Phonological Parsing

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Abstract

This paper presents a declarative formulation of a metrical theory of Dutch word stress using phrase structure rules. Metrical trees are encoded as binary-branching headed phrase structure trees, and complex feature structures are used to encode phonological information. Standard parsing algorithms may be used to implement a phonological parser. A notation is developed which allows concepts from metrical theory to be encoded in a transparent, intuitive fashion.

1 Introduction

This paper discusses an approach to Dutch word stress which is based on METRICAL PHONOLOGY, but uses PHRASE STRUCTURE GRAMMAR (PSG) as a vehicle for implementation, as suggested by Coleman (1990, 1991, 1992). The motivation for such an approach is both theoretical and practical. From a theoretical point of view, phrase structure rules define well-formed representations in a strictly declarative fashion, removing the need to specify in procedural terms how rules and general principles interact to assign an analysis to an utterance (the INTERACTION PROBLEM, see Scobbie 1991). Also, a phrase structure approach to phonology makes it easier to define the interface between phonology and other components of the grammar, e.g. morphology and syntax. From a practical point of view, a PSG can be used with standard parsing algorithms in applications such as text-to-speech conversion. There is no need for special-purpose syllabification and foot construction algorithms, thus making it easier to evaluate different versions of a theory.

Below, we examine how a fairly standard analysis of Dutch word stress (based largely on an introductory textbook by Trommelen & Zonneveld 1989) can be encoded as a PSG. We limit our attention to underived words, so as not to complicate matters too much. Also, we will pay little attention to the internal structure of sub-syllabic units such as *onset*, *nucleus* and *coda*.

It should be noted that the phrase structure rules presented below are preliminary in that they do not yet constitute a full grammar, and are subject to continuous improvement. As

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a consequence, a detailed evaluation of these rules (i.e. by parsing a large set of data) is beyond the scope of this paper. Also, the question of how exactly the techniques developed here can be made useful in an application environment is not taken up, even though the matter is of considerable interest. The main goal of our case study, then, is to examine what mechanisms are needed to encode the phonotactics of underived words and to assign (primary and secondary) stress in a declarative, transparent fashion.

The structure of this paper is as follows. First, in Section 2 we deal with the question of how to suitably represent metrical trees. Next, Section 3 discusses features and general constraints on feature sharing. We then proceed with a case study of Dutch word stress (Section 4) and how to deal with exceptions (Section 5). Finally, Section 6 summarizes the results and briefly discusses the necessity of filters and other devices.

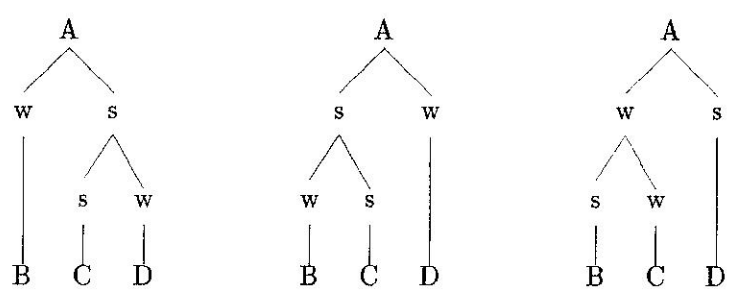
2 Metrical trees

Metrical trees are used to encode both Syntagmatic and Paradigmatic aspects of sentence- and word-level prosody (Ladd 1991). In this section, we will clarify these notions and develop a notation which allows us to define metrical structure by means of phrase structure rules.

Syntagmatic aspects, or Prosodic Prominence relations, are accounted for by labeling the nodes of a binary-branching tree as either *weak* or *strong*. A *strong* node is more prominent than its *weak* sister. Alternatively, one may say that a *strong* node serves as the Prosodic Head of a structure. In order to represent the syntagmatic aspects of metrical trees in terms of phrase structure rules, what is needed is a convenient notation for binary-branching headed constituents. We will use two binary operators '/' and '\', such that (A / B) or (B \ A) identifies **B** as the head of the category that immediately dominates it (Dirksen 1992). Using this notation, we might write rules such as those in (1) and (2).

(1)a	$A \rightarrow (B \ / \ C).$	(2)a	$A \rightarrow (B \ / \ (C \backslash D)).$
b	$A \rightarrow (B \backslash C).$	b	$A \rightarrow ((B \ / \ C) \backslash D).$
c	$A \rightarrow B.$	c	$A \rightarrow ((B \backslash C) \ / \ D).$

The rules of (2) encode the (partial) metrical trees shown below. Note that in (2)a and b, **C**



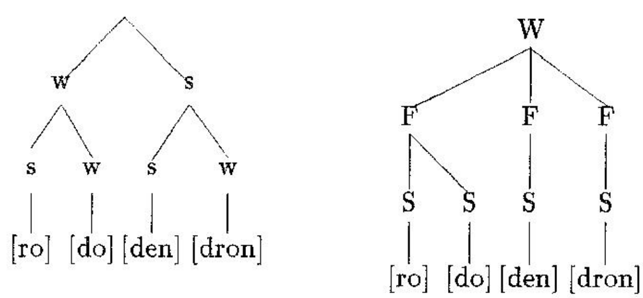
is the prosodic head of **A**, whereas in (2)c, **D** is the head of **A** and **B** is a local head of the sub-structure [**B C**].

Paradigmatic aspects of metrical trees include prosodic constituency and phonological features such as [±**stress**]. It is assumed that prosodic constituents are formed in accordance with the Prosodic Hierarchy (e.g. Nespor & Vogel 1986), which orders prosodic categories from higher to lower-level units, as indicated (in simplified form) in (3).

(3) phrase > word > foot > syllable > segment

The elements of the prosodic hierarchy represent layers of metrical structure, in such a way that each element of level n dominates one or more elements of level $n-1$ or lower. That is, segments are grouped into syllables according to the rules of Metrical Theory, and syllables are grouped into prosodic feet, which in turn are grouped into phonological words, and so on. In terms of phrase structure rules, the prosodic hierarchy translates into a number of subgrammars, such that the terminal nodes in the level n grammar are root nodes of a lower-level grammar.

As an example of the difference between syntagmatic and paradigmatic aspects of metrical structure, consider the two representations below of the Dutch word **ro-do-dén-dron** *rhododendron*, shown from a syntagmatic point of view on the left, from a paradigmatic one on the right. In the paradigmatic representation, the head/non-head distinction is indicated by a vertical/non-vertical line respectively. It can easily be seen that these trees encode different



kinds of information. For example, the tree on the left treats **[do]** and **[dron]** equally as *weak* syllables, while the tree on the right tells us that **[do]** is the weak (unstressed) syllable of a foot, while **[dron]** is analyzed as a foot (hence as stressed). On the other hand, the right-hand tree tells us little about the internal make-up of the word tree, except that the second foot is the head, and thus receives the main stress. That is, the paradigmatic representation is *iterative* rather than *recursive*. It is interesting to note the close similarity between the paradigmatic representation and the so-called BRACKETED GRID NOTATION used by Halle & Vergnaud (1987). The similarity can be brought about by replacing prosodic constituents with "beats", aligning higher-level beats with lower- level heads, and placing brackets around constituents, as shown below.

		$\star$	
($\star$		$\star$	$\star$)
($\star$	$\star$)	($\star$)	($\star$)
ro	do	den	dron

To the extent that grids are more adequate than (standard) metrical trees as representations of rhythmic properties of utterances (as is often suggested), our paradigmatic trees will do just as well, and we will use them as graphic representations of metrical trees throughout this paper. However, as an *internal* representation (i.e. a representation that is assigned by a parser in accordance with a set of phrase structure rules) we assume one that combines syntagmatic and paradigmatic properties. The combined representation allows us to derive both the syntagmatic, relational tree and the paradigmatic, grid-like representation. The former is derived by pruning labels and unary nodes, the latter by eliminating recursive nodes.

3 Head and non-head features

We will use boolean features such as [±**stress**] to encode phonological information other than prosodic category, and unification of (possibly complex) feature structures (Shieber 1986) to implement general constraints on metrical structure: the HEAD CONSTRAINT and the PERIPHERY CONSTRAINT.

Each prosodic category may select one or more features as *head* features of that category. The distribution of these features is governed by the Head Constraint, such that if two categories **A** and **B** select a feature as a head feature, and **B** is the prosodic head of **A**, then **A** and **B** share the value for this feature. For example, if the feature *stress* is defined as a head feature of the categories **A** and **B**, then rule (4)a describes a situation which can never arise as it is inconsistent with the Head Constraint. In rule (4)b, on the other hand, the value [+**stress**], assigned to **A**, is automatically shared with **B**.[1]

(4)a A:[+stress] → (B / C:[−stress]). b A:[+stress] → (B \ C:[−stress]).

The Head Constraint allows us to account for the distribution of schwa in underived words, simply by limiting its occurrence to unstressed syllables. That is, we assume that schwa is introduced in the grammar by rule (5), and no other rule.

(5) nucleus:[−stress] → schwa.

The structure defined by rule (5) might serve as the prosodic head of **C** in rule (4)b, but it cannot be analyzed as the prosodic head of **B**. Note that rule (5) does not imply that unstressed syllables are necessarily headed by schwa, as other rules may introduce full vowels in both stressed and unstressed syllables (see below).

Another application of the Head Constraint is found in the interaction between pitch accent and word stress. A pitch accent is assigned at the word or phrase level if a word/phrase is *focused* (Ladd 1980, Baart 1987, Dirksen 1992). It is interpreted phonetically at the syllable level (i.e. as a "rise" and/or "fall"), on the condition that the syllable which realizes the pitch accent serves as the prosodic head of the accented word/phrase and is stressed. This is accounted for by assuming that *accent* is a head feature of the entire range of categories defined by (3) and is thus shared among these categories in accordance with the Head Constraint. The interaction with the feature *stress* is formalized by the rules in (6).

(6)a [+accent] ⇒ [+stress] b [−stress] ⇒ [−accent]

These rules are interpreted in the following manner: if a category **X** has the feature specification on the left-hand side of (6)a and b (rather than being unspecified for the feature, or oppositely specified), then **X** must also match the feature specification on the right-hand side. Thus, the combination of the two head features *accent* and *stress* yields three possibilities:

[1] While it is the task of a grammar writer to specify which features are head features of a prosodic category **X**, it is the job of a parser (or, alternatively, a rule compiler) to guarantee that these features are shared in accordance with the Head Constraint.

+accent	+stress	accented word/syllable
−accent	+stress	stressed word/syllable
−accent	−stress	unstressed word/syllable

These features also allow us to account for effects on syllable duration: syllables which are marked [**+accent**] have a greater temporal extent than those which are marked [**−accent**], whereas unstressed syllables, i.e. syllables which are marked [**−stress**], are temporally as well as spectrally reduced.

The Periphery Constraint is an auxiliary device used to account for subregularities in metrical-phonological rules, which are normally associated with peripheral elements of a domain, for example the initial/final foot or syllable of a phonological word. To implement this constraint, we use the *non-head* features *ini*tial and *fin*al, whose distribution is such that non-initial and non-final elements of a phonological word are marked [**−ini**] and [**−fin**], respectively. This allows us to write a rule of the form **A:[+ini] → ...**, which is blocked unless the category **A** occurs word-initially.[2]

Together, the Head Constraint and the Periphery Constraint allow us to define metrical structure by means of compact, non-redundant phrase structure rules.

4 A case study of Dutch

Having done these preliminaries, we can turn our attention to Dutch word stress. In this section, we will define a set of phrase structure rules for each prosodic category and indicate how our rules implement metrical universals (with their parameters set for Dutch) as well as language-specific details.[3]

The first rule in our grammar is a rule with no left-hand side. Its right-hand side is used to initialize the parser and defines the interface with higher-level components, i.e. syntactic and morphological processors.

(7) → word:[+ini, +fin, +stress].

The rule in (7) defines a phonological word as having a left and right periphery and (whether accented or not) at least one stressed element. The next three rules define the word tree as consisting of one or more feet, each of which is stressed (i.e. Dutch feet are iterative).

(8)a word → (foot:[+stress] / word).
b word → (foot \ foot:[+stress, +em]).
c word → foot:[−em].

According to these rules, the final foot serves as the prosodic head of the word tree unless it is marked [**+em**], in which case the pre-final foot receives the main stress. The feature *em* is used to accommodate "late" extrametricality of final syllables, and needs some explanation.

It is assumed that in poly-syllabic words the final syllable is marked "extrametrical". This is formalized by the rule in (9).

(9) syl:[−ini, +fin] ⇒ [+em]; [−em].

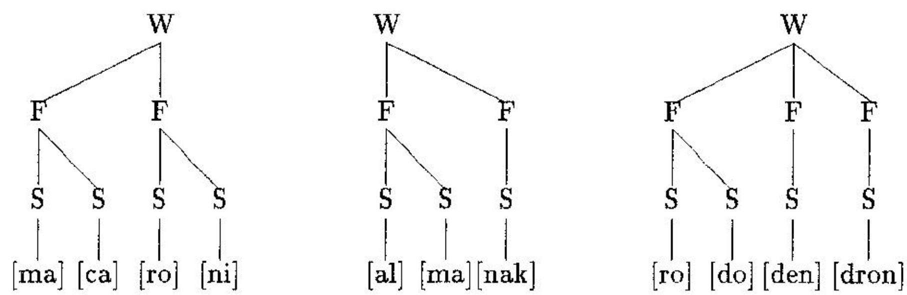
[2]It is the job of a parser or rule compiler to enforce the Periphery Constraint.

[3]See Coleman (1991) for a parameter-based analysis of metrical universals in a GPSG-style framework. Also, Dresher & Kaye (1990) discuss metrical parameter-setting in a machine-learning context.

This rule is similar to those of (6), except that it specifies [−**em**] as a *default* (that is, the construction **x** ⇒ **y**; **z** reads: if **x** then **y**, else **z**)).

As to the effects of the feature *em*, a distinction is made between "early" and "late" extrametricality. In English, extrametricality is invoked "early": a syllable which is marked [+**em**] is not incorporated into a foot by the foot construction rules, but adjoined as a *weak* node to the word tree. In Dutch, on the other hand, extrametricality is invoked "late": a syllable which is marked [+**em**] is treated like any other syllable by the foot construction rules. Assuming that *em* is a head feature, a (non-initial, final) foot is marked [+**em**] if it dominates a (non-initial, final) syllable which is marked [+**em**] and which is also a head. As we will see below, this situation arises only in the case of a mono-syllabic foot which dominates a heavy syllable (one with a **VC** rime). Rule (8)b specifies that such an extrametrical foot is adjoined as a *weak* node to the word tree, receiving a (secondary) stress.

Some examples of how the rules in (8) apply to derive the emphword tree (**W**) are shown below: the word **ma-ca-ró-ni** *macaroni* is formed by applying (8)a followed by (8)c; **ál-ma-nak** *almanac* is formed by applying (8)b; **ro-do-dén-dron** *rhododendron* is formed by combining (8)a and b. The internal structure of the categories *foot* (**F**) and *syl*lable (**S**) is derived by applying the rules in (10) and (11), to be discussed shortly.



Moving down one level in the prosodic hierarchy, we will now define the foot. From a parameter-setting point of view, the Dutch foot is characterized as maximally binary rather than unbounded (i.e. a foot consists of either one or two syllables), left-dominant (the first syllable of a foot is the prosodic head) and quantity-sensitive (subject to syllable weight restrictions). The weak syllable of a binary foot is unstressed. This is formalized by the two rules in (10). Note that in (10)a, the head is always in a non-final position, hence [−**em**].

(10)a foot → (syl \ syl:[−heavy, −stress]).
  b foot → syl:[+heavy].

Also, feet are built in a right-to-left fashion, which in non-procedural terms means that an initial light syllable may remain that cannot be incorporated into a foot by the rules of (10) (see also Coleman 1991:71–72). Such a syllable is assigned to a "defective" foot by a special rule, (10)c.

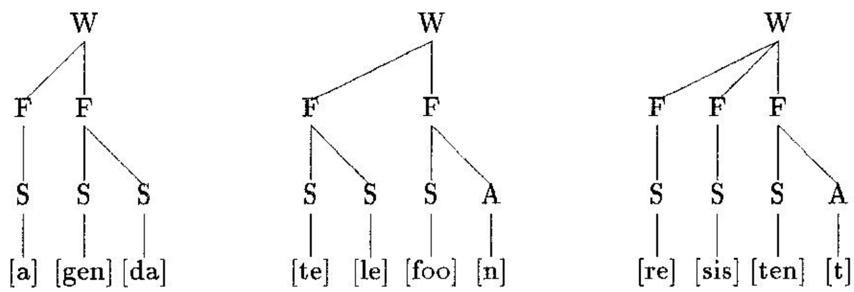
(10)c foot:[+ini] → syl:[−heavy].

Finally, in addition to light and heavy syllables (see below), Dutch allows so-called "super-heavy" syllables, which are restricted to word-final positions and always attract the main stress. Several analyses of these super-heavies are found in the literature. Here, we will adopt one along the lines of Kager & Zonneveld (1986), which allows a final mono-syllabic foot to contain extra *appendix* consonants.[4] This is formalized by adding the following rule.

(10)d foot:[+fin] $\rightarrow$ (syl \ app).

One immediate advantage of this analysis is that a foot which is formed according to (10)d is always [$-$**em**]: the mere presence of the *appendix* causes the head to be analyzed as [$-$**fin**], barring extrametricality. As a result, no further stipulations are necessary to account for the fact that a foot formed according to (10)d must carry the main stress.

Some examples involving all rules of (10) are shown below: the word **a-gén-da** *agenda* is formed by (10)c and (10)a, **te-le-fóon** *telephone* by (10)a and (10)d, **re-sis-tént** *resistant* by (10)c, (10)b and (10)d.



Syllables in Dutch are either heavy or light, depending on whether or not the rime branches. More precisely, the structure of the rime is either **VV** (i.e. a long vowel or diphthong) or **VC** (a short vowel followed by a consonant). In our grammar, this is modeled by using two features *heavy* and *long*. The feature *heavy* is a head feature of the categories *syl*lable and *rime*, the feature *long* is a head feature of *vowel* and *nucleus*. The rules of (11) and (12) illustrate the use of these features.

(11)a syl $\rightarrow$ (onset / rime). b syl $\rightarrow$ rime.

(12)a rime:[+heavy] $\rightarrow$ (nucleus:[$-$long] \ coda).
b rime:[$-$heavy] $\rightarrow$ nucleus:[+long].

We will not attempt to fully characterize the sub-syllabic units *onset*, *nucleus* and *coda* in terms of phrase structure rules, as the complexities involved are beyond the scope of this paper. Instead, we will make do with a simplified characterization of the onset, defined by the phrase structure rules in (13).

(13)a onset:[+ini] $\rightarrow$ ("s" / onset).
b onset $\rightarrow$ (cons:[$-$son] / cons:[+son, +cont]).
c onset $\rightarrow$ cons.

The first rule, (13)a, allows an extrametrical consonant **s** in word-initial positions. Rule (13)b states that a complex onset consists of an obstruent followed by liquid, of which the latter

[4] We will not go into the details of the internal structure of the appendix. Note, however, that the use of this category makes it somewhat more difficult to formulate correctly sonority restrictions applying to the rime.

serves as the head. Rule (13)c accommodates the case of an onset consisting of a single consonant, or a single consonant following word-initial **s**. The characterization in (13) is incomplete in that it generates more than is attested in Dutch and also excludes some less productive possibilities, but this will be disregarded for the purposes of this paper.

Summarizing, a handful of strictly declarative phrase structure rules suffices to define the internal structure of Dutch underived words in a fairly transparent manner as a specific instance of a small number of parameter-settings, together with some language-specific properties. Most of the work is done by the Head Constraint and the Periphery Constraint, implementing generic constraints on feature percolation, thus avoiding redundancy in our rules.

One small problem remains, however, concerning the distribution of schwa. According to rule (5), schwa is neither a long nor a short vowel, but merely restricted to unstressed syllables, whether heavy or light. More generally, unstressed syllables allow for vowel reduction, which is both optional and gradient in Dutch, whereas stressed syllables normally do not. On the other hand, in our grammar all syllables are stressed, except weak syllables of binary feet, which are always [−**heavy**]. As a result, a schwa is accepted in the second syllable of **te-le-fóon** *telephone*, which is correct, but we incorrectly predict that a schwa or a reduced vowel cannot occur in the second syllables of **tem-pe-ra-túur** *temperature*, **la-bo-ra-tó-ri-um** *laboratory* or **con-ser-va-tiéf** *conservative*, or in the second and third syllables of **cor-res-pon-dént** *correspondent*. In these latter examples a full vowel is allowed, but there is a strong tendency towards vowel reduction in fast or casual speech.[5] Trommelen & Zonneveld (1989) account for this tendency by assuming optional rules for DEFOOTING and RHYTHMIC READJUSTMENT. As the names suggest, these rules destructively modify representations, an option which is not allowed in declarative systems. However, the effect of these rules can be approximated by phrase structure rules such as the one in (14).

(14) foot:[−head, −fin] → ((syl \ syl:[−stress]) \ syl:[−stress]).

This rule allows a "rhythmic" foot to occur in non-final positions, provided it is not a prosodic head.[6] However, we have done nothing to enforce rhythmic feet, thus retaining their optionality.[7] Some examples involving rule (14) are shown below. Note that the internal structure of the first foot (i.e. the fact that its stress pattern is **2-4-3** rather than **2-3-4**) is not brought about in these paradigmatic representations.

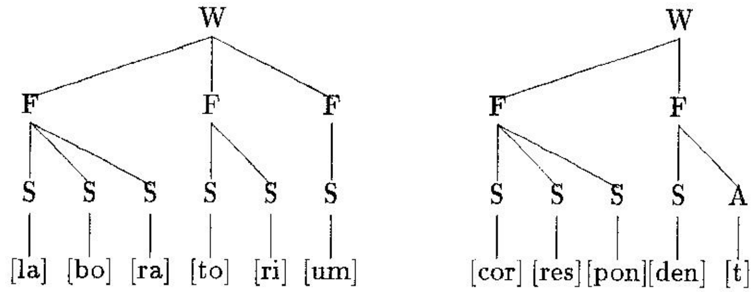
5 Dealing with exceptions

As in any system, we need to deal with (apparent) exceptions to the regularities expressed in the grammar. Interestingly, there are many subregularities to be found in Dutch underived

[5] In fact, contrary to what our grammar predicts the second syllable in these words reduces more easily than the third as shown by the following contrasts: **la-be-ra-tó-ri-um**, **la-be-re-tó-ri-um**, but ***la-bo-re-tó-ri-um**. We also incorrectly predict that an initial light syllable in a word like **ba-náan** *banana* cannot reduce, as such a syllable is assigned to a foot by rule (10)c, hence is stressed. However, a discussion of the murky details of vowel reduction in Dutch is beyond the scope of this paper, so we leave it as a problem for further research. For an interesting analysis see Van Zonneveld (1982).

[6] The distribution of the feature [±**head**] is taken care of by the Head Constraint.

[7] A *preference* for rhythmic stress patterns can be accounted for by ordering rule (14) before the rules of (10), or by any other means of making a non-deterministic parser generate solutions in an ordered fashion, according to well they match "optimality" constraints (Prince & Smolensky 1993).



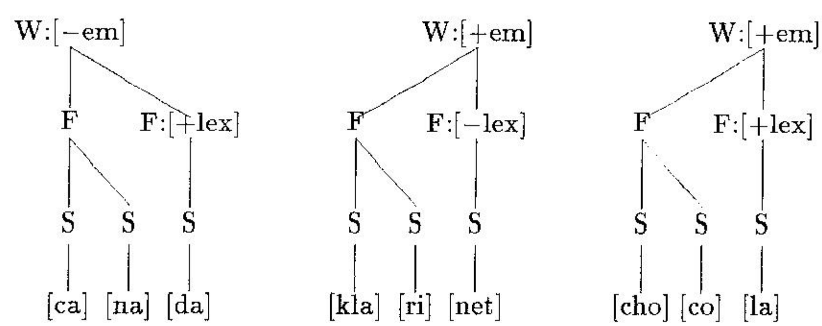
words. Here, we discuss two such subregularities, both of which involve the final syllable. Examples are **cá-na-da** *Canada* rather than the fully regular form **ca-ná-da**, **kla-ri-nét** *clarinet* rather than **klá-ri-net**. In the first case, the stress pattern would count as regular if the final syllable could somehow be analyzed as a foot rather than as the weak syllable of a foot. In the second case, the final syllable "behaves" as if it were a super-heavy syllable or a branching foot.

These exceptions can be accounted for by relaxing some of the constraints in our grammar rules, in such a way that non-regular stress patterns are generated in addition to the fully regular ones. The **cá-na-da** type is accounted for by adding rule (15) to the foot construction rules.

(15) foot:[+fin, +lex] $\rightarrow$ syl:[−heavy].

The feature specification [**+lex**] (for "lexical foot") serves to mark the exceptional nature of this rule. It is assumed that [**−lex**] is added to the other foot construction rules as a default. The **kla-ri-nét** type is accounted for by allowing exceptions to extrametricality. That is, the feature specification [**−em**] is removed from rule (8)c. Instead, the feature [**±em**] is shared between the categories *word* and *foot* in accordance with the Head Constraint. We can now make a distinction between the "normal" case, which is represented by **word:**[**−em**], and a "marked" case, represented by **word:**[**+em**], which applies to words of the **kla-ri-nét** type.

The acid test for this analysis is a prediction that one may find words in which a lexical foot is also an exception to extrametricality. And indeed, examples such as **cho-co-lá** *chocolate* instead of **cho-có-la** occur, albeit less frequently (Trommelen & Zonneveld 1989:92–94). Some examples of how the two features may be combined are shown below.



Presumably, these exception features are defined in the lexicon, along with grammatical category and other information which cannot be predicted by rule. Their use amounts to a claim that, even if the main stress cannot be predicted, secondary stresses are always regular.

Our grammar, modified as indicated above, now characterizes "marked" as well as "unmarked" stress patterns. Still, as the marked patterns are identified as such by appropriate feature specifications, it cannot be said that the grammar overgenerates, nor that it suffers from spurious ambiguity. Rather, when the grammar is used by a parser to analyze a word, a "candidate set" of well-formed structures is produced, from which an application must make an informed selection.

6 Conclusion

The notational devices used in this paper allow us to state phonological rules in a fairly transparent, declarative way, with as little redundancy as possible. Still, our notation differs only marginally from the notations employed in other versions of PSG, and none of the devices used is necessarily specific to Metrical Phonology. For example, the "slash" notation used to encode metrical structure may well be used to encode syntactic or morphological headedness, and similar considerations apply to the other types of rules.

On the other hand, it should be noted that our PSG is somewhat less modular than the parameter-oriented theory that it encodes. One area where a higher-level description seems desirable is stress assignment. As a general rule, *weak* nodes of the word tree receive a (secondary) stress, whereas the *weak* nodes of a *foot* are unstressed. So, if this is a general rule, why not state it just once? Instead, we have assigned stress directly in the phrase structure rules, and though we have followed the general rule, the fact that it is a general rule is not expressed as such in the grammar.

Also, although it is theoretically possible to characterize *all and only* the well-formed metrical trees strictly in terms of phrase structure rules, it is not always practical to do so, and additional mechanisms are needed. For example, our grammar allows both **ze-bra** *zebra* and ***zeb-ra** (but not ***zeeb-ra** or ***zebr-a**, due to the restriction of "super heavy" syllables to word-final position). In order to exclude ***zeb-ra**, we need to assume for Dutch that a consonant cluster which can be analyzed as an *onset*, cannot be analyzed any other way (cf. Kager 1989:200). Such a negative statement requires the use of a FILTER, formalized in (16). (The construction **x** • **y** requires **x** and **y** to be *string-adjacent*).

(17) *coda:[−son] • cons:[+son, +cont].

The filter states that if a coda dominates an obstruent it cannot be followed by a liquid or glide. Assuming that the filter applies within the domain of a phonological word, this excludes ***zeb-ra** as well as ***zebr**, where the second consonant is an appendix consonant.

More generally, filters provide a practical mechanism to encode (language-specific) constraints on syllable structure and syllabification, so we should include them in our repertoire. Also, structure-changing phonological processes can often be given a declarative formulation by leaving certain positions unspecified or underspecified in the phrase structure rules, and using FEATURE-FILLING RULES to (further) specify these positions (Scobbie 1991, Local 1992).

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