosodic promotion follow naturally from general constraints on prosody and information structure.

(15) *collect-phon*: *list(dom-obj)* $\mapsto$ *list(pros)*

a. *collect-phon*($\langle\rangle$)= $\langle\rangle$

b. *collect-phon*($\langle \boxed{1} \mid \boxed{2} \rangle$) = $\langle [\text{PHON } \boxed{1}] \mid$ *collect-phon*($\boxed{2}$)$\rangle$

(16) $\textit{sign} \Rightarrow \begin{bmatrix} \text{PHON} & \mathsf{mkMtr}\Big(\textit{collect-phon}\big(\boxed{1}\big)\Big) \\ \text{DOM} & \boxed{1} \end{bmatrix}$

(17) $mkAllLnrs : list(pros) \mapsto list(pros)$

a. $mkAllLnrs(\boxed{1} \oplus \boxed{2} \oplus \boxed{3}) = mkAllLnrs(\boxed{1} \oplus \langle \mathsf{mkMtr}^{lnr}(\boxed{2})\rangle \oplus \boxed{3})$

b. $mkAllLnrs(\boxed{1}) = \boxed{1}$

(14a) is the top-level function called by *sign* objects. It uses the *mkAllLnrs* function defined in (17) to generate all the possible leaner groups in the list of domain objects, and passes the resulting mixed list of leaner groups and prosodic words to mkMtr^{full} to generate a complete prosodic structure for the original list of domain objects.

(14b) is essentially the same as before. It simply returns a singleton argument intact because a metrical tree requires at least two daughters. (14c), similar to the

$$
\textit{hd-cx} \Rightarrow
\begin{bmatrix}
\textsc{hd-dtr}\ \boxed{1}\begin{bmatrix}
\textsc{ph} \begin{bmatrix} \textit{p-wrd} \\ \textsc{tone} & \left\langle \begin{bmatrix} \boxed{2}\textit{tone} \end{bmatrix} \right\rangle \end{bmatrix} \\
\textsc{info} \left\langle \begin{bmatrix} \boxed{3}\textit{info} \end{bmatrix} \right\rangle
\end{bmatrix} \\
\textsc{non-hd-dtr} \left\langle \ldots, \boxed{4}\begin{bmatrix}
\textsc{ph} \begin{bmatrix} \textit{p-wrd} \\ \textsc{tone} & \left\langle \begin{bmatrix} \boxed{2}\textit{tone} \end{bmatrix} \right\rangle \end{bmatrix} \\
\textsc{info} \left\langle \begin{bmatrix} \boxed{3}\textit{info} \end{bmatrix} \right\rangle
\end{bmatrix}, \ldots \right\rangle \\
\textsc{dom} \left\langle \ldots, \boxed{1}, \ldots, \boxed{4}, \ldots \right\rangle \\
\textsc{info} \left\langle \begin{bmatrix} \boxed{3}\textit{info} \\ \textsc{i-dom} & \left\langle \boxed{1} \right\rangle \oplus \left\langle \boxed{4} \right\rangle \end{bmatrix} \right\rangle
\end{bmatrix}
\vee
\begin{bmatrix}
\textsc{hd-dtr}\ \boxed{1}\begin{bmatrix} \textsc{info} \left\langle \boxed{2}\textit{info} \right\rangle \end{bmatrix} \\
\textsc{non-hd-dtr} \left\langle \ldots, \boxed{3}\begin{bmatrix} \textsc{info} \left\langle \boxed{4}\textit{info} \right\rangle \end{bmatrix}, \ldots \right\rangle \\
\textsc{dom} \left\langle \ldots, \boxed{1}, \ldots, \boxed{3}, \ldots \right\rangle \\
\textsc{info} \left\langle \begin{bmatrix} \boxed{2}\textit{info} \\ \textsc{i-dom} & \boxed{1} \end{bmatrix}, \begin{bmatrix} \boxed{4}\textit{info} \\ \textsc{i-dom} & \boxed{3} \end{bmatrix} \right\rangle \\
\boxed{2} \neq \boxed{4}
\end{bmatrix}
$$

Figure 5: Information Status Projection Constraint (ISPC)

original formulation of mkMtr, defines metrical trees as consisting of a group of leaners attached to a final prosodic word with the latter being the DTE. The leaner group has the value of its TONE feature structure-shared with that of the prosodic word of the leaner group. (14d-i) is the first of the two definitions for mkMtr^{full}. It requires that all the members of its argument list share the same tone value, which means they should all belong to the same intonational phrase (IP). In that case, it makes a metrical tree in the usual manner and structure-shares its tone value with that of the daughters. (14d-ii) places metrical objects in the same prosodic constituent just in case those objects bear the same tone specification. Then it makes a metrical tree out of the result with the remainder of the list of prosodic objects passed to it. Notice that mkMtr_{LA} has been omitted because we are no longer making prosodic structures based on syntactic ones.

3.4 Scope of *Theme/Rheme* Status

The issue of the scope of *theme* and *rheme*, also known as “the projection problem” is approached in this subsection. We define this concept in the form of the *Information Status Projection Constraint (ISPC)* as a type constraint on *hd-cx*. ISPC is formalised in Figure 5.

According to ISPC the arguments of the head daughter in a headed construction by default inherit the information status of that predicate through structure sharing. When an argument is overtly marked for *theme* or *rheme*, it will not inherit the information status (and tone) of the head. Thus in (9c), repeated here as (18), for example, *begin* inherits theme status from *want*, and *write* and *play* inherit *rheme* from *try*.

(18) [(I want) (to begin)]$_\theta$ [(to try) [(to write) (a play)]]$_\rho$
L+H* LH% H*LL%

Multiple theme and rheme markings are also possible and they can be distinguished by the fact that multiple themes/rhemes are listed separately in the INFO feature. We do not consider the projection problem in non-head constructions in this work. Since we assume that the rule schemata allow for the union of the domain objects of their daughters as well as the lists of informational objects, we always have access to the information status of any given prosodic word.

3.5 Accounting for the Data

Let us now go over the derivation of the examples in (13). These derivations are straightforward. In the following two derivations, we use the AVM notation for better exposition. Subsequent examples are represented in Klein's more succinct notation.

Figure 6 shows the derivation of (13a) in terms of its syntactic and information structures. Initially, *milk* is not marked for information status. It inherits the *rheme* status because of ISPC due to being an argument of the verb. This is shown in the VP construction. The subject does not fall under the scope of *rheme* because it is already marked as *theme*. The application of the ITAC throughout the derivation provides the list of domain objects shown in (19) for the resulting S construction.

(19)
$$\left[\textsc{dom}\ \left\langle \begin{array}{l} \boxed{1}\left[\textsc{ph}\ \left[\begin{array}{ll} \textit{Jane} & \\ \textsc{tone} & \left\langle\left[\boxed{4}\textit{rfr}\right]\right\rangle \end{array}\right]\right], \boxed{2}\left[\textsc{ph}\ \left[\begin{array}{ll} \textit{drank} & \\ \textsc{tone} & \left\langle\left[\boxed{5}\textit{fall}\right]\right\rangle \end{array}\right]\right], \\ \boxed{3}\left[\textsc{ph}\ \left[\begin{array}{ll} \textit{milk} & \\ \textsc{tone} & \left\langle\left[\boxed{5}\textit{fall}\right]\right\rangle \end{array}\right]\right] \end{array} \right\rangle\right]$$

The application of mkMtr to the list of domain objects shown in (19) is represented in (20). The second example, (13b) is derived analogously.

(20)
$$\mathsf{mkMtr}\left(\left\langle \boxed{1}\left[\begin{array}{l} \textit{Jane} \\ \textsc{tone}\left\langle\left[\boxed{4}\textit{rfr}\right]\right\rangle \end{array}\right], \boxed{2}\left[\begin{array}{l} \textit{drank} \\ \textsc{tone}\left\langle\left[\boxed{5}\textit{fall}\right]\right\rangle \end{array}\right], \boxed{3}\left[\begin{array}{l} \textit{milk} \\ \textsc{tone}\left\langle\left[\boxed{5}\right]\right\rangle \end{array}\right] \right\rangle\right) =$$
$$\mathsf{mkMtr}^{full}\left(\textit{mkAllLnrs}\left(\left\langle \boxed{1}, \boxed{2}, \boxed{3} \right\rangle\right)\right) = \mathsf{mkMtr}^{full}\left(\left\langle \boxed{1}, \boxed{2}, \boxed{3} \right\rangle\right) =$$

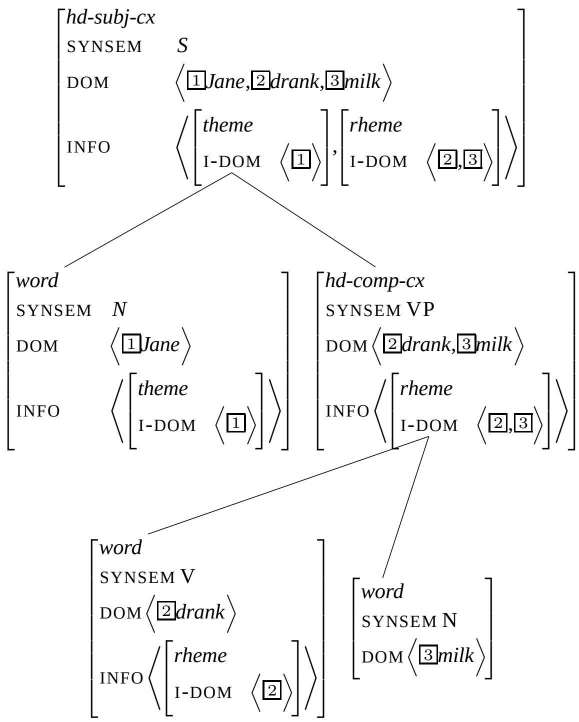


Figure 6: Syntactic/information-structural derivation of (13a)

$$\mathsf{mkMtr}^{full}\left(\left\langle \mathsf{mkMtr}^{full}\left(\left\langle \boxed{1}\right\rangle\right), \mathsf{mkMtr}^{full}\left(\left\langle \boxed{2},\boxed{3}\right\rangle\right)\right\rangle\right) =$$
$$\begin{bmatrix} \textit{mtr}(\textit{full}) & \\ \textsc{dom} & \left\langle \boxed{1}, \boxed{4}\begin{bmatrix}\textit{mtr}(\textit{full}) & \\ \textsc{dom} & \left\langle \boxed{2}, \boxed{3}\textit{milk}\right\rangle \\ \textsc{dte} \ \boxed{3} & \end{bmatrix}\right\rangle \\ \textsc{dte} & \boxed{4}\end{bmatrix}$$

We can again consider the play writing examples, which are shown in (21). Let us assume that these sentences roughly correspond to the semantic specifications represented in Figure 7. In fact, we present the semantic specifications that correspond to (21c). The difference between Figure 7 and the semantic specifications of (21a, b, d) is merely in the scope of theme/rheme (see section 3.4). (21e) is not marked for theme/rheme and gets the default prosodic constituency. (21c), therefore, receives the prosodic structure shown in (22). The cases of (21b, d) are similar.

(21) a. [I want]$_\theta$[to begin to try to write a play]$_\rho$.
b. [I want to begin]$_\theta$[to try to write a play]$_\rho$.
c. [I want to begin to try]$_\theta$[to write a play]$_\rho$.
d. [I want to begin to try to write]$_\theta$[a play]$_\rho$.
e. [I want to begin to try to write a play].

$$\begin{bmatrix} \textit{hd-subj-cx} & \\ \textsc{hd-dtr}\ \textit{want} & \\ \textsc{info}\ \textit{theme} & \\ \textsc{non-hd-dtrs} & \left\langle \begin{bmatrix}\textsc{hd-dtr}\ \boxed{1}\textit{I}\end{bmatrix}, \begin{bmatrix} \textsc{hd-dtr}\ \textit{begin} & \\ \textsc{non-hd-dtrs} & \left\langle \boxed{1}, \begin{bmatrix} \textsc{hd-dtr}\ \textit{try} & \\ \textsc{info}\ \textit{rheme} & \\ \textsc{non-hd-dtrs} & \left\langle \boxed{1}, \begin{bmatrix} \textsc{hd-dtr}\ \textit{write} & \\ \textsc{non-hd-dtrs} & \left\langle \boxed{1}, \begin{bmatrix} \textsc{hd-dtr}\ \textit{play} & \\ \textsc{non-hd-dtrs} & \langle\rangle \end{bmatrix} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix}$$

Figure 7: Basic semantics and information structure of (21c)

(22) $$\mathsf{mkMtr}\Big(\boxed{1}\Big\langle \textit{I, want, to, begin, to, try, to, write, a, play}\Big\rangle\Big)=$$
$$\mathsf{mkMtr}^{full}\Big(\textit{mkAllLnrs}\big(\boxed{1}\big)\Big)=$$
$$\mathsf{mkMtr}^{full}\Big(\Big\langle\big(\textit{I want}\big),\big(\textit{to begin}\big),\big(\textit{to try}\big),\big(\textit{to write}\big),\big(\textit{a play}\big)\Big\rangle\Big)=$$
$$\Big[\Big[\big(\textit{I want}\big)\big(\textit{to begin}\big)\Big]^{rfr}\Big[\big(\textit{to try}\big)\big(\textit{to write}\big)\big(\textit{a play}\big)\Big]^{fall}\Big]$$

(23) $$\Big[\big(\textit{I want}\big)\big(\textit{to begin}\big)\big(\textit{to try}\big)\big(\textit{to write}\big)\big(\textit{a play}\big)\Big]$$

Notice that because the lexical items are unmarked in (21e) with respect to their information status, the prosodic structure that emerges is flat as shown in (23). This is an example where we see that what is generally known as prosodic flattening follows naturally from this account and no special theoretical devices are required to derive that structure from a highly structured syntactic tree.

The case of (9a) is somewhat different from the others. In this example, the pronoun *I*, a leaner, forms its own prosodic phrase bearing the L+H* LH% intonation that corresponds to theme. According to our model, however, the feature TONE is not appropriate to *lnr* because leaners by definition need a prosodic word to attach to. This can be solved by introducing a lexical rule that type-shifts leaners when their INFO feature is marked. This is formulated as (24) below.

(24) ***lnr* Type-Shifting Rule**

$$\begin{bmatrix}\text{PHON} & \textit{lnr}\\ \text{INFO} & \textit{marked-info}\end{bmatrix} \Rightarrow \begin{bmatrix}\text{PHON} & \textit{p-wrd}\end{bmatrix}$$

Let us now discuss example (7) repeated below as (25).

(25) *[Three mathematicians] [in ten prefer margarine]

In Klein's model, this constituency simply does not arise because of PIH. In this model, we do not get the unacceptable constituency in (25) either because the informational status of one argument does not affect the other(s); i.e. if *prefer* is marked as theme and *margarine* as rheme, we still get the correct prosodic structure because the subject, *three mathematicians in ten*, inherits the theme status from *prefer*. However, one can think of a very implausible case that could give rise to (25) in our information-based analysis, and that is when *mathematicians* alone is marked as theme and *in ten* and *prefer* are marked as multiple rhemes. This information structure may not be felicitous in any context, but if it ever is, (25) will still be unacceptable because two different rhemes in (25) occur in the same IP. The correct prosodic structure that complies with the new definition of mkMtr is (26).

(26) [[Three mathematicians]$_\theta$ (in ten)$_\rho$ [prefer margarine]$_\rho$]

The above example brings us to our next set of data presented earlier in (8) repeated below as (27).

(27) a. [Jane gave the book to Mary]
b. [Jane] [gave the book to Mary]
c. [Jane gave the book] [to Mary]
d. [Jane gave] [the book] [to Mary]
e. * [Jane] [gave] [the book to Mary]
f. * [Jane gave] [the book to Mary]
g. [Jane] [gave the book] [to Mary]
h. [Jane] [gave] [the book] [to Mary]

According to our analysis, (27a) is considered the unmarked case. In (27b), *Jane* has been marked as theme and *gave* as rheme, which passes down this status to its arguments *book* and *Mary*. Furthermore, in (27c), *gave* has been marked as theme and *Mary* as rheme. As mentioned earlier, Selkirk (1984) attributes the ungrammaticality of (27e, f) to the violation of the Sense Unit Condition since *the book* and *to Mary* do not form a sense unit. We achieve the same effect in this approach by ISPC and assuming that no more than one information unit (i.e. theme/rheme) can be present in one IP. In other words, each intonation phrase corresponds to only one information unit. This is in line with our version of PIH. Such an analysis entails that in (27d, g, h), there are multiple themes or rhemes and those multiple themes or rhemes are reflected as separate IPs in phonology. (27e, f) are ungrammatical because *the book* and *to Mary* have different informational markings, i.e. theme/rheme, rheme$_1$/rheme$_2$ or the like. This condition also prevents (25) because the only way that *in ten* can be separated from *three mathematicians* is to have a different informational marking, which by ISPC could not be structure-shared with the informational marking of *prefer margarine*. Not only ISPC ensures that each information unit reflects the right intonation in phonology; together with the mkMtr function, they also provide an implementations of Selkirk's (1984) *Sense Unit Condition* without resorting to another level of representation and unnecessary complication of the theory.

As an example, let us look at the sentences in (27) again. (27d, g, h) have multiple themes or rhemes. The indexed *info* and its corresponding *tone* value ensure that multiple themes or rhemes are not mistakenly grouped together. (27c) receives the following prosodic and information structure if we assume that *give* and *book* are marked as multiple themes.

(28) [[Jane gave]$_{\theta 1}^{rfr1}$ (the book)$_{\theta 2}^{rfr2}$ (to Mary)$_{\rho 1}^{fall1}$]

Examples (27e, f) are automatically rejected because the two arguments of *give* are sisters of one another; therefore, they cannot bear the same information status by ISPC, and thus, cannot be in the same IP.

Another interesting consequence of the information-based account of prosody in a tripartite grammar architecture is the fact that an ill-formed prosodic structure like (29) never arises because of the way `mkMtr` has been defined and this relieves us from positing Klein's *Lexical Head Association Constraint*, which according to him is a partial implementation of Selkirk's end-based mapping.

(29) * [[this treasured] possession (of the samurai)]

this [treasured possession (of the samurai)]

4 Concluding Remarks

This paper started off with Klein's (2000) analysis of prosodic constituency in HPSG and extended it to account for some prosodic variation phenomena that are dependent upon the information structure of the sentence. Because a constraint-based approach to prosodic phenomena is employed here, we can capture some interesting linguistic generalities without recourse to *ad hoc* operational rules. In addition, the modular design of the theory allows for better readability and maintainability. The departure from a syntactocentric theory towards a tripartite one in terms of Jackendoff (2002) proved to be a promising approach as it captured a lot of the phenomena previously discussed in the literature in much simpler terms.

The most natural course of action to take from this point is to map all the other intonation forms with information structure in this approach and see what effects they have on the grammar overall. We should also try to find more constraints that syntax, semantics, or pragmatics impose on prosodic structure and even word order. For example, an account of heavy-NP shift and other similar phenomena in this model seems promising.

References

Asudeh, A. and L. H. Mikkelsen (2000). Incorporation in Danish: Implications for interfaces. See Cann et al. (2000), pp. 1–15.

Bing, J. (1970). *Aspects of English Prosody*. Ph. D. thesis, University of Massachusetts.

Bird, S. (1990). *Constraint-Based Phonology*. Ph.D. thesis, University of Edinburgh.

Bird, S. (1995). *Computational Phonology: A Constraint-Based Approach*. Studies in Natural Language Processing. Cambridge: Cambridge.

Bird, S. and E. Klein (1991). Phonological analysis in typed feature systems. *Computational Linguistics 20*(3), 455–491.

Borsley, R. D. and A. Przepiórkowski (Eds.) (1999). *Slavic in Head-Driven Phrase Structure Grammar*. Studies in Constraint-Based Lexicalism. Stanford: CSLI.

Butt, M. and T. H. King (1998). Interfacing phonology with LFG. In M. Butt and T. H. King (Eds.), *Proceedings of the LFG98 Conference*, Stanford, CA. CSLI. http://csli-publications.stanford.edu/LFG/3/butt-king/butt-king.html.

Cann, R., C. Grover, and P. Miller (Eds.) (2000). *Grammatical Interfaces in HPSG*. Studies in Constraint-Based Lexicalism. Stanford: CSLI.

Cooper, W. and J. Paccia-Cooper (1980). *Syntax and Speech*. Cambridge, Mass.: Harvard University Press.

De Kuthy, K. (2002). The information structure of discontinuous NPs in German. In L. H. van Eynde, Frank and D. Beermann (Eds.), *Proceedings of the 8th International HPSG Conference*, Stanford, pp. 148–161. Norwegian University of Science and Technology: CSLI.

Engdahl, E. and E. Vallduví (1994). *Information Packaging and Grammar Architecture: A Constraint-Based Approach*, Volume 1.3.B of DYANNA-2 Report, pp. 41–78. Amsterdam: ILLC.

Höhle, T. N. (1999). An architecture for phonology. See Borsley and Przepiórkowski (Eds.) (1999), pp. 61–90.

Jackendoff, R. (1997). *The Architecture of the Language Faculty*. Linguistic Inquiry: Monograph Twenty-Eight. Cambridge, Mass.: MIT Press.

Jackendoff, R. (2002). *Foundations of language: Brain, Meaning, Grammar, Evolution*. New York, NY: Oxford.

Kahane, H. and R. Beym (1948). Syntactical juncture in colloquial Mexican Spanish. *Language 24*, 388–396.

Kathol, A. (1995). *Linearization-Based German Syntax*. Ph.D. thesis, Ohio State University.

Kathol, A. (2000). *Linear Syntax*. Oxford University Press.

Klein, E. (2000). Prosodic constituency in HPSG. See Cann et al. (2000), pp. 169–200.

Ladd, D. R. (1996). *Intonational Phonology*. Cambridge Studies in Linguistics. New York: Cambridge.

Penn, G. (1999a). A generalized-domain-based approach to Serbo-Croatian second position clitic placement. In G. Bouma, E. Hinrichs, G. Kruijff, and R. Oehrle (Eds.), *Constraints and Resources in Natural Language Syntax and Semantics*, Studies in Constraint-Based Lexicalism, pp. 119–136. Stanford: CSLI.

Penn, G. (1999b). Linearization and WH-extraction in HPSG: Evidence from Serbo-Croatian. See Borsley and Przepiórkowski (Eds.) (1999), pp. 149–182.

Penn, G. and M. Haji-Abdolhosseini (2003). Topological parsing. In *Proceedings of the 10th Conference of the European Chapter of the Association for Computational Linguistics*, pp. 283–290.

Pierrehumbert, J. (1980). *The phonology and phonetics of English intonation*. Ph.D. thesis, MIT. published 1988 by IULC.

Pollard, C. and I. Sag (1994). *Head-Driven Phrase Structure Grammar*. Studies in Contemporary Linguistics. Chicago: CSLI.

Prevost, S. (1995). *A semantics of contrast and information structure specifying intonation in spoken language generation*. Ph.D. thesis, University of Pennsylvania.

Prevost, S. and M. Steedman (1994). Specifying intonation from context for speech synthesis. *Speech Communication 15*, 139–153.

Pulgram, E. (1970). *Syllable, Word, Nexus, Cursus*. The Hague: Mouton.

Reape, M. (1994). Domain union and word order variation in German. In J. Nerbonne, K. Netter, and C. J. Pollard (Eds.), *German in Head-Driven Phrase Structure Grammar*, Number 46 in CSLI Lecture Notes, pp. 151–197. CSLI Publications.

Selkirk, E. O. (1981). On prosodic structure and its relation to syntactic structure. In T. Fretheim (Ed.), *Nordic Prosody II: Papers from a Symposium*, pp. 111–140. Trondheim: Tapir.

Selkirk, E. O. (1984). *Phonology and Syntax: The Relation between Sound and Structure*. Cambridge, MA: MIT Press.

Steedman, M. (1991). Structure and intonation. *Language 25*(2), 193–247.

Steedman, M. (2000a). Information structure and syntax-phonology interface. *Linguistic Inquiry 31*(4), 649–689.

Steedman, M. (2000b). *The syntactic process*. Cambridge, MA: MIT Press.

Vallduví, E. and E. Engdahl (1996). The linguistic realization of information packaging. *Linguistics 34*, 459–519.

Yoshimoto, K. (2000). A bistratal approach to the prosody-syntax interface in Japanese. See Cann et al. (2000), pp. 267–281.

Zwicky, A. M. (1982). Stranded *to* and phonological phrasing. *Linguistics 20*, 3–57.