10. The Metrical Theory of Word Stress

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0 Introduction

0.1 Remarks on the Nature of Stress

The study of word stress addresses the location of prominent syllables within words, as well as the rhythmic, positional, quantitative, and morphological factors that govern patterns of syllable prominence. Although the mental reality of prominence is undisputed, an unambiguous phonetic correlate has not yet been discovered. Prominent syllables are potentially capable of bearing pitch movements with a strong perceptual load. They also tend to be of longer duration, as well as of higher intensity, but both of the latter factors are usually subordinated to pitch. On the other hand, the use of pitch is by no means an exclusive property of stress systems, as it is widespread in tonal and pitch accent systems. However, stress is different from both tone and pitch accent in several ways.

Firstly, stress is culminative, that is, in stress languages (with few exceptions) every (content) word has at least one stressed syllable. Second, stress is hierarchical, since a prominence hierarchy may occur among multiple stresses. Third, stress is delimitative in systems where it marks word edges. Fourth, stress is rhythmic in systems where stressed and stressless syllables alternate, and where clashes (adjacent stresses) are avoided. Naturally, stress does not assimilate to adjacent syllables, as this would produce clashes. Fifth, stress contrasts tend to be enhanced segmentally: stressed syllables may be strengthened by vowel lengthening or by gemination, while stressless syllables may be weakened by vowel reduction.

Traditionally, word stress systems have been categorized along various dimensions. One distinction is between fixed systems, where the location of stress is predictable (that is, rule-governed), and free systems, where it is unpredictable (that is, distinctive). A second distinction is that between systems where stress is governed purely by phonological factors such as distance from word edges, rhythmic factors, and syllable weight, and systems where it is governed by morphological factors, such as the distinction between roots and suffixes. A third distinction is that between bounded systems, where stresses fall within limited distances from each other and from word edges, and unbounded systems, where no constraints on interstress distance hold.

We outline below developments in the metrical theory of word stress over the past decade. On the empirical side, this implies a narrowing to those aspects of word stress that have been most closely studied for their theoretical relevance, and some inevitable neglect of other aspects.

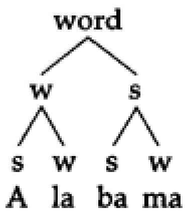
0.2 The Origins of Metrical Theory

Metrical theory arose during the late seventies as part of nonlinear phonology, the research program of which autosegmental phonology is the other main branch. Founded by Liberman (1975), and elaborated on by Liberman and Prince (1977) and Halle and Vergnaud (1978), metrical theory shared with its autosegmental counterpart the goal of developing alternatives to the nonlocal devices of linear theory, such as rule variables and abbreviatory conventions. To that end, hierarchical representations were defined, on which processes involving nonadjacent elements could be formalized as local operations. From the beginning, word stress has been the central empirical domain of metrical phonology, although the theory has also been applied to nonstress phenomena such as vowel harmony and syllable structure.

0.2.1 The Metrical Tree

A central idea of metrical theory is to capture the hierarchical nature of stress in a representation of its own, outside the segmental matrix that includes other features. In the metrical tree, stress is represented as a hierarchy of binary branching structures, each of which is labeled *strong-weak* (*sw*) or *weak-strong* (*ws*). Consider the metrical tree of the word *Alabama*, in (1).

(1)



Stress, as represented in the metrical tree, is a *relational* property: a node is strong only by virtue of the fact that it is the sister of a weak node. Thus in (1), the first syllable is stronger than the second, while the third is stronger than the fourth. The superior nodes are themselves in a weak-strong relationship, which represents the relative prominence of the first and third syllables.

0.2.2 Metrical Grids

While the metrical tree displays the relative prominence of nodes, it fails to represent rhythmic alternation between strong and weak syllables, as well as clash, a situation which occurs when adjacent syllables are stressed. Liberman (1975) introduced the metrical grid as a representation of rhythmic structure. The grid corresponding to the tree in (1) is (2):

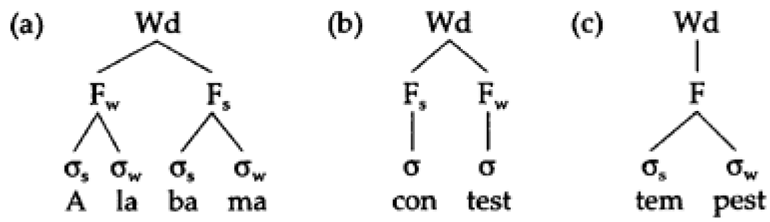
(2)

The height of the grid columns represents the degree of prominece. Thus in (2) the third syllable is the most prominent, the initial one is less prominent by one degree, while the second and fourth are the least prominent. The grid perspicuously depicts the rhythmic alternation of strong and weak syllables. Early metrical theory derived the grid from the tree by a mapping rule, which imposes a prominence relation between syllables dominated by pairs of sister nodes.

0.2.3 Prosodic Categories and the Foot

Purely relational trees without feet, as in (1), fail to represent *non*relational stress contrasts that may actually be found in trees of identical shape. Such a contrast occurs between the final syllables of pairs such as *cóntest* vs. *témpest*, whose strong-weak trees are indistinguishable. Thus, purely relational trees do not provide a uniform representation of stressed syllables. For this purpose, Liberman and Prince (1977) retained a segmental stress feature. Aiming at a fully metrical theory, Halle and Vergnaud (1978) and Selkirk (1980) introduced the foot as a categorial label into trees. Each foot has a unique head (its strong, or only syllable), and optional weak syllables. This introduction allowed the elimination of segmental stress features, since the distribution of stressed syllables coincides with that of *heads* of feet. Consider the enriched trees in (3):

(3)



The foot is included in a hierarchy of prosodic categories ranging upward from the syllable (σ), the foot (F), the prosodic word (Wd), to still higher categories (see chapters 15 and 16, this volume). The hierarchy is closed, in that every category of level *n* must be dominated by some category of level *n+1*. An exhaustivity condition requires every syllable to be included in metrical structure. Since the word *Wd* dominates at least one foot *F*, every word must have a stressed syllable (culminativity).

Independent evidence for feet was found in their function as a domain for segmental rules. Selkirk (1980) observed that some consonantal allophones in English are conditioned by feet; for example, aspirated alveolar stops occur foot-initially, their flapped allophones foot-medially (cf. t^hówDəl, t^howt^hæIIDi). Nespor and Vogel (1986) adduce a large number of cases from other languages.

1 Classical Metrical Theory

Metrical theory was given a substantial body of principles in Hayes (1980), elaborating on earlier versions of parametric stress theory such as Prince (1976), Halle and Vergnaud (1978), and McCarthy (1979), and on typological work by Hyman (1977) and Odden (1979). Hayes broadened the scope of metrical theory to include a large number of typologically widely varying systems, while shifting the focus of the theory to a small number of parameters. In this parametric approach, grammars fall apart into a *core* and a *periphery*. Core grammars consist of a set of rule specifications, defined by values of parameters that are provided by Universal Grammar. Limiting the number of parameters constrains the expressive power of the theory, which is desirable from the perspective that grammars can be learned.[1] Stress systems turned out to be a highly successful testing ground for the parametric approach.[2]

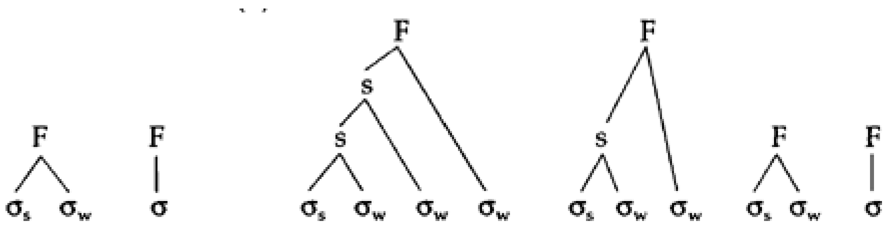
1.1 Basic Parameters of Word Stress

Parameters govern the shape of metrical feet, the way in which feet are assigned, as well as metrical structure above the feet. We start our review with footshape parameters.

1.1.1 Boundedness

A major distinction can be drawn between systems in which stresses fall within limited distances both from each other and from word edges, and systems where the distribution of stresses is not restricted in this way. The relevant parameter of *boundedness* has two values bounded and unbounded. Bounded feet contain no more than *two syllables*, while unbounded feet are not subject to any restrictions on size. We illustrate this with head-initial feet, in (4).

(4) (a) Bounded feet (b) Unbounded feet

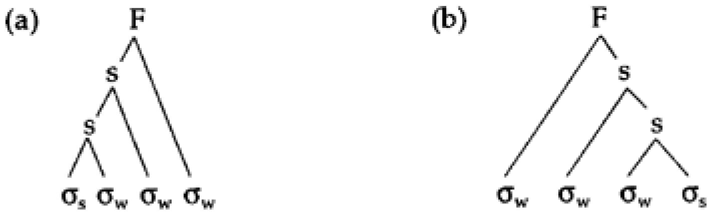


Feet are always uniformly right-branching or left-branching. Foot construction is constrained by a universal Maximal Foot Construction Principle, which ensures that the largest possible foot must be constructed. Monosyllabic expansions, or degenerate feet, are motivated both by culminativity and by exhaustivity. By culminativity, every content word must contain one stressed syllable, hence one foot. A monosyllable cannot fulfill this requirement unless its single syllable forms a degenerate foot. By exhaustivity, all syllables of a word must be organized into feet. Words whose syllables cannot all be parsed in maximal feet (such as words with an odd number of syllables which are parsed into bounded feet) require the help of degenerate feet to parse the remaining syllables. See section 1.2 below.

1.1.2 Foot Dominance

The second foot-shape parameter, *foot dominance*, determines the side of the foot where the head is located. It achieves this indirectly, through the notions dominant and recessive node. In left-dominant feet, all left nodes are dominant and right nodes recessive, while the reverse situation holds in right-dominant feet. Universally, recessive nodes may not branch, so that left-dominant feet must be left-branching, and right-dominant feet right-branching. The unmarked foot-labeling principle marks all dominant nodes as strong, as in (5), but we will see below the justification for keeping the dominant/recessive distinction separate from the strong/weak distinction.

(5)

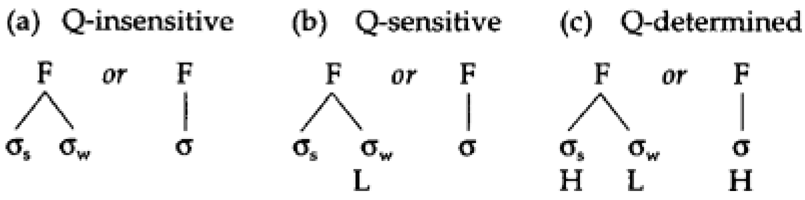


In informal terminology, which we will occasionally use in following sections, bounded left-dominant feet are called *trochees*, and bounded right-headed feet are called *iambs*.

1.1.3 Quantity-sensitivity

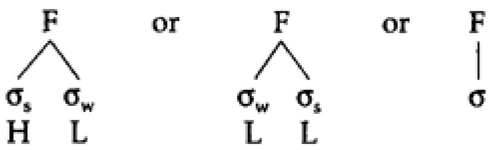
The third foot shape parameter, *quantity-sensitivity*, governs the distribution of light and heavy syllables in terminal nodes of feet. In quantity-*insensitive* feet, no restrictions hold, so that all syllables are treated as light (or equally heavy). In quantity-*sensitive* feet, heavy syllables may not occur in recessive positions, and are stressed. Quantity-*determined* (or Obligatory Branching) feet are quantity-sensitive, with the extra requirement that dominant terminal nodes must dominate heavy syllables. The three types are shown below with left-dominant, bounded feet in which dominant nodes are strong. We indicate heavy syllables as H, and light syllables as L in (6). Where either H or L is indicated, the template indicated refers specifically to patterns possessing the requisite H or L; when a simple σ is indicated, the template is appropriate for either an H or L syllable, with the more specific template taking precedence over the more general, in this informal presentation.

(6)



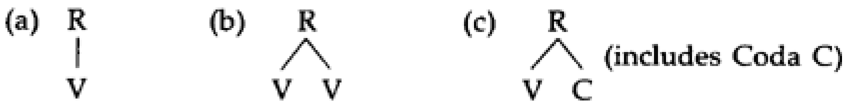
We made reference above to an unmarked labeling convention. Here we observe the marked convention, according to which dominant nodes are marked as strong *iff* they dominate a branching node (heavy syllables count as branching, as we will see shortly). This produces one more quantity-sensitive foot, the *Labeling Based on Branching* (LBOB) foot. Its left-dominant version is in (7).[3].

(7)

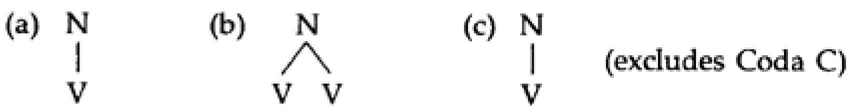


In the geometrical spirit of early metrical theory, Hayes proposes that syllable weight is tied essentially to whether certain syllable-internal constituents do or do not branch. The constituents in question are the *rhyme* and the *nucleus*.[4] Foot construction inspects branchingness on one of two projections. On the rhyme projection (8), both long-voweled and closed syllables are heavy, as opposed to open short-voweled syllables. On the nucleus projection (9), long-voweled syllables are heavy as opposed to all others.

(8)



(9)



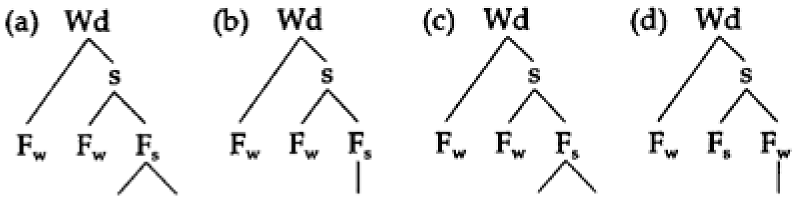
1.1.4 Directionality and Iterativity

Next we consider the parameters of foot construction. One parameter of *directionality* determines the direction in which foot construction scans the stress domain: starting at the right edge (right-to-left), or at the left edge (left-to-right). As a rule of thumb, construction starts at the word edge where the stress pattern is invariant, while at the other edge it systematically varies with the number of syllables in the word. By a second parameter of *iterativity*, feet are constructed iteratively or noniteratively. In noniterative systems, words have a single foot at the edge. *Bidirectional* systems result from noniterative foot assignment at one edge, and iterative foot assignment starting at the opposite side.

1.1.5 Word Tree Dominance: Branching and Labeling

Finally, let us turn to the parameters of the *word tree*, the supra-foot structure governing prominence hierarchies among stresses. The word tree branches uniformly, and its labeling is derived indirectly, much as at foot-level. The *dominance* parameter has two values: *left*-dominant and *right*-dominant. Again, the unmarked convention labels dominant nodes strong, placing main stress on a peripheral foot (10a, b). The marked rule labels dominant nodes strong if and only if they branch, so that nonbranching dominant feet are weak (10c, d). This is illustrated with right-dominant word trees in (10).

(10)



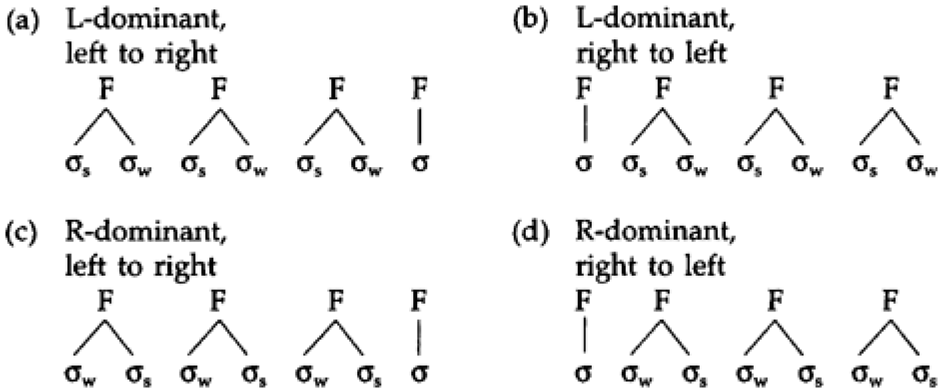
Word-level labeling may refer to the internal structure of feet, but never to that of syllables. More generally, the *Metrical Locality* principle (Hammond 1982) states that rules may refer only to elements at the same or adjacent layers of metrical structure.

1.2 Exemplification of Bounded Systems

1.2.1 Quantity-insensitive Bounded Systems

Four quantity-insensitive bounded patterns arise by varying the parameters of dominance and directionality, as in (11).

(11)



Hungarian (Kerek 1971) exemplifies (11a). Main stress is initial and secondary stresses fall on all odd-numbered syllables. A left-dominant word tree produces initial main stress, as in (12).

(12)

(a) bóldog	"happy"
(b) bóldogsàig	"happiness"
(c) bóldogtàlan	"unhappy"
(d) bóldogtàlansàig	"unhappiness"
légešlègmegèngestèlhetètlenèbbeknèk	
	"to the most irreconcilable ones"

Warao (Osborn 1966) exemplifies (11b). Main stress is on the penultimate syllable, and secondary stresses on even-numbered syllables counting backward from the main stress:

(13)

(a) yà.pu.rù.ki.tà.ne.há.se "verily to climb"
(b) e.nà.ho.rò.a.hà.ku.tá.i "one who caused him to cat"

The word tree is right-dominant. Words such as (13b) require an additional rule to delete initial degenerate feet in weak positions (such *destressing* rules are discussed in section 1.5).

The pattern of (11c) is attested in Araucanian (Echeverría and Contreras 1965), where main stress is on the second syllable, and secondary stresses on following even-numbered syllables. The word tree is left-dominant, and weak degenerate feet are deleted, as in Warao. See (14).

(14)

(a) e.lú.a.è.new "he will give me"
(b) ki.mú.fa.lù.wu.lày "he pretended not to know"

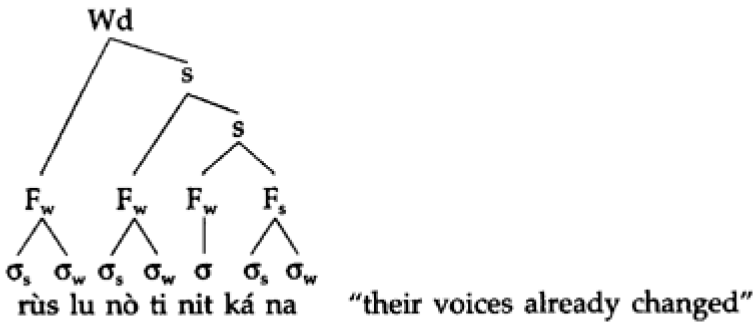
The pattern of (11d) occurs in Weri (Boxwell and Boxwell 1966). Main stress is on the final syllable, and secondaries are on preceding odd-numbered syllables counting from the word end. The word tree is right-dominant. See (15).

(15)

(a) ul'ùamít "mist"
(b) àkunètepál' "times"

Piro (Matteson 1965) is a *bidirectional* system. Main stress is on the penult, and secondary stresses are on odd-numbered syllables counting from the word begining. Quantity-insensitive trochees are assigned noniteratively at the right edge, and then iteratively from left to right:

(16)



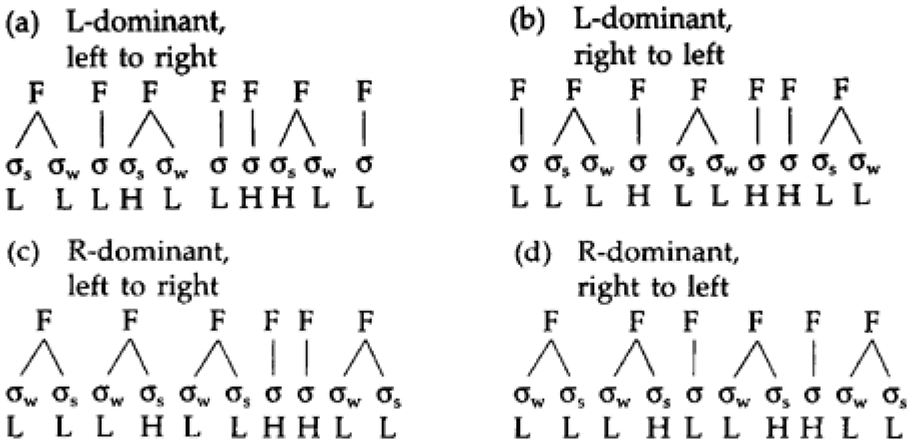
The word tree is right-dominant, and the weak degenerate foot preceding the main stress foot is eliminated.

In all systems discussed so far, main stress falls at the edge where foot construction starts. Hammond (1985) states this in his Directionality Dominance Hypothesis, according to which the first application of foot assignment uniquely determines word tree dominance.[5] The Directionality Dominance Hypothesis seems to be falsified by Creek (Hayes 1981) and Cairene Arabic (McCarthy 1979), where rightward foot construction combines with a right-dominant word tree. Hammond, observing that both systems lack overt secondary stresses, suggests that main stress and secondary stresses are on distinct parallel metrical planes, a situation which renders them immune to the Directionality Dominance Hypothesis. However, overt secondary stresses running towards the main stress do occur in systems such as Wargamay (Dixon 1981) and Cayuga (Foster 1982), which seems to reduce the Directional Dominance Hypothesis to a statement regarding frequency, rather than a firm metrical universal.

1.2.2 Quantity-sensitive Bounded Systems (Uniform Labeling)

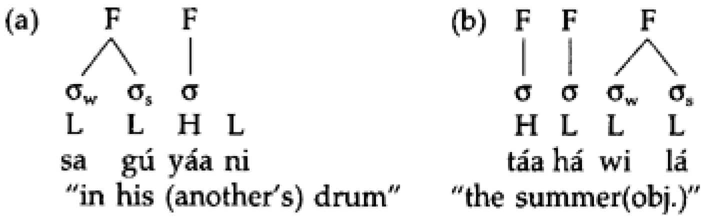
Four types of quantity-sensitive bounded systems result from Dominance and directionality:

(17)



Central Siberian Yupik (Jacobson 1985) has rightward iambs (the final syllable is never stressed, see section 1.4 on extrametricality) (see 18a), while Tübatulabal (Voegelin 1935) has leftward iambs (see 18b).

(18)



Both languages seem to lack prominence distinctions between stresses, which is accounted for by not assigning a word tree. Iterative quantity-sensitive trochaic systems are extremely rare, an observation to which we will return in section 5.1. A noniterative example is Latin, as we see in section 1.4.1.

1.2.3 Bounded Labeling-Based-on-Branching Feet

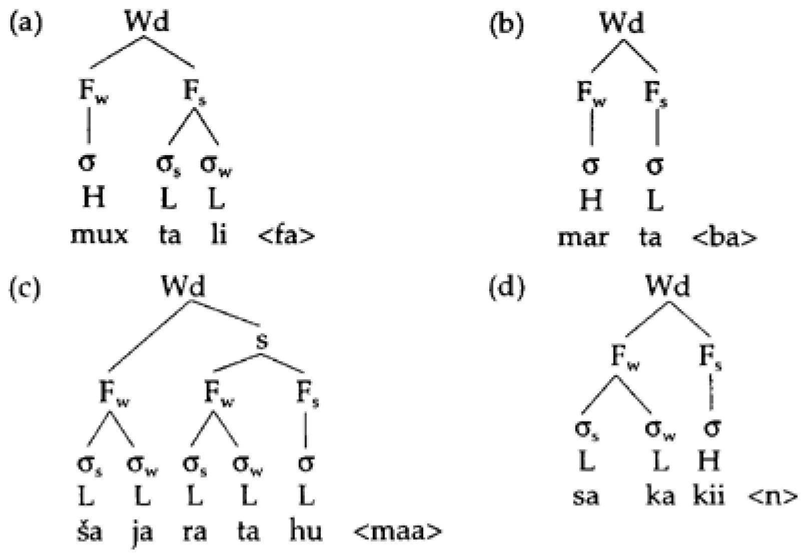
In Cairene Arabic (McCarthy 1979), main stress is (a) on final *superheavy* syllables (CVVC, CVCC), else (b) on heavy penults (CVV, CVC), or else (c) on the rightmost nonfinal odd-numbered light syllable counting from the nearest preceding heavy syllable or the intial syllable; see (19).

(19)

(a) sakakíin "knives"	(e) muxt´lifa "different (fem. sg.)"
(b) qamálti "you (fem. sg.) did"	(f) šajarátuhu "his tree"
(c) martába "mattress"	(g) šajaratahúmaa "their (dual) tree (nom.)"
(d) búxala "misers"	

McCarthy analyzes superheavy syllables into a heavy syllable plus a degenerate syllable which is the final consonant. The absence of final stress is analyzed by making final syllables invisible to the stress rules (by extra-metricality, see section 1.4 below). Word stress is located by assigning right-dominant Labeling-Based-on-Branching feet from left to right, and building a right-dominant word tree, as in (20).

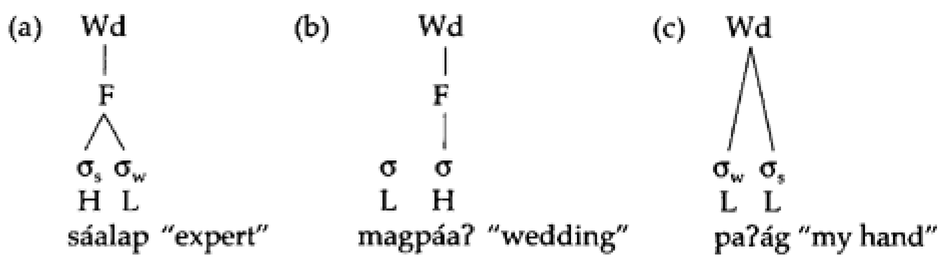
(20)



1.2.4 Obligatory Branching (OB) Feet

Yapese (Jensen 1977) has final stress except in words whose final vowel is short and whose penultimate vowel is long. A bounded left-dominant Obligatory Branching (OB) foot at the right edge of the word produces this pattern. In (21c) we have a word that has no heavy syllables, and thus no OB foot can be constructed; as a result, a right-dominant word tree is constructed directly over syllables; see (21).

(21)



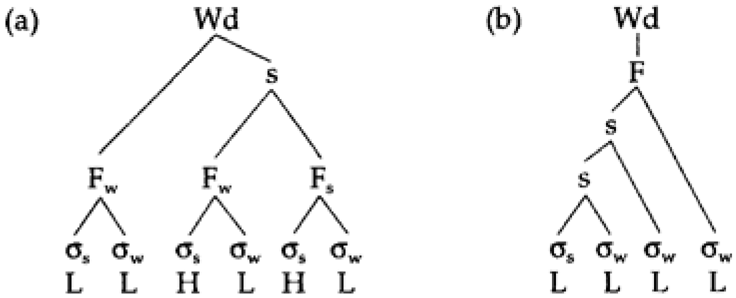
The mirror-image pattern of Yapese occurs in Malayalam (Mohanan 1986).

1.3 Exemplification of Unbounded Systems

There are three basic types of unbounded systems, default-to-opposite, default-to-same and peripheral-plus-heavies.

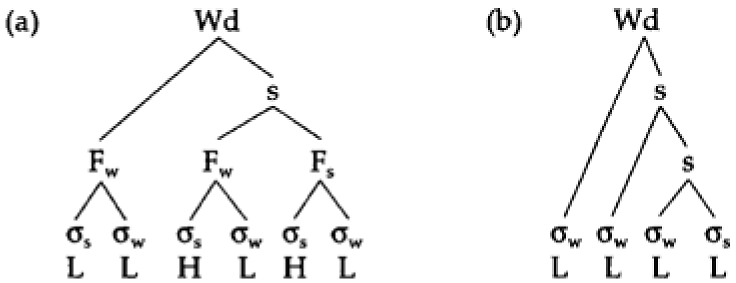
Default-to-opposite systems stress a heavy syllable closest to an edge, else (in words without heavy syllables) the syllable at the opposite edge. They occur in two mirror-image variants: Eastern Cheremis (Sebeok and Ingemann 1961) stresses the rightmost heavy, else the initial syllable, while Komi Jazva (Kiparsky 1973a) stresses the leftmost heavy, else the final syllable. Prince (1976) introduced an analysis based on unbounded quantity-sensitive feet, which are left-dominant when stress defaults initially, and right-dominant when it defaults finally. Word tree dominance is of opposite parity to that of feet in such a language; see (22), which represents the analysis of Eastern Cheremis.

(22)



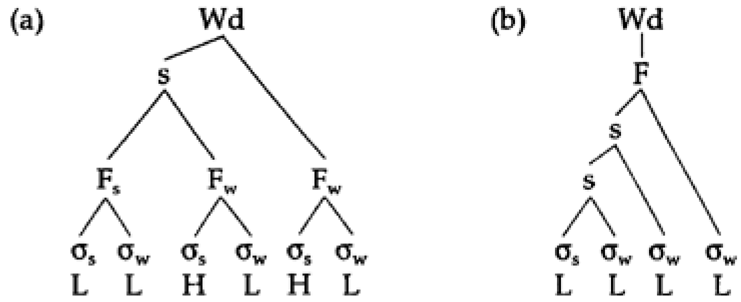
Default-to-same systems stress a heavy syllable closest to an edge, else the syllable at the same edge. Again, two mirror-image variants occur. Aguacatec Mayan (McArthur and McArthur 1956) stresses the rightmost heavy syllable, else the final syllable, Khalka Mongolian (Street 1963) the leftmost heavy syllable, else the initial syllable. Halle and Vergnaud (1978) employ unbounded Obligatory Branching feet. In words that have no heavy syllables, and hence no feet, the word tree is constructed directly over syllables. Word tree dominance matches the default side, as in (23), which represents the analysis of Aguacatec Mayan.

(23)



Peripheral-plus-heavies systems stress a peripheral syllable and all heavy syllables. The mirror-image variants are initial main stress plus heavies (Papago, see Saxton 1963), and final main stress and heavies (Western Greenlandic Eskimo, see Schultz-Lorentzen 1945). Here, the dominance of feet and word trees match, as shown in (24), which represents the analysis of Papago.

(24)



1.4 Extrametricality

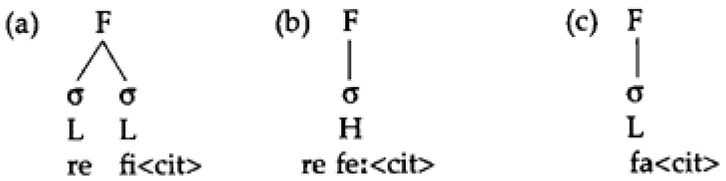
The concept of *extrametricality*, introduced by Liberman and Prince (1977), became a cornerstone of metrical theory in Hayes (1981). Extrametrical elements are not analyzed by the metrical stress rules, neither regarding its structural descriptions nor its structural change; informally speaking, rules may be said to be “blind” to extrametrical elements, and those extrametrical elements may be said to be “invisible” to the rules. Extrametricality is restricted to peripheral elements, and has three types of motivation: (a) at word edges, it avoids foot types that are otherwise rare or not found; (b) it functions to analyze stresslessness of peripheral syllables, and (c) it marks exceptions to the stress rules.

1.4.1 Motivating Extrametricality

Extrametricality helps to constrain foot typology in bounded systems that stress the third syllable from the edge. Cross-linguistically, *ternary* feet are relatively rare in nonperipheral positions (but see sections 4.2.3 and 5.4), and extrametricality theoretically eliminates them in favor of *binary* feet.

In Latin, stress is antepenultimate if the penult is light (*réficit*), else penultimate (*reféicit, reféctus, fácit*). The pattern is generated by making final syllables extrametrical and by assigning a quantity-sensitive trochee at the right edge. We indicate extrametricality by angled brackets:

(25)



Hayes claims that extrametricality allows the elimination of ternary feet in languages like Latin and English, universally restricting the class of bounded feet to binary feet.[6]

Extrametricality's second function can be illustrated with Hopi (Jeanne 1982). Hopi has second syllable stress (manifested as high tone) in words whose initial syllable is light, and initial stress otherwise. But disyllabic words have initial stress regardless of the weight of the initial syllable:

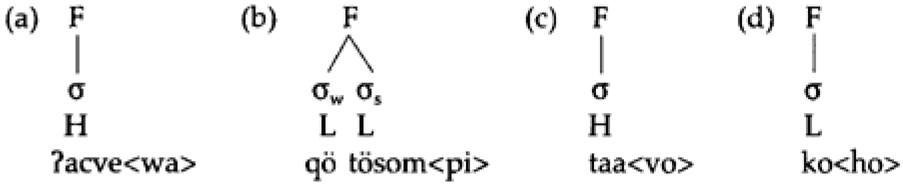
(26)

(a) ?ácvewa “chair” (b) qötösompi “headband”

(c) táávo “cottontail” (d) kóho “wood”

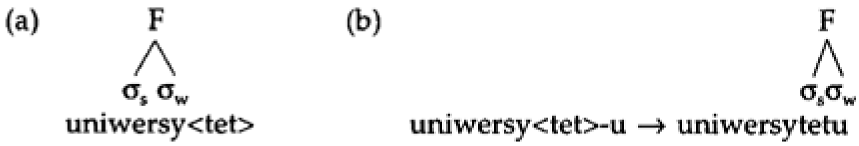
Both quantity-sensitive troches and iambs fail to produce this pattern. However, final syllable extrametricality leads to a simple analysis with a quantity-sensitive iamb at the left edge, as in (27); this illustrates how final extrametricality may affect foot construction at the opposite edge.

(27)



Finally, extrametricality as an exception-marking device can be illustrated with Polish (Franks 1985), where main stress is penultimate except for a small number of words, such as *uniwérsytet* “university”, which have antepenultimate stress. Interestingly, the addition of a suffix leads to regular penultimate stress, as in *uniwersytét+u*. This is explained by the assumption that extrametricality markings are lost automatically in nonperipheral positions, as illustrated in (28b):

(28)



Segment extrametricality is motivated by systems that have different criteria for syllable weight in final and nonfinal positions. In Estonian (Prince 1980) nonfinal CVV and CVC syllables are heavy. But in final position, only CVV(C) and CVCC are heavy. By consonant extrametricality, CV(C) is formally nonbranching, hence light, but CVC(C) is still formally branching.

1.4.2 Constraining Extrametricality

Extrametricality is subject to the following constraints (Hayes 1981): (a) Only phonological or morphological constituents, such as the segment, syllable, suffix, etc., can be extrametrical. (b) A Peripherality Condition requires extrametrical elements to be at the edge of the stress domain. Harris (1983) deviates from this in his analysis of Spanish, where the stem is the domain of segment extrametricality, but the word is the stress domain. Archangeli (1986) solves a similar problem in Yawelmani by transferring extrametricality from the stem, in which it is lexically marked, to the stress domain. (c) The *right* edge is the unmarked (and perhaps only) edge where extrametricality may occur. (d) Nonperipheral extrametricality is automatically erased (as in 28b). Kiparsky (1985) argues that extrametricality can be persistent even when temporarily suppressed by nonperipherality, and is lost only at the end of the lexicon.[7] Inkelas (1989) construes extrametricality as a mismatch between morphological and prosodic structures of words in the lexicon, as in (29).

(29)

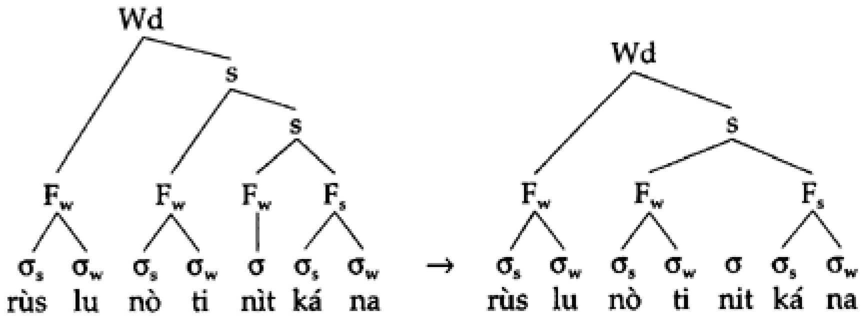
[Pame]$_{n}$ la prosodic structure
[Pamela]$_{M}$ morphological structure

She argues that peripherality, nonexhaustivity, and postlexical erasure of extrametricality are consequences of this domains approach. (e) Finally, extrametricality is blocked when it would affect the entire domain (e.g., a monosyllable), which guarantees culminativity.

1.5 Destressing and Stray Syllable Adjunction

In section 1.2, we discussed systems that required a rule to eliminate excessive stresses produced by foot construction. Destressing is implemented as foot deletion in foot-based theory. Consider again Piro, where weak degenerate feet are deleted, as in (30).

(30)



The output of destressing in (30) violates the prosodic exhaustivity requirement. Metrical theory assumes that repair is automatic, in the form of a universal convention of Stray Syllable Adjunction. Hayes suggests that Stray Syllable Adjunction is structure-preserving: the dominance of derived feet matches the system's parametric value, when possible. In (30) this makes the stray syllable adjoin leftward under the preceding foot. Where this is impossible, stray syllables are adjoined directly under the word tree.

Foot deletion renders the surface pattern stress opaque with respect to foot assignment rules. Familiar considerations of learnability thus necessitate constraints on destressing rules, an example of which is Hayes's condition that destressing may not affect the main stress foot.

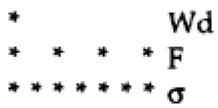
2 Grid Theory

Tree theory came under attack when Prince (1983) and Selkirk (1984) introduced a pure grid theory. They showed that rhythmic notions such as *alternation* and *clash* are best represented in grids. They also argued that metrical theory is simplified by eliminating constituency altogether, since parametric theory can be stated equally well in terms of pure grids.

2.1 The Autonomous Metrical Grid

The grid is a hierarchical representation of stress and rhythm, and in its purest form eliminates reference to the notion of constituency. It consists of a sequence of columns of grid marks, whose height represents *prominence levels*, while horizontal distance between marks represent *rhythmic structure*. All syllables are represented by a mark at the lowest layer, stressed syllables by a mark on the next layer up, while distinctions between main and secondary stresses are represented on still higher layers. Grid layers roughly correspond to the categorial levels (σ, F, Wd) of tree notation, as indicated vertically alongside the grid in (31).

(31)



Let us now focus on some formal properties of grid notation: (1) The grid represents stress as a hierarchical rather than a relational property. (2) Grid structure is subject to a constraint that forms the analogue of the closed prosodic hierarchy in tree theory:

(32) *Continuous Column Constraint* (after Hayes 1994)
A grid containing a column with a mark on layer $n + 1$ and no mark on layer n is ill-formed.

Phonological rules are blocked when they would create such a configuration.

(3) Culminativity is not a formal consequence of the grid, whereas it follows from the prosodic hierarchy in tree theory. Deriving culminativity in grid theory would require an ad hoc principle to the effect that every grid has at least one Foot layer mark, and another to the effect that the highest layer consists of only one mark. (4) Rhythmic notions are defined in grids quite adequately: *clash* as the adjacency of two marks on layer *n* without an intervening mark on layer *n–1* (as in 33a); *lapse* as a sequence of marks on layer *n*, none of which has a corresponding mark on layer *n+1* (as in 33b); *alternation* as a sequence of marks without clash or lapse (as in 33c). (5) The grid allows for straightforward implementation of the delimitative aspects of word stress. By definition, End Rules affect peripheral marks, and so does extrametricality.

(33)

The autonomous grid requires parametric construction principles, which, as van der Hulst (1984) shows, fully match up to those of tree theory in descriptive capacities.

2.2 Parameters of Grid Theory

2.2.1 Quantity-sensitivity

Prince (1983) introduces a mora-based approach to quantity-sensitivity (on the mora, see chapter 5, this volume). The moraic representation he proposes consists also of marks organized in rows. In the grid, a light syllable is represented with one mark at the mora layer, a heavy syllable with two (this is referred to as *bipositional* representation). The characteristic sonority decline between the moras of heavy syllables, interpreted as falling prominence, is projected on the Foot layer by a rule called *Quantity-sensitivity* (QS):

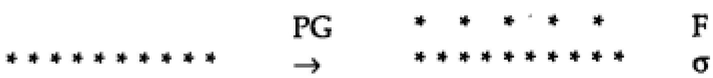
(34)

Thus grid theory marks heavy syllables as *inherently* stressed. In contrast, tree theory marks heavy syllables as stressed only if they are heads of feet, and unfooted heavy syllables are stressless.

2.2.2 Perfect Grid

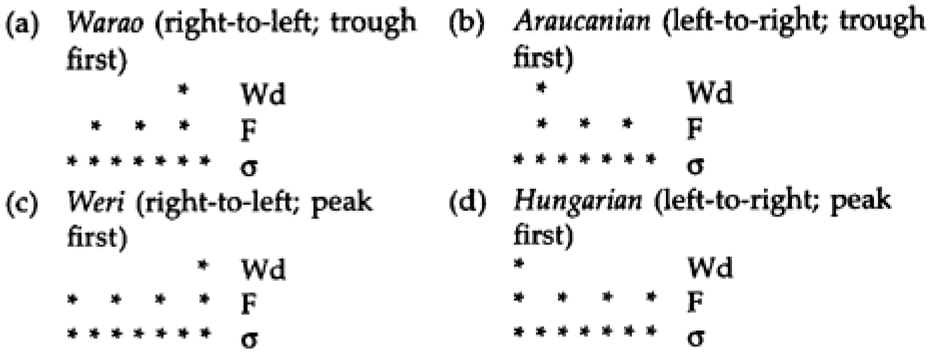
The best illustration of the rhythm-based nature of grid-only theory is its treatment of iterative bounded systems by the rule of Perfect Grid. Perfect Grid (PG) provides the rhythmic basis of such systems by adding a Foot layer mark on top of every other syllable layer mark:

(35)



Perfect Grid is governed by two parameters. *Directionality* fixes its starting point at the left or right edge. A *starting* parameter makes Perfect Grid start either with a rhythmic *peak*, or with a rhythmic *trough*. This generates the four basic quantity-insensitive systems of section 1.2.1, as illustrated in (36).

(36)



Starting with a trough at the right edge, or with a peak at the left edge, produces “trochaic” rhythm (36a, d). Starting with a trough at the left edge, or with a peak at the right edge, produces “iambic” rhythm (36b, c). Thus Perfect Grid makes a notion such as *trochaic* stress rule undefinable, since the starting edge has to be taken into account. By the strictly alternating clash-avoiding nature of Perfect Grid, no additional rules are needed to eliminate analogues of degenerate feet in clashing positions. Compare (36a) to (11b), and (36b) to (11c).

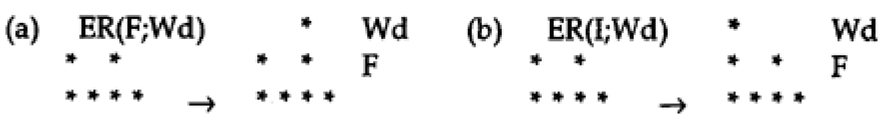
Since Perfect Grid only fills out portions of the grid that have been left blank by the rule Quantity-sensitivity, quantity and rhythm become separate notions. In contrast, tree theory intergrates both into the concept of *Foot*.

2.2.3 End Rules

End Rules place a mark on top of a mark that is peripheral on the next layer down. A particular instance of End Rule must be specified for which row of the grid it applies to; we may say it is “parameterized” in that respect. When applying to the Foot layer, or row, End Rule produces edge stresses, but its common function is to assign main stress at Word layer by promoting a Foot layer mark to word prominence. *Dominance* specifies whether to select the rightmost (ER(F)), or leftmost (ER(I)) landing site, which is to say, whether the leftmost or the rightmost stress has the greatest prominence in the word; see (37).

End Rules are constrained by the Continous Column Constraint. Thus, for a mark to be inserted at a layer, a landing site has to be present in the form of a mark at the next layer down.

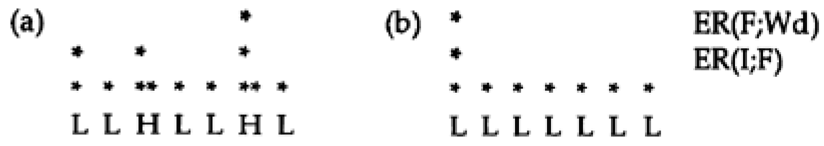
(37)



2.2.4 Unbounded Systems

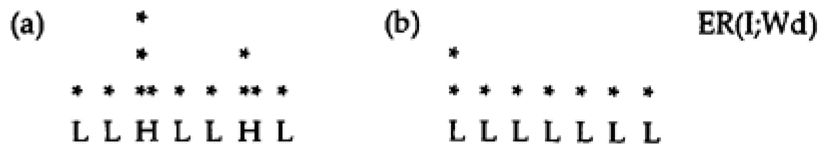
The analysis of unbounded systems is based on two devices: Quantity Sensitivity (QS) and the End Rule (ER). *Default-to-opposite* systems require an End Rule at Foot layer, and another at Word layer at the opposite edge. The “rightmost heavy, else initial” type is defined by the rule set QS, ER(I;F), ER (F;Wd):

(38)



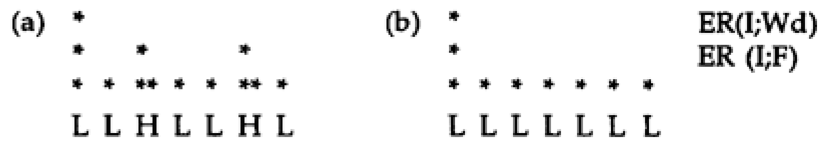
For *Default-to-same* systems, tree theory constructs the word tree over syllables without intervening feet in the default case (see section 1.3.2). Analogously, in grid theory, the End Rule defaults one layer down if no proper Foot layer landing site is found, as in (39).

(39)



Peripheral-plus-heavies systems require End Rules at Foot and Word layers, at identical edges, as in (40)

(40)



2.3 Operations on Grids

Grid theory shows its rhythm-based nature in its formalization of destressing and rhythmic stress shifts. Such processes become simple operations (deletions, insertions, movements) of grid marks, triggered by illformed grid configurations such as clash or lapse. We will review these operations here.

2.3.1 Delete x

Destressing rules can be written in a simple format: *Delete x*. Three advantages come from this. (a) This is a local operation, requiring no deletion of a prosodic category, nor stay adjuction. (b) The triggering clash is directly represented. A dominance parameter specifies whether to delete the first or the second of two clashing grid marks, as in (41). (c) The integrity of the main stress needs no stipulation, because the Continuous Column Constraint blocks deletion of a grid mark supporting another on the next layer up.

(41)

2.3.2 Insert x

The second type of adjustment is the insertion of a grid mark to resolve a lapse. *Insert x* is parametrized for dominance in much the same way as *Delete x*, yielding two basic types, those in (42a) and (b).

(42)

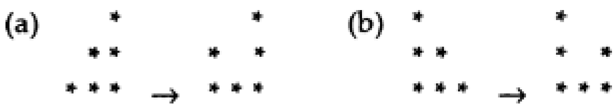
Insert x typically applies peripherally to produce a “rhythmic antipole.” Selkirk (1984) observes that rhythmically conditioned *Insert x* preserves culminativity, i.e., the relative prominence of main stress. She proposes a convention to the effect that insertion of a mark on the highest layer is automatically accompanied by a corresponding rise of the culminative peak:

(43)

2.3.3 Move x

Move x involves a (leftward or rightward) shift of a mark to resolve a clash, as in (44).

(44)



By the Continuous Column Constrain, *Move x* cannot effect the strongest of two beats (45a), and requires a proper landing site on the next layer down (45b).

(45)

Prince and Selkirk suggest that *Move x* may be decomposed into *delete x* and *Insert x. delete x* resolves the clash, while *Insert x* assigns the rhythmic “antipole.”

3 Early Bracketed Grid Theory

Evidence for feet in studies of prosodic morphology and foot-governed stress shifts have renewed interest in the question of whether rhythmic structure in phonology involves consituent structure. The advantages of the grid sketched above encouraged not a return to metrical trees, but rather a metrical grid with constituency markers added to it. The representations that arose were characterized by flat, *n*-ary constituency and direct representation of rhythmic structure.

3.1 New Arguments for Constituency

3.1.1 Stress Shifts by Deletion of Stressed Vowels

Significant arguments for metrical constituency were advanced based on the behavior of stress shifts accompanying deletions of stressed vowels. Al-Mozainy, Bley-Vroman, and McCarthy (1985) found that syncope in Bedouin Hijazi Arabic leads to migrations of stress whose direction depends on the shape of the metrical tree. In Bedouin Hajazi Arabic, stress is on superheavy final syllables (46a); if there is no superheavy final syllable, it falls on a heavy penult (46b); if there is no heavy penult, it falls on the antepenult (46c).

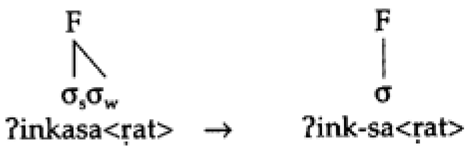
(46)

(a) maktúub "written" (b) maktúufah "tied" (fem. sg.)

(c) máalana "our Property"

The analysis is essentially the same as for Latin (see section 1.4.1), while final superheavy syllables are analyzed as in Cairene Arabic (see section 1.2.3). Final syllables are extrametrical, and a quantity-sensitive trochee is constructed at the right edge. A rule of Low Vowel Deletion deletes short /a/ in an open syllable if the following syllable is also open and contains short /a/. This rule produces alternations such as *sáḥab* "he pulled", *saḥában* "we pulled", versus *sḥábat* "she pulled". A particular interaction between stress and Low Vowel Deletion is revealed by alternations such as *?ínkisṛ* "he got broken" vs. *?ínksárat* "she got broken" (gt; / ?inkasáṛat /). Stress assignment cannot follow Low Vowel Deletion, since this would produce *?*ínksaṛat*. The surface opacity is explained by ordering stress before Low Vowel Deletion, if it is assumed that a deletion of the vowel in the head of a foot results in a rightward migration of stress within the foot:

(47)



This analysis has two interesting implications, both of which have been confirmed by studies of similar phenomena in other languages, including Tiberian Hebrew (Prince 1975), various Arabic dialects (Kenstowicz 1983; Hayes 1994), Russian (Halle and Vergnaud 1987), and Sanskrit (Halle and Vergnaud 1987). First, the deletion of a stressed vowel does not result in the deletion of the stress, but rather into its migration to an adjacent vowel. Thus, stess seems to display a *stability* effect that hitherto had been observed only in autosegmental phenomena such as tone and length. Second, the *direction* of the stress shift is predictable from the dominance of the foot whose head is deleted: stress shifts rightward in trochees, leftward in iambs. More generally, within the foot, the stress shifts to the nonhead syllable. Stability follows from the intergrity of constituency, and the assumption that every constituent must have a head.

3.1.2 Prosodic Morphology and Phrasal Rhythmic Adjustments

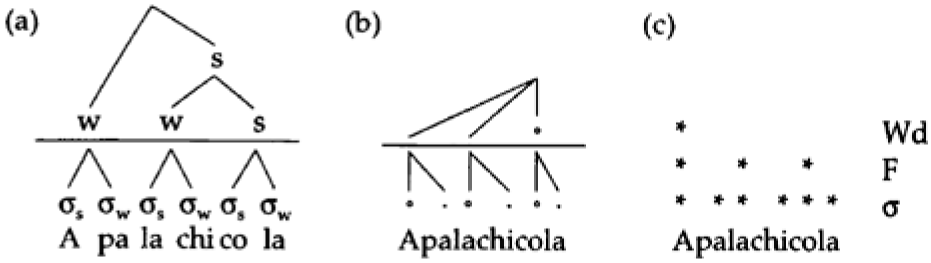
McCarthy and Prince (1986) demonstrate that many languages have morphological operations (infixation, reduplication, etc.) that refer to prosodic units such as the syllable and the foot. Minimal word conditions also refer to feet. See chapter 9, for extensive discussion. Another domain of evidence for metrical constituency is in stress shifts and other rhythmic adjustments at the phrasal level. Chapters 15 and 16 discuss phrasal phonology in more detail.

3.2 The Arboreal Grid

The arboreal tree notation of Hammond (1984) has ancestors in Leben (1982), Lerdahl and Jackendoff (1983), as well as work in dependency phonology. These proposals shared a flat, *n-ary* constituent structure, and a direct representation of constituent heads and nonheads. The strict relationality of early tree notation, with its binary branching and strong-weak labeling, were weakened within tree theory by the nonrelational notion of *head of a prsodic category*. Moreover, Prince (1983) demonstrated how tree geometry could be bypassed by pure grid mechanisms to locate heavy syllables and peripheral elements. Hammond (1984) added to this by detecting inadequacies in the classical tree with respect to the representation of rhythm.

Hammond (1984) modified the classical tree by vertically aligning heads with their mother constituent nodes, so that a grid-like hierarchical configuration of heads arises. Compare the standard tree of *Apalachicola* (48a) to that in Hammond's notation (48b), where circles represent heads of constituents:

(48)



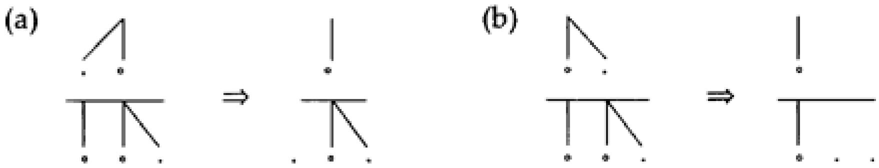
Containing all information present in grids, the notation is equally adequate as a representation of rhythmic structure (compare 48b and 48c). Hammond builds a major argument for arboreal grids on the fact that they allow for an adequate format of destressing rules. He hypothesizes that universally, stress clash is the obligatory trigger for destressing rules:

(49) Clash Resolution hypothesis (CRH)

All destressing rules must apply so as to eliminate adjacent heads of feet.

In the arboreal grid, clash is very directly represented as the adjacency of two heads of subtrees. Consequently, rules of destressing can be stated as deletion of a head of a foot (with the automatic removal of the foot). (50a) illustrates prestress destressing, (50b) poststress destressing (both outputs are subject to further stray syllable adjunction):

(50)

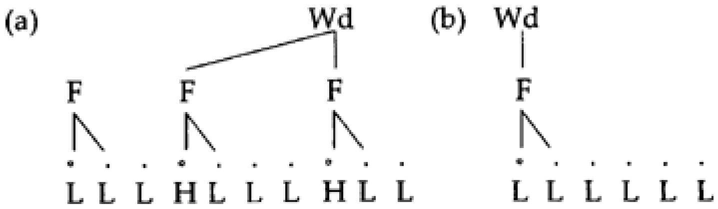


Thus arboreal grids rationalize restrictions on foot-branching in Hayesian defooting rules.

3.3 Improving tree theory: Prince (1985)

Prince (1985) argues that the boundedness parameter can be eliminated from tree theory, as unbounded feet are derivable by independently needed means. Unbounded feet serve to locate heavy syllables, and to mark domain edges, as he had already suggested in Prince (1983). Tree theory already provides machinery for both purposes: heavy syllables can be located by bounded Obligatory Branching feet, while edges are marked by peripheral noniterative bounded feet. For example, "Rightmost heavy, else initial" systems can be reanalyzed by bounded Obligatory Branching feet, and a noniterative trochee at the left edge. A right-dominant bounded word tree is constructed at the right word edge:

(51)



The exhaustivity requirement makes primitive bounded feet expand into derived unbounded feet by Stray Syllable Adjunction. Elimination of primitive unbounded feet is supported by the observation that they are hard to motivate as prosodic constituents by familiar diagnostics such as stress shifts, foot-domain rules, and prosodic morphology (Prince 1983; Kager 1989).

The second major contribution of Prince (1985) is collapsing foot construction and destressing rules. Let us see how this is achieved. First, Prince spells out a principle of foot assignment tacitly assumed in earlier work. Iterative rules produce "back-to-back" parsings (52a), and never apply to syllables that have already been footed on previous iterations (52b).

(52)

This is formulated in the Free Element Condition (53).

(53) Free Element Condition

Rules of primary metrical analysis apply only to Free Elements – those that do not stand in the metrical relationship being established; i. e., they are "feature-filling" only.

The Free Element Condition constitutes a diagnostic of rules that build metrical structure. It excludes destressing rules from this class, as they do not respect previously assigned structure. Under the hypothesis that the Free Element Condition explicates the difference between foot assignment and destressing rules, the rule types may be collapsed in every other respect. This can be formally achieved by merging the parts of destressing (deletion of the foot and a subsequent application of Stray Adjunction) into one format, foot *reassignment*: $[\sigma]_F[\sigma]_F$ σ $[\sigma\ \sigma]_F$. Destressing rules are then structure-*changing* applications of foot assignment. This hypothesis correctly predicts that foot shape parameters extend to destressing rules. *Foot dominance* determines which of the two syllables survives as the head of the new foot. *Quantity-sensitivity* may restrict the weight of syllables to be destressed (in some cases, heavy syllables are immune in English, cf. *banána* vs. *bàndánna*, while in others, they are not: *dəpártment* vs. *dèpàrtméntal*).

4 The Halle and Vergnaud Theory

Halle and Vergnaud (1987), proposed a different approach to metrical theory, based on a bracketed grid notation. The theory strongly emphasizes formal properties of constituency.

4.1 The Representation of Stress

In Halle and Vergnaud's bracketed grid notation, stress is represented as a grid enriched by bracketing to indicate stress constituents. A hierarchy of layers is assumed, in which they are labeled as line 0, 1, and so forth. By bracketing, adjacent marks on the same line are organized into constituents, whose unique head is vertically aligned with a mark at the next-higher line:

(54)

```
              *          line 2
(*      *     *)         line 1
(* *) (* *) (* *)        line 0
Apa lachi cola
```

Line O represents the place markers of stress-bearing units, which may be either syllables or rhyme elements (moras, under some interpretatons). Brackets on line O match the foot boundaries of tree theory. Line 1 contains the heads of line O constituents, which may be organized into constituents that correspond to the higher level prosodic categories of tree theory, such as the word tree. Line 2 contains the heads of line 1 constituents, and so forth.

The bracketed grid notation shares with Hammond's arboreal grid simultaneous representation of prominence, rhythm, and constituency. However, bracketed grid notation has the additional option of representing constituency without prominence, and prominence without constituency, applications of which we will see below.[8] A related difference is that bracketed grids allow the formulation of rules that move, delete, or insert grid marks, as in pure grid theory, as well as operations on brackets.

4.2 Parameters and Conditions

4.2.1 Constituent Construction

Three major parameters of constituent construction are *Boundedness* (bounded, unbounded), *Headedness* (left-headed, right-headed), and *Directionality* (left-to-right, right-to-left). For Hungarian (cf. 12), bounded left-headed constituents are constructed on line O, whose heads are located on line 1. On line 1, an unbounded left-headed constituent is constructed whose head is located on line 2:

(55)

```
 *                          line 2
(*     *     *     *)       line 1
(* *) (* *) (* *) (*)       line 0
```

In Halle and Vergnaud's terminology, the rule set that constructs bounded constituents on line O and locates their heads on line 1 is the *Alternator*, similar to Perfect Grid, discussed above. It must be iterative by the *Exhaustivity Condition*, requiring all line O elements to be in a constituent, and which they construe as a condition on foot construction, i.e., on rule application. Thus Halle and Vergnaud reject the *iterativity* parameter.

4.2.2 Quantity-sensitivity and Premarked Brackets

Halle and Vergnaud's approach to quantity-sensitivity follows Prince (1983): a rule pre-assigns a grid mark on line 1 (an "accent") to all heavy syllables.[9] The Faithfulness Condition guarantees that heavy syllables are parsed as heads of line 0 constituents:

(56) Faithfulness Condition (HV, pp. 15-16)

The output metrical structure respects the distrubution of heads (accented elements), in the sense that each head is asociated with consitunt boundaries in the output structure and that these are located at the appropriate positions in the sequence. [...]

In (57), an accent blocks construction of a left-headed foot ove the first and second syllable (under rightward application).

(57)

```
            QS     *             *   *     *       line 1
* * * * *   →    * * * * *   →  (*) (*  *) (*  *)  line 0
L H L L L        L H L L L       L   H  L   L  L
```

Decomposition of quantity-sensitivity and rhythm unifies all bounded feet construction by a single rule, the Alternator. We will see advantages of this in section 4.3 on bidirectionality.

Another way in which heavy syllables can be marked off is by preassigning a bracket at line O, a mechanism introduced in Halle (1990). This device may be employed in systems where stress-bearing units are rhyme segments (moras), as in Cairene Arabic (see section 1.2.3). A preassigned left bracket “[” before a heavy syllable blocks the construction of a line O constituent over the first and second moras in (58):

(58)

```
                                  *    *    *    *
* ** * * *   →   * [** * * *   →  (*) [**) (* *) (*)
L H  L L L       L H  L L L       L    H    LL   L
```

If rhyme segments (moras) can be stress-bearing units, it is predicted that foot boundaries may occur inside heavy syllables. Halle and Vergnaud argue that this is the case in systems such as Winnebago. In words starting with a sequence of light syllables, stress is on the third syllable, while in words starting with a heavy syllable, stress is on the second syllable. The third mora is stressed by initial mora extrametricality, and an initial right-headed bounded foot, as in (59).

(59)

```
(a)                        *     (b)                     *
    <*>  *  *  →  <*> (*   *)        <*>*  *  →  <*> (*  *)
     L   L  L      L   L   L          H    L      H      L
```

4.2.3 Ternarity

Hayes (1980) and Levin (1988a) draw attention to the stress pattern of Cayuvava (Key 1961), where stresses are on the antepenultimate syllable and on every third syllable preceding it. For such ternary systems, Halle and Vergnaud introduce a parameter (+/- Head-Terminal). If the parameter is set negatively, one nonhead element is allowed between a foot bracket and the head. The result is a ternary, head-medial, *amphibrach*. The Cayuvava pattern is generated by marking final syllables extrametrical and a leftward application of bounded [-HT] feet:

(60)

```
                   *       *       *           line 1
* * * * * * * * * * →  (* * *) (* * *) (* * *) <*>    line 0
```

4.3 Line Conflation and Bidirectionality

In the analysis of most unbounded systems, one stress is realized phonetically, while the other “stresses” are merely potential. Halle and Vergnaud eliminate the latter by *Line Conflation*. When two lines are conflated, a constituent on the lower line is preserved only if its head is also the head of a constituent on the next higher line. Consider conflation of lines 0 and 1:

(61)

```
                         *                                  *      line 2
(*        *              *)      (                          *)     line 1
(*  *  *) (*  *  *  *)  (*  *)    *  *  *  *  *  *  *  (*   *)     line 0
 L  L  L   H  L  L  L    H  L     L  L  L  H  L  L  L   H   L
```

Line Conflation also functions to analyze *bidirectionality*. Rejecting the iterativity parameter, HV reanalyze bidirectional systems by means of two iterative rules of opposing directionality. Main stress is generated by one iterative pass, the output of which is subject to Line Conflation. A second iterative pass from the opposite edge generates secondary stresses as in (62).[10]

(62)

```
           *                   *                   *          line 2
(*    *    *)         (        *)         (*   *   *)         line 1
(*) (* *) (* *)  →    * * * (* *)   →     (* *) (*) (* *)     line 0
```

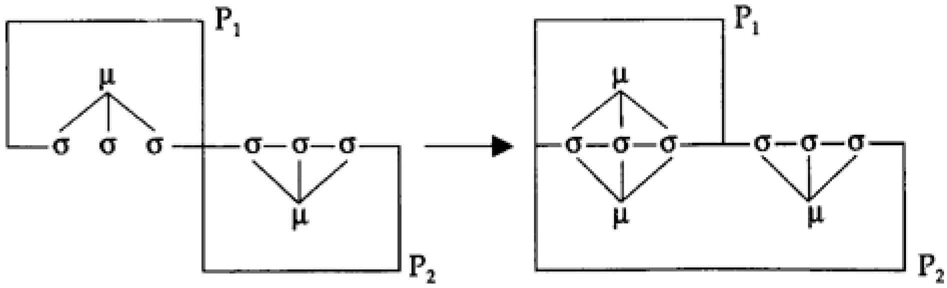
Finally, Halle and Vergnaud use Line Conflation for systems such as English, that have a quantity-sensitive main stress rule and a quantity-insensitive secondary stress rule. The rules can be identified if the Alternator applies in two strata. In the *cyclic* stratum, where the Alternator is preceded by Quantity Sensitivity, Line Conflation eliminates all stresses but the primary. The *noncyclic* Alternator assigns secondary stress quantity-insensitively, since Quantity Sensitivity is not in the noncyclic stratum.

4.4 Cyclicity and Stress Erasure

Halle and Vergnaud develop a theory of cyclic stress which can be appreciated by reviewing their analysis of Vedic, based on generalizations proposed by Kiparsky in an unpublished manuscript. In Vedic, vowels in stems and suffixes can bear lexical stress diacritics, which we will call accents. The location of the word stress is determined by the Basic Accentuation Principle: “Stress the leftmost accented vowel or, in the absence of accented vowels, the leftmost vowel.” The Basic Accentuation Principle is apparently restricted to words that are composed of a stem and a set of suffixes which we will refer to as *recessive* suffixes. Words with one or more suffixes not chosen from the set of recessive suffixes (which we may therefore call *dominant*) follow a different mode: stress falls on the last dominant suffix in the word if it is accented, else on the initial syllable, even if the stem is accented. Two aspects need explanation. First, the contrast between accented and unaccented stems is neutralized before dominant suffixes (accented -*iṇ* takes stress in *rath+íṇ+e* “charioteer” (dat. sg.), with an accented stem *rath*, as well as in *mitr+íṇ+e* “befriended” (dat. sg.), with an unaccented stem *mitr*). Second, accented recessive suffixes that follow a dominant suffix are ignored.

Following a proposal by Halle and Mohanan (1985), HV assume that dominant suffixes are *cyclic*, and trigger the rules of the cyclic stratum, while recessive suffixes are *noncyclic*. Noncyclic affixes are represented on the same metrical plane as the stem, but each cyclic affix induces a new metrical plane. Below, we show the addition of a cyclic suffix m_2 to a stem m_1. Stem and suffix each have their metrical planes P_1, P_2. The suffixal plane P_2 is automatically expanded with a copy of the content of previous planes (here P_1):

(63)



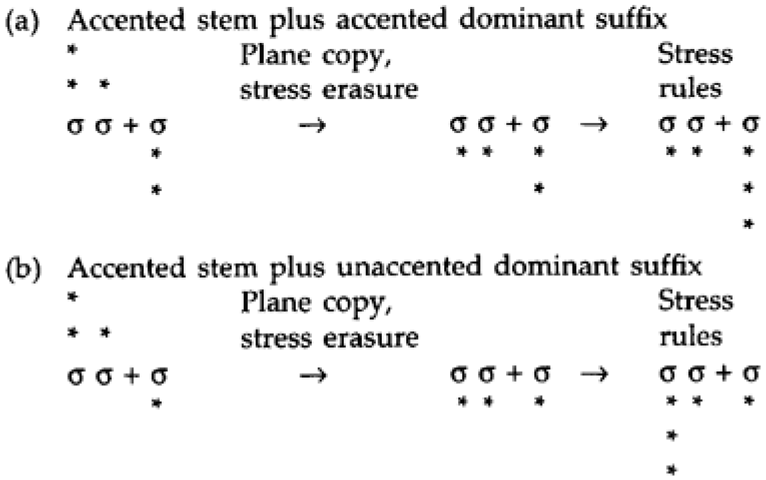
The stress rules of the cyclic stratum apply to each of the planes P_1, P_2. Halle and Vergnaud propose that information about stress recorded on the stem plane is not carried over in the plane-copying;[11] see (64).

(64) **Stress Erasure Convention (SEC, HV, p. 83)**

The input to rules of cyclic strata information about stress generated on previous passes through the cyclic rules is carried over only if the affixed constituent is itself a domain for the cyclic stress rules. If the affixed constituent is not a domain for the cyclic rules, information about stresses assigned on previous passes is erased.

Let us see how the Vedic stress data are analyzed under this proposal. The Basic Accentuation Principle can be formalized by a rule set which essentially functions as the analysis of default-to-same systems (see section 1.3). In the noncyclic stratum this rule set accounts for words with only recessive suffixes. The same rule set is applied in the cyclic stratum to words containing dominant cyclic suffixes. Here, stress erasure neutralizes any contrasts between accented and unaccented stems before dominant suffixes. When the last dominant suffix is accented, it ends up as the only accent surviving erasure, and it attracts word stress. When the last dominant suffix is unaccented no accents survive at all, and stress defaults to the initial syllable; see (65).

(65)



Addition of an accented recessive affix has no effect on the stress pattern of the base, as it is adjoined onto the same plane. The cyclic stress rules guarantee one accent on the base plane to the left of the recessive accent, so that the noncyclic stress rules (i.e., the Basic Accentuation Principle) ignore the latter.

4.5 Integrity of Metrical Structure

Integrity of metrical structure (that is, the tendency for rules not to change metrical structure once assigned in a derivation) is a main source of motivation of constituency. Here, we will review Steriade's (1988) argument for integrity from enclitic stress in Latin. (See for nonenclitic stress section 1.4.1). Upon addition of an enclitic element such as *–que* “and “, stress shifts to the syllable immediately before the enclitic:

(66)

(a) lí:mina “thresholds” li:miná#que “and thresholds”

(b) mú:sa “the muse” mu:sá#que “and the muse”

The patterns of the enclitic forms do not match the basic generalization on stress, which is that stress is antepenultimate (instead of penultimate) when the penult is light. The opacity of stress is explained if the stress rules reapply to enclitic forms while respecting the metrical structure of the base (cf. the Free Element Condition discussed in section 3.3). Nonperipheral base-final syllables lose their extrametricality:

(67)

```
(a)  *                  *    *             *   *
     (*   *).           (* *) (*)          (*) (* *)
     lí:mina<que>  →    li:miná<que>   not *li:mína<que>
(b)   *                 *    *                *
     (*).               (*)  (*)             (*   *)
     mú:sa<que>   →     mu:sá<que>     not *mú:sa<que>
```

A right-headed line 1 constituent promotes final feet. This analysis demonstrates the integrity of constituency in two ways. First, stress rules, when reapplying, cannot construct a foot over syllables that are already part of a foot (cf. 67a). Second, stress rules, when reapplying, fail to expand existing feet by incorporation of free elements (cf. 67b). Steriade employs a stronger version of Prince's Free Element Condition, one that extends to foot reassignment.

5 Asymmetric Rhythmic Theory

Hayes (1985, 1987, 1994), McCarthy and Prince (1986), and Prince (1990) develop a theory based on an *asymmetric* inventory of foot templates. It is motivated by the typology of iterative bounded systems, as well as by processes that change syllable quantity in foot-governed contexts. Another field of motivation, prosodic morphology, is discussed in chapter 9 this volume.

5.1 The Iambic-Trochaic Rhythmic Law and the asymmetric foot inventory

At the root of asymmetric rhythmic theory is an observation about the correlation between quantity-sensitivity and rhythm in iterative systems. Hayes (1985) proposes a significant asymmetry between iambic and trochaic styles of alternation. Iterative iambic systems display quantity-sensitivity almost without exception, and use feet whose members are of *uneven* duration. In contrast, iterative trochaic systems strongly tend towards durational *evenness* of the members of feet.[12] Hayes (1987, 1994) reflects this asymmetry in his asymmetric foot inventory:

(68)

(a) Syllabic trochee: Form (* .)
σ σ
(b) Moraic trochee: Form (* .) or (*)
L L H
(c) Iamb: Form (. *) if possible; else form (. *) or (*)
L H L L H

Trochees are durationally balanced, and contain two elements of identical duration, either syllables or moras. Iambs are durationally unbalanced, and contain a light syllable plus a heavy syllable in their maximal (canonical) expansion. This foot inventory is slightly less parametric than that of Hayes (1981), since quantity-sensitivity and dominance no longer combine freely to yield four foot types. A comparison of the feet in (68) to those of Hayes (1981) shows us that the syllabic trochee closely corresponds to the quantity-insensitive left-dominant foot, and the iamb to the quantity-sensitive right-dominant foot. There is one important difference, however, since degenerate feet are no longer automatically constructed when no larger foot can be formed. That is, in many systems the syllabic trochee lacks a monosyllabic expansion, while mora-based feet (the moraic trochee and the iamb) lack monomoraic expansions.[13] We will address degenerate feet in section 5.2.

Continuing the comparison with the foot inventory of Hayes (1981), we see that the bounded quantity-insensitive right-dominant foot has disappeared. This is motivated by the typological rarity of quantity-insensitive iambic styles of alternation (see Weri and Araucanian in section 1.2.1, and the reanalysis in section 5.1.3). Finally, the quantity-sensitive left-dominant foot has been replaced by the bimoraic trochee, which embodies the ancient law of equivalence between one long syllable and two short ones. This foot no longer includes an uneven expansion of a heavy plus a light syllable $[H\ L]_F$, which seems to be unattested in iterative systems. Let us now exemplify the asymmetric foot inventory.[14]

5.1.1 Syllabic Trochees

The syllabic trochee produces the following patterns in its rightward and leftward modes:

(69)

(a) Syllabic trochees (left-to-right)
(* .) (* .) (* .) (* .) .
σ σ σ σ σ σ σ σ σ

(b) Syllabic trochees (right-to-left)
. (* .) (* .) (* .) (* .)
σ σ σ σ σ σ σ σ σ

Warao (see section 1.2.1) exemplifies (69b). In contrast to the approach described earlier, no defooting of degenerate feet is required. Pintupi (Hansen and Hansen 1969) exemplifies (69a):

(70)

(a) púḷiŋkàlatʲu "we (sat) on the hill"
(b) tʲámulìmpatʲùŋku "our relation"

In the earlier theory, this pattern would be generated by syllable extrametricality. Section 5.2 addresses the apparent complication of secondary stresses at edges in rightward trochaic systems such as Hungarian. Most syllabic trochee systems, such as Warao and Pintupi, have no underlying quantitative distinctions. Piro constitutes a truly quantity-insensitive system, in which underlying weight distinctions are completely ignored by trochaic feet.

5.1.2 Moraic Trochees

The moraic trochee produces the patterns of (71):

(71)

```
(a) Moraic trochees                  (b) Moraic trochees
    (left-to-right)                      (right-to-left)
    (* .) (*) (* .) . (*) (* .)          (* .) (*) . (* .) (*) (* .)
    L L  H  L L  L  H  L L               L L  H  L  L L  H  L L
```

The *rightward* pattern is attested in Cairene Arabic. It had been captured in classical theory by Labeling–Based–on–Branching (LBOB) feet (see section 1.2.3). Since LBOB feet are not motivated outside the cases that the moraic trochee now serves to analyze, they can be eliminated from the theory. *Leftward* moraic trochees occur in Wargamay (Dixon 1981) and in some other systems. In the earlier theory, this pattern would require *uneven* quantity–sensitive trochees, with an irrelevant difference of bracketing: a string of a heavy syllable plus a light syllable is parsed by uneven trochees as a single foot (H L)$_F$, while moraic trochees parses it as a heavy foot followed by a stray syllable (H)$_F$ L. The case for uneven trochees is weakened further by Hayes's (1985) observation that their rightward mode is unattested (this would parse a heavy syllable followed by light syllables as (H L)$_F$ (L L)$_F$). Hayes claims that, consequently, the uneven trochee can be completely eliminated. However, evidence for the uneven trochee is presented by Myers (1987) and Kager (1989) for English, Jacobs (1990) for Latin, and Dresher and Lahiri (1991) for Germanic.

5.1.3 Iambs

The iamb produces patterns such as those below:

(72)

```
(a) Iambs (left-to-right)            (b) Iambs (right-to-left)
    (. *) (. *) (*) (. *) .              (. *) . (. *) . (. *)
     L H   L L   H   L L  L               L H  L  L H  L  L L
```

Absence of degenerate feet is motivated by the stress patterns of final syllables in systems with rightward iambs, which form the great majority of iambic systems. The few leftward iambic systems (such as Tübatulabal [Voegelin 1935], 18b) apparently require degenerate feet. Kager (1989), however, shows that these can be reanalyzed by moraic trochees.

Most iambic systems have underlying quantitative contrasts, and are what we might call truly quantity–sensitive. However, iambic rhythms also occur in a few systems lacking weight distinctions, such as Weri. Hayes argues that such systems are formally within the scope of the iambic expansion (L L)$_F$, even though they lack the uneven expansion (L H)$_F$. Moreover, some of these systems establish unevenness at the *surface* by rhythmic lengthening (see section 5.3).

5.2 Degenerate Feet

Degenerate feet are often discriminated against by metrical rules and conditions in several ways. (a) Many languages impose minimal word conditions requiring words to contain minimally one bimoraic or bisyllabic foot. (b) Degenerate feet tend not to qualify as proper foot templates in *prosodic morphology* (cf. chapter 9 this volume). (c) Degenerate feet in weak positions often lose their foot status at the surface by *destressing* (see section 1.5). (d) Degenerate feet are "repaired" by various strategies such as lengthening and reparsing (cf. Kager 1989, 1993, Prince 1990, Hayes 1994, Mester to appear).

Although metrical theory has always recognized the marked status of degenerate feet, they were motivated on both theoretical and empirical grounds. (a) *Exhaustivity*, the theoretical requirement that all syllables be parsed as part of a foot, dictates that a degenerate foot be produced automatically when no larger foot is possible. (b) *Edge beats* with secondary stress in iterative systems are generated automatically by degenerate feet. (d) Degenerate feet may trigger rules, in particular destressing rules, at intermediate stages in the course of the derivation. (4) *Culminativity* requires degenerate feet in languages that do not impose minimal word conditions.

With respect to exhaustivity, Hayes (1994) takes the position that foot construction is maximally exhaustive within the limits of what constitute well-formed feet in a particular system, and exhaustivity becomes a "soft" constraint whose satisfaction is weighed against other constraints. The favorable consequences of eliminating degenerate feet for the typology of alternating systems, as reviewed above, support this. Nonexhaustive foot parsing finds another application in Hayes's theory of ternarity; see section 5.4. Hayes claims that *phonological* evidence for weak edge beats is meager, and that their phonetic or perceptual status may derive from sources other than stress, both durational (prepausal lengthening) and intonational (boundary tones). for example, weak degenerate feet in Icelandic (Árnason 1985) show a different phonological behavior than binary feet, since they are ignored by the rule of compound stress assignment. Finally, in view of the fact that degenerate feet bear main stress, Hayes (1991) proposes to restrict the occurrence of degenerate feet on a parametric basis, as in (73).

> (73) Degenerate foot parameter:
>
> Parsing may form degenerate feet under the following conditions:
>
> (a) *Strong prohibition*: absolutely disallowed.
>
> (b) *Weak prohibition*: allowed only in strong position; i.e., when dominated by a higher grid mark.

The weak prohibition may be circumvented by the proposal of Kager (1989) to generate strong degenerate feet by means of a default option of the End Rule, as suggested by Prince (1983) for unbounded systems. Where no proper Foot layer landing site can be found, the End Rule assigns default word stress to the next layer down, i.e., the syllable layer.

5.3 Templatic Structure and Quantitative Rules

As a consequence of templatic foot structure, feet are defined independently of the rules that assign them. Thus foot templates may be referred to transderivationally by both stress and nonstress rules, a phenomenon called *metrical coherence* (Dresher and Lahiri 1991). A templatic view of foot structure echoes similar results in the theory of syllabification (Itô 1986), which invites a general templatic prosodic theory.

Metrical coherence provides the second main source of motivation for the asymmetric foot typology. It manifests itself in processes which conspire toward the iambic-trochaic rhythmic law by altering the quantity of syllables. Hayes (1985) observes that iambic systems tend to aspire towards durational unevenness, and have rules such as rhythmic vowel lengthening, consonant gemination, vowel reduction, and vowel deletion, all of which increase the durational constrasts between syllables. This makes sense from the viewpoint that foot templates actively impose their quantitative requirements through phonological rules. Consider Hixkaryana (Derbyshire 1979; Hayes 1994), where iambs are assigned from left to right with final extrametricality. Bimoraic iambs of the form $[\mathrm{L\ L}]_F$ are expanded into canonical iambs $[\mathrm{L\ H}]_F$ by rhythmic iambic lengthening: (*tóh*)(*kur*ʲ*éː*)(*honáː*)(*hašaː*) <ka> "finally to Tohkurye".

In contrast, syllabic trochee systems generally lack rules that introduce durational unevenness. Moraic trochee systems, which by definition have underlying quantitative contrasts, are predicted to display processes that increase durational evenness within the foot. Prince (1990) argues that English instantiates the prediction by vowel shortening to match the moraic trochee foot template. The addition of suffixes such as *-ic* and *-ity* to a stem with a long vowel induces a shortening of the latter, as can be seen in alternations such as *cóːne* □ *cónic*. As Myers (1987b) shows, the suffixes that trigger shortening are nonextrametrical Level-1 suffixes, whose addition produces a disyllabic trochee over the final heavy stem syllable and the suffix. Prince construes shortening as a process that modifies an *uneven* trochee $(\mathrm{H\ L})_F$ into a rhythmically balanced *even* bimoraic trochee $(\mathrm{L\ L})_F$, cf.

$(\text{koːn})_F \rightarrow (\text{konik})_F$. Observe that the uneven trochee, which forms the domain of trochaic shortening, must be allowed as a possible foot under this analysis. Prince suggests a markedness theory of foot well-formedness, according to which the uneven trochee is a legal, but marked expansion of the ideally bimoraic trochee.

5.4 Ternarity and Persistent Footing

Hayes (1994) proposes a theory of ternary systems which does not postulate ternary feet, but rather derives ternarity by a marked foot assignment mode. In the unmarked case, systems employ the unmarked Strong Local Parsing mode (74a), which assigns feet adjacently, producing binary rhythm. Ternary systems draw from the universal asymmetric foot inventory, but follow a Weak Local Parsing mode (74b), which skips a syllable after each foot that has been established. The extra unbracketed syllables between feet produce ternary rhythm:

(74)

```
(a) (* .) (* .) (* .) (* .) .        (b) (* .) .  (* .)  .  (* .)
    σ σ   σ σ   σ σ   σ σ σ              σ σ σ    σ σ    σ  σ σ
```

In systems based on the iamb or the moraic trochee, one mora may be skipped, in systems based on the syllabic trochee, one syllable (the *Minimal Prosodic Distance*).

Weak Local Parsing is another source of nonexhaustive foot parsing in Hayes's theory. It many even produce sequences of two unbracketed syllables when after skipping, one syllable remains at the end of the domain, which cannot be footed, because of the ban on degenerate feet. Such sequences are dealt with on a language-specific basis. They are tolerated in Cayuvava (75a), which has leftward construction of syllabic trochees under final extrametricality. Alternatively, foot construction is reapplied to the unbracketed sequence. This option of persistent footing is exemplified by Chugach Yupik (Leer 1985) (75b), which has rightward iambs:

(75)

```
(a) .  . (* .) . (* .)
    σ σ σ σ σ σ σ <σ>
(b) (. *) . (. *) .  .      →   (. *) . (. *) (. *)
    L L L L L L L                L L L L L L L
```

6 Conclusion

After a decade of theoretical work on metrical systems, a consensus has emerged on a number of points. First, stress requires hierarchical representation in order to capture culminativity and prominence differences between stresses. Second, the rhythmic nature of stress is most adequately represented by the grid. Third, the grid is enriched by metrical constituency in order to capture stress shifts, requirements of prosodic morphology, and template-governed phenomena such as quantitative asymmetries. Researchers still seem to differ in opinion about the symmetrical nature of the foot inventory, the status of degenerate feet, exhaustivity, and the issue of what may constitute stress bearing units.

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1 The learnability of stress systems is studied from a parametric viewpoint by Dresher and Kaye (1990) and Hammond (1990).

2 Other applications are dialectal variation (Kenstowicz 1983) and diacronic phonology (Wheeler 1980).

3 Hammond (1986) argues for a foot type that restricts its dominant nodes (to heavy syllables), without restricting its recessive nodes. He proposes that this *Revised Obligatory Branching* foot should replace the Obligatory Branching foot. The complex arguments for Revised Obligatory Branching feet will not be reviewed here.

4 Onsets fail to contribute to weight, or only hardly ever do, though the reader may see Everett and Everett (1984) on Pirahâ, and Davis (1988) on Western Aranda, Madimadi, Italian, and English.

5 Van der Hulst (1984) proposes a more radical *Main Stress First* theory: Main stress is assigned first, and secondary stresses run from the main stress, or the opposite edge.

6 Nonbinary bounded feet have been proposed by Prince (1980) for Estonian, Levin (1988a) for Cayuvava, Woodbury (1987) for Yupik, and Dresher and Lahiri (1991) for Germanic. See also sections 4.2.1 and 5.4 on ternarity.

7 For discussion of interactions between metrical structure and lexical phonology, see Kiparsky (1982a, 1985) and chapters 2 and 3, this volume.

8 Hammond (1987) claims that this power is not crucially needed.

9 There is thus no inherent connection between internal syllable structure and prosodic prominence, a link whose absence has been noticed.

10 HV's analysis of bidirectionality is disputed by Levin (1988b). For an answer, see Halle (1990).

11 See for discussion of the SEC, Harris (1989) and Halle, Harris, and Vergnaud (1991).

12 Hayes cites experimental evidence from Woodrow (1951), who found that rhythmically alternating stimuli with durational prominence marking were perceived as iambic, and those with intensity marking were perceived as trochaic.

13 Here we follow Hayes (1994), who eliminates the degenerate stressless feet of Hayes (1987).

14 Recently, the asymmetric foot inventory has been challenged by proposals that advocate a symmetric foot inventory, and derive the rhythmic asymmetry by independent means, cf. Jacobs (1990), Hammond (1990), Kager (1993).

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