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Rule Locality in the Computation of Word Prosody*

December 2023

Contents

*This work is dedicated to the memory of Morris Halle, who showed me how interesting problems in phonology can be. My results are all built on the foundation of his work and his approach to phonology. Thanks also to Noam Chomsky for teaching me how to do linguistics, and to Sam Gutmann for the years of discussion which helped us to begin to understand what Noam and Morris were saying (although we did not always agree with it). Not at all least, my thanks and profound admiration for all those who conducted the skilled empirical investigations which this paper purports to explain.

The title is an homage to Bill Idsardi's 1992 thesis, *The computation of word prosody*. It is the starting point for the theory developed in this paper.

This paper is an edited version of a paper that circulated in 2019.

1. Introduction

This paper returns to an old issue in the metrical theory of word stress that has never been adequately addressed. Why is it that those word stress systems which have rhythmic stress come in only two basic forms, binary and ternary? I will call this the binary/ternary duality. What accounts for this? Optimality Theory (OT) is hamstrung in furnishing an explanation for it since its modus operandi is to start from the array of possibilities and provide a theory of how the best possibility is chosen. Rice (2007) argues convincingly that the restriction to binary/ternary possibilities cannot be understood in OT without stipulating restrictions on the array of structures that are submitted to the optimality computation (by GEN). This leaves the question of what explains the restrictions on GEN. Transformational phonology, on the other hand, which supposes that surface forms are the result of progressive modification of underlying forms, has a much better chance of providing an account of the duality. It could be something about the architecture of the computation of stress, something more abstract and general than a stipulation about what kinds of feet can be constructed, which leads to the binary/ternary duality. In this paper, I will argue that this is indeed the case; the binary/ternary duality is a consequence of general locality conditions on the operations which construct feet. The key idea, of course, is a formulation of a notion of rule locality which is conceptually minimal, sufficiently restrictive to limit rhythmic stress patterns to binary and ternary, and sufficiently permissive to account for the various actually occurring stress systems.

I assume that words are structured metrically as a sequence of beats and that the metrical structure of words derives from the groupings of these beats into feet. I then build on the important idea of Idsardi (1992), further developed in Halle and Idsardi (1995) (henceforth H&I), that these groupings are derived from an abstract structure in which silent delimiters (foot endings and foot beginnings) have been inserted between the beats of words. Further, that these delimiters are more fundamental than the groups they demarcate.

> In our framework, the foot is not a theoretical primitive. Rather, metrical boundaries are placed among the stress-bearing elements. In this way, the sequence of stress-bearing elements is subdivided to constituents . . . (H&I, p. 440)

Delimiters are not viewed as marking the boundaries of a foot object; rather, feet are viewed as the groupings that delimiter objects create. The H&I theory has no notion of ‘foot type’ or ‘foot inventory’; feet are whatever groups delimiters create. The theory therefore focuses on the rules that insert delimiters into an initial line of beats. The H&I theory has been very successful in accounting for a wide range of phenomena, particularly systems with unbounded feet and systems with lexically specified footing. It is deficient, however, in two respects. There are no limitations on the form of delimiter insertion rules, so there is no way to make predictions about the expected metrical structures. Related to this, the empirical adequacy of the proposals is questionable for several ternary systems. The aim of this paper is to rework the H&I theory in a way that eliminates these defects. A large share of the present paper is devoted to revising the H&I theory in order to more tightly constrain the class of possible stress systems and to better account for ternary stress systems.

The plan of the paper should be evident from the Table of Contents. The main theoretical result is a rigorous proof that under the assumptions about the architecture of footing systems and rule locality which are adopted, systems with rhythmic footing are either binary or ternary. Attention then shifts to analyzing the word stress systems of a few complex languages, intended to convince the reader that there is some chance that the analysis developed is general enough to analyze a wide array of word stress systems.

2. Delimiter Insertion Rules (DIRs)

I assume that the metrical structure of a word is represented by a prosodic grid (Liberman 1975, Liberman and Prince 1977). For example, in a language in which metrical beats correspond to syllables, the metrical structure of a word might be (1). The height of a column over a syllable represents its relative metrical prominence.

	×						main stress	(line 2)
	×		×		×		stressed beats	(line 1)
(1)	×	×	×	×	×	×	beat line	(line 0)
	σ	σ	σ	σ	σ	σ		

Our interest in this paper is how line 1 is computed from line 0. In almost all systems, computing line 2 is trivial, with the rightmost or leftmost line 1 beat projected to line 2. The computation of line 1 is indirect. First, beats are grouped (in some way) into disjoint groups of adjacent beats (called feet). Then one beat in each group is projected to the higher line. Either the leftmost element in each group is projected, *trochaic stress*, or the rightmost element in each group is projected, *iambic stress*. Beats project stress, but we also say (somewhat inaccurately, but conveniently) that a foot projects stress, or is assigned stress, if one of its beats projects stress. Although there are exceptions, in most systems, including all the systems discussed in this paper, the iambic/trochaic choice is a system choice, not depending on which particular foot is assigned stress.

I adopt Idsardi's important and ingenious idea that footing is carried out by inserting delimiters, *one at a time*, into the line of beats. There is no requirement that foot delimiters are paired. The delimiters *indirectly* specify the feet. There are two foot delimiters, '⟨' and '⟩'. The two foot delimiters are actual objects which appear on the beat line, not a notation to associate certain beats with some actual foot object which appears on a line of feet; there is no 'line of feet'. The notion foot is a secondary, but important notion.

(2) a. Say that a beat is *locally footed* if it is in the context $/ \langle \_\_$ or the context $/ \_\_ \rangle$.
  b. Say that a beat is *footed* if it is locally footed or is adjacent to a footed beat.
  c. A *foot* is a maximal set of mutually adjacent footed beats.

Attention therefore shifts from the question of how feet are formed, one by one, directionally, to how delimiters are inserted, one by one, directionally. Delimiters are inserted by rules which target beats and insert a delimiter either immediately before or immediately after the target. A footing system is a system of *delimiter insertion rules* (DIRs).

Before we give some illustrations of footing systems, we need to define a condition on beats which is important, sometimes in a weakened variation, in almost all stress systems.

(3) A beat satisfies *Unary if it is adjacent to another beat or is not locally footed.

Delimiters are objects on the beat tier, so $\times$ is not adjacent to $\times'$ in $\cdots \times \langle \times' \cdots$, for example. Importantly, *Unary *is condition on beats, not a condition on feet.* Its name derives from the fact if a beat satisfied *Unary, it is not in a foot which contains only a single beat.

Now consider the simple system (4). There is a single rule which is iterated from left to right. GB is the rule $\times \rightarrow \times \rangle$. GB is an acronym for Group Backward; GB groups beats back toward the starting edge, which is at the left in an LR system. The semi-colon separates a rule from a derivational constraint. *Unary blocks applications of GB which create a beat which does not satisfy *Unary. An example of the derivation of foot structure which this system generates is given in (5).

(4) $[\times \rightarrow \times \rangle]_{\mathrm{LR}}$; *Unary (GB)

(5)

$$
\begin{array}{lll}
 & \underset{\blacktriangle}{\times}\ \times\ \times\ \times\ \times & \\
 & \times\ \underset{\blacktriangle}{\times}\ \times\ \times\ \times & \text{*U{\scriptsize NARY} blocks GB} \\
\text{GB} & \times\ \times\rangle\underset{\blacktriangle}{\times}\ \times\ \times & \\
 & \times\ \times\rangle\times\ \underset{\blacktriangle}{\times}\ \times & \text{*U{\scriptsize NARY} blocks GB} \\
\text{GB} & \times\ \times\rangle\times\ \times\rangle\underset{\blacktriangle}{\times} & \\
 & \times\ \times\rangle\times\ \times\rangle\times & \text{*U{\scriptsize NARY} blocks GB} \\
 & (\times\ \times)(\times\ \times)\times^{\dagger} &
\end{array}
$$

† This line is not a stage in the derivation, just a note to the reader about what feet have been generated.

The directional iteration is governed by a cursor, which moves to the right at each step. In alternate steps, *UNARY prevents application of GB.

Alongside GB, there is an operation GF, Group Forward, which groups beats away from the starting edge. GF and GB both position the target beat inside the group which the inserted delimiter establishes. There are other operations (GB^{x} and GF^{x}) which group beats backward and forward, but position the target outside the group which is delimited. The four operations GB, GB^{x}, GF, and GF^{x} come up repeatedly in what follows, so it is worthwhile to be clear about the naming conventions. There are 3 factors; LR/RL, forward/backward, and internal/external. The table is put in a box to emphasize that the names will be used many times in what follows.

(6)

name	*LR action*	*RL action*	
GB	$\times \to \times\rangle$	$\times \to \langle\times$	target is inside the foot created
GF	$\times \to \langle\times$	$\times \to \times\rangle$	
GB^{x}	$\times \to \rangle\times$	$\times \to \times\langle$	target is outside the foot created
GF^{x}	$\times \to \times\langle$	$\times \to \rangle\times$	

Now consider the iterative rule (7) and some examples (8) which show how it operates. The rule which is iterated is a scheme. It applies in the standard way that a scheme operates; if GB is applicable, it applies, otherwise if GF^{x} is applicable, it applies. In any event, the iteration moves onto the next beat and the process is repeated until all the beats have been targeted.

(7)

$$
\begin{bmatrix} \times \to \times\rangle \\ \times \to \times\langle \end{bmatrix}_{\mathrm{LR}} ;\ \text{*U{\scriptsize NARY}} \qquad \begin{array}{l} (\mathrm{GB}) \\ (\mathrm{GF}^{\mathrm{x}}) \end{array}
$$

(8) a.

	× × × ×
GF^x	×⟨× × ×
	×⟨× × ×
GB	×⟨× ×⟩×
	×⟨× ×⟩×

b.

	× × × × ×
GF^x	×⟨× × × ×
	×⟨× × × ×
GB	×⟨× ×⟩× ×
	×⟨× ×⟩× ×
GB	×⟨× ×⟩× ×⟩

c.

	× × × × × ×
GF^x	×⟨× × × × ×
	×⟨× × × × ×
GB	×⟨× ×⟩× × ×
GF^x	×⟨× ×⟩×⟨× ×
	×⟨× ×⟩×⟨× ×
GB	×⟨× ×⟩×⟨× ×⟩

Ternary footing is generated. Ternary refers to the interval between stressed beats which this footing leads to, not to the size of feet. Hammond (1990a,b) and Hayes (1995) identified the foot structure (8c), in which unfooted beats intervene between binary feet, as the source of ternary footing. Hayes proposed a framework in which footing was carried out by a special foot parsing algorithm. The framework here is quite different. Iterative footing is carried out by a normal directional iterative rule, no different in kind than other directional iterative rules. The directional iterative rule goes down a line of phonological elements and targets them in turn. Hammond and Hayes's idea was very important in understanding ternary stress patterns. The idea of iterated rule schemes is in large part an attempt to put the idea on firmer footing.

In addition to a directional iterative rule, footing systems have what H&I, who introduced the idea, call *marking rules*. These are non-iterative rules which create a framework in which the iterative rule establishes a rhythm. The marking rules apply in order (if there are more than one) before the iterative rule creates the rhythmic structure. $GF_\#$ and $GF^x_\#$ are two very common marking rules. I will assume, in fact, that $GF_\#$ is the default marking rule. It ensures that a foot starts at the edge at which directional iteration is initiated.

(9)

name	*LR action*	*RL action*
$GF_\#$	×→⟨× / #__	×→×⟩ / __#
$GF^x_\#$	×→×⟨ / #__	×→⟩× / __#

3. Locality

There are 3 kinds of items that can appear on the beat line: beats, foot delimiters, and junctures. The later two will be called metrical boundaries, or simply boundaries. In this paper, the only juncture which appears is the edge marker.

Beats can have properties of various kinds; at least (perhaps only) weight properties, junctural properties, and lexically specified properties.

(10) A condition on beats is called a *local condition on beats* if its value at a beat $\times$ is independent of any beat line items which are not adjacent to $\times$.

Junctures pose a subtle problem. Consider the condition $/\ \_\_\times\#$, the 'penultimate' condition. If nothing further is said, it is not a local condition. In fact, as we shall see, it will turn out that it does act like a local condition. I will therefore assume that *junctures induce properties in the beats they separate*. (We view an 'end marker' as separating the word final beat from the initial beat of the following word, with a similar consideration at the 'begin marker'.) Hence there is a 'final beat' property, so $/\ \_\_\times\#$ is true of a beat which is directly followed by a beat with the 'final beat' property and is therefore a local condition. $/\_\_\rangle\#$ is true of a beat which has the 'final beat' property and which is followed by a right foot delimiter.

There is one important non-local condition. It cannot be determined locally if a beat is footed. The final beats in $\cdots\rangle\times\times\#$ and in $\cdots\langle\times\times\#$ both occur in the context $/\times\_\_\#$, but one is footed and the other is not. Satisfaction of *Unary, on the other hand, is a local condition.

The notion *Local Delimiter Insertion Rule* (LDIR) plays a central role in which follows. It would be simple if it were sufficient to restrict attention to rules which inserted a delimiter adjacent to the target beat (i.e. one of the rules GB, GB^{x}, GF, or GF^{x}) provided the target satisfied some local condition *SC* (a structural condition). But this is impossibly restrictive. The rule $\times\rightarrow\langle\times\ /\times\_\_\times$, for example, can create a *Unary violation in certain contexts; $\cdots\langle\times\underset{\blacktriangle}{\times}\times\cdots$ for example. There is no way to avoid *Unary violations by imposing a local structural condition on rule application. It is at least necessary to allow some derivational constraint which is sensitive to the configuration which delimiter insertion would produce.

(11) A triple $\rho\,/\,SC\ ;DC$ is called a *Local Delimiter Insertion Rule (LDIR)* if:

1. ρ is one of the rules GB, GB^{x}, GF, or GF^{x}.[1] These rules are called *primitive DIRs*; they insert a delimiter adjacent to their targets.
2. SC, the *structural condition*, and DC, the *derivational constraint*, are local conditions.

(12) $\rho\,/\,SC\ ;DC$ is applicable to a target, with action ρ, if:

1. the target satisfies the structural condition SC.
2. if ρ were applied, *beats adjacent to the inserted delimiter* would satisfy the constraint DC and a vacuous foot would not be created. A vacuous foot is any of $\#\rangle\times$, $\times\langle\#$, $\langle\langle$, $\langle\,\rangle$, or $\rangle\rangle$.[2]

The rule $\rho\ =\ \text{GF}\,;{*}\textsc{Unary}$, for example, is not applicable to $\langle\times\times\underset{\blacktriangle}{\times}\times$ (the cursor indicates the target) because if ρ were applied the result would be $\langle\times\langle\times\times\times$ and one of the beats adjacent to the inserted delimiter would not satisfy *Unary. But $\rho = \text{GF}\,;{*}\textsc{Unary}$ is applicable to $\langle\times\langle\times\times\underset{\blacktriangle}{\times}\times\times$. If ρ were applied, the result would be $\langle\times\langle\times\times\langle\times\times\times$. Since both beats which are adjacent to the inserted delimiter satisfy *Unary, ρ is applicable. The fact that some beat which is not adjacent to the inserted delimiter does not satisfy *Unary is not relevant.

3.1. Right and left LDIRs

Right LDIRs, whose action is GB or GF^{x}, insert a delimiter to the right of the target; left LDIRs, with action GF or GB^{x}, insert a delimiter to the left of the target. Suppose we consider the applicability of an LDIR r to $\cdots a\times\underset{\blacktriangle}{\times}\times b\cdots$, where a and b are beats or delimiters. If r is a right LDIR, applicability of r will depend on b, but is independent of a. If it applied and inserted the delimiter D

$$\cdots a\times\underset{\blacktriangle}{\times}\times b\cdots \quad \xrightarrow{r} \quad \cdots a\times\times\text{D}\times b\cdots$$

One of the beats adjacent to the inserted delimiter is in the context $\times\_\_\text{D}$ and the other is in the context $\text{D}\_\_\ b$. In either case, a is not relevant.

Lemma (13) below, which follows from the considerations above, will be important later.

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1. If necessary, see p. 4 to remind yourself of the definitions of these rules.
2. The ‘ban on vacuous feet’ is taken to be an implicit structural condition on rule application. Vacuous feet cannot be excluded by a derivational constraint. For example, $\rangle\rangle$ cannot be excluded by a local condition on beats. In $\times_1\rangle\rangle\times_2$, for example, a local condition at $\times_1$ or $\times_2$ cannot ‘see’ past the adjacent delimiter.

(13) a. The applicability of a right LDIR to $\alpha\times\underset{\blacktriangle}{\times}\times\times\beta$ is independent of both α and β.
b. The applicability of a left LDIR to $\alpha\times\times\underset{\blacktriangle}{\times}\times\beta$ is independent of both α and β.
c. The applicability of any LDIR to $\alpha\times\times\underset{\blacktriangle}{\times}\times\times\beta$ is independent of both α and β.

4. Marking rules

A characteristic of the scheme of DIRs which carry out rhythmic footing is that it is generally applicable at many adjacent targets and directionality is used to pick out the target at which it can apply. There are other local DIRs which apply before rhythmic (iterative) footing that have a different character.

(14) DEFINITIONS:
a. A rule which is applicable to multiple targets will be called *adirectional* if any order of application or simultaneous application produce the same output.
b. An *M-rule* is an adirectional LDIR whose structural description does not mention foot delimiters.

We will require marking rules to be M-rules. The first condition is imposed because this cleanly separates marking rules from the directional iterative rule. Directionality is not relevant to marking rules. All directionality aspects of footing reside with iterative footing. The second condition expresses the intuition that marking rules are never in a feeding relation with each other. It is imposed to insist on the fact that marking rules target beats which have some particular property (edge or heaviness for example) which is identifiable in the initial representation, before delimiter insertion is initiated. Delimiters do not induce properties on beats. Being in the context $\_\_\langle$, for example, is not a property of a beat.

(15) gives a sufficient condition to show that an LDIR is adirectional. It is not a necessary condition.

(15) *Lemma*: Suppose $\times_1$ and $\times_2$ are not adjacent and r is an LDIR which is applicable at both $\times_1$ and $\times_2$. Then application of r at $\times_1$ does not affect the applicability of R at $\times_2$.

Suppose, for example, that r is a right rule with action $\times\rightarrow\times\mathrm{D}$ and $\times_1$ is to the left of $\times_2$. If r were to apply to $\times_1$ in $\cdots\times_1\alpha\times_2\cdots$, with α not empty, the result would be $\ldots\times_1\mathrm{D}\,\alpha\times_2\cdots$. Because α is non-empty, (13) ensures that the applicability of r at $\times_2$ is not affected by the inserted delimiter. The argument is essentially the same if R inserts a delimiter to the left and/or $\times_1$ is to the right of $\times_2$.

In Finnish, for example, there is a marking rule $\times \rightarrow \langle \times$ which applies to heavy beats which follow light beats. Such beats cannot be adjacent, so (15) implies that (14a) is satisfied. In Bani-Hassan Arabic there is a marking rule $\times \rightarrow \langle \times$ which applies to heavy beats, even adjacent heavy beats. But heavy beats are not required to satisfy *Unary in Bani-Hassan Arabic, so application of the marking rule at one heavy beat does not affect its applicability at a different heavy beat.

(16) Definition: A *footing system* is an ordered list of rules M-rules optionally followed by directional scheme of LDIRs.

The marking rules in M first apply, in order, providing a skeletal foot structure. Then the scheme applies directionally iteratively, providing a rhythmic structure.[3]

Most stress systems have simple marking rules, often a single edge marking rule. In order to illustrate the possibilites, two systems are given below where the marking rules are more unusual. They will make clear the difference between marking and rhythm.

4.1. Lenakel, marking the far edge

The Lenakel stress system was described and first analyzed by Lynch (1974, 1977, 1978). Edge marking in most stress systems is at the *near edge* of the word, the edge from which iterative footing proceeds. Lenakel is unusual in marking the *far edge*.[4] For verbs and adjectives with only light syllables, the footing system is (17).

(17)
$$\times \rightarrow \times\rangle \;/\; \_\_\# \qquad (\mathrm{GF}^{\mathrm{FAR}}_{\#})$$
$$\times \rightarrow \langle\times \;/\; \_\_\times\# \qquad (\mathrm{Bin}^{\mathrm{FAR}}_{\#})$$
$$[\times \rightarrow \times\rangle]_{\mathrm{LR}} \;;\; {*}\mathrm{Unary} \qquad (\mathrm{GB})$$

Some derivations follow. The delimiters inserted by marking rules in (18b) are doubled, to make it easier for the reader to see how the form is derived. Doubled delimiters are a convenient annotation to highlight delimiters inserted by marking rules; they should not be confused with empty feet, which have been totally banned. Doubled delimiters are just an expository device; the computation does not distinguish delimiters inserted by marking rules from delimiters inserted by the iterative rule.

3. Since the structural conditions of marking rules cannot mention delimiters, it is almost the case that the application of one marking rule cannot feed application of a different marking rule. But since constraints must be allowed to mention delimiters, it is possible to contrive artificial examples in which marking rules are in a feeding relation. This could be ‘fixed’ by imposing suitable restrictions on the constraint component of marking rules, but it does not seem worth the trouble.

4. It is not an accident that footing Lenakel nouns proceeds from right to left.

(18)

a.

	×
GF$_{\#}^{\text{FAR}}$	×⟫
	(×́)

b.

	× ×
GF$_{\#}^{\text{FAR}}$	× ×⟫
BIN$_{\#}^{\text{FAR}}$	⟪× ×⟫
	(×́ ×)

c.

	× × ×
GF$_{\#}^{\text{FAR}}$	× × ×⟫
BIN$_{\#}^{\text{FAR}}$	×⟪× ×⟫
	×(×́ ×)

d.

	× × × ×
GF$_{\#}^{\text{FAR}}$	× × × ×⟫
BIN$_{\#}^{\text{FAR}}$	× ×⟪× ×⟫
GB	×́ ×⟩⟪×́ ×⟫
	(×́ ×)(×́ ×)

e.

	× × × × ×
GF$_{\#}^{\text{FAR}}$	× × × × ×⟫
BIN$_{\#}^{\text{FAR}}$	× × ×⟪× ×⟫
GB	× ×⟩×⟪× ×⟫
	(×́ ×)×(×́ ×)

f.

	× × × × × ×
GF$_{\#}^{\text{FAR}}$	× × × × × ×⟫
BIN$_{\#}^{\text{FAR}}$	× × × ×⟪× ×⟫
GB	× ×⟩× ×⟪× ×⟫
GB	× ×⟩× ×⟩⟪× ×⟫
	(×́ ×)(×́ ×)(×́ ×)

g.

	× × × × × × ×
GF$_{\#}^{\text{FAR}}$	× × × × × × ×⟫
BIN$_{\#}^{\text{FAR}}$	× × × × ×⟪× ×⟫
GB	× ×⟩× × ×⟪× ×⟫
GB	× ×⟩× ×⟩×⟪× ×⟫
	(×́ ×)(×́ ×)×(×́ ×)

4.2. Finnish; marking away from an edge

The description of the distribution of stress is straightforward. It relies on a distinction between syllables which have a coda, heavy syllables, and those that do not, light syllables.

(19) The initial syllable is stressed if it is nonfinal. If σ_n is stressed, then σ_{n+3} is stressed if it is heavy and nonfinal and σ_{n+2} is light, otherwise σ_{n+2} is stressed.

Finnish associates a beat with each syllable, but makes a distinction between beats associated with heavy syllables, heavy beats, and those associated with light syllables, light beats. I suppose that beats associated with syllables which have a coda have a [+HVY] property and that other beats do not. I follow Hayes' very useful notation and use $-$ to denote a heavy beat and $\smile$ to denote light beat (i.e., one which is not heavy).[5]

A straightforward way to achieve this is including the rule $- \rightarrow \langle - \;/\; \smile \_\_$ (call it GF$_{\text{LH}}$) in the marking rules.

5. Here $\smile$ and $-$ denote beats; Hayes uses them to denote syllables.

(20) Finnish footing system

$$\left.\begin{array}{l} \times \rightarrow \langle \times \;/\; \#\_\_ \\ - \;\rightarrow \langle - \;/\; \smile \_\_ \\ [\times \rightarrow \times \rangle]_{\mathrm{LR}} \end{array}\right\} ;\ {}^{*}\textsc{Unary} \qquad \begin{array}{l} (\mathrm{GF}_{\#}) \\ (\mathrm{GF}_{\mathrm{LH}}) \\ (\mathrm{GB}) \end{array}$$

Because of its structural description, which does not mention delimiters, $\mathrm{GF}_{\mathrm{LH}}$ cannot apply to adjacent beats, so it is a valid marking rule. $\mathrm{GF}_{\mathrm{LH}}$ is not written in standard form, $\times \rightarrow \langle \times \;/\; SC$, but $- \rightarrow \langle - \;/\; \smile \_\_$ is equivalent to $\times \rightarrow \langle \times \;/\; \smile \underline{-}$.

The examples (21) illustrates how the sysytem carries out footing.[6] Stress is trochaic, so the beats to which $\mathrm{GF}_{\mathrm{LH}}$ applies are always stressed. (21a,d) illustrates that one marking rule can bleed a different marking rule. The application of $\mathrm{GF}_{\#}$ blocks $\mathrm{GF}_{\mathrm{LH}}$ from applying to the second beat because *Unary must be satisfied. $\mathrm{GF}_{\mathrm{LH}}$ is also blocked by *Unary from applying to the final beat, even though its structural condition is satisfied. The last line in the (21) examples show the result of stress assignment on the basis of the foot structure; stress is trochaic with main stress left. The horizontal line separates the structure supplied by the marking rules from the later structure contibuted by the iterative rule.

(21) a. *ká.las.tè.le.mì.nen*

	⌣ – ⌣ ⌣ ⌣ –
$\mathrm{GF}_{\#}$	《⌣ – ⌣ ⌣ ⌣ –
$\mathrm{GF}_{\mathrm{LH}}$	does not apply
GB	《⌣ –〉⌣ ⌣ ⌣ –
GB	《⌣ –〉⌣ ⌣〉⌣ –
GB	《⌣ –〉⌣ ⌣〉⌣ –〉
	(⌣́ –)(⌣̀ ⌣)(⌣̀ ⌣)

b. jắr.jes.tèl.mäl.li.sỳy.dël.lằ.ni

	– – – – ⌣ – ⌣ ⌣
$\mathrm{GF}_{\#}$	《– – – – ⌣ – – ⌣ ⌣
$\mathrm{GF}_{\mathrm{LH}}$	《– – – – ⌣《– – ⌣ ⌣
GB	《– –〉– – ⌣《– –〉⌣ ⌣
GB	《– –〉– –〉⌣《– –〉⌣ ⌣〉
	(–́ –)(–̀ –)⌣(–̀ –)(⌣̀ ⌣)

c. *vói.mis.te.lùt.te.le.màs.ta*

	– – ⌣ – ⌣ ⌣ – ⌣
$\mathrm{GF}_{\#}$	《– – ⌣ – ⌣ ⌣ – ⌣
$\mathrm{GF}_{\mathrm{LH}}$	《– – ⌣《– ⌣ ⌣《– ⌣
GB	《– –〉⌣《– ⌣〉⌣《– ⌣〉
	(–́ –)⌣(–́ ⌣)⌣(–́ ⌣)

d. *rá.vin.tò.lat*

	⌣ – ⌣ –
$\mathrm{GF}_{\#}$	《⌣ – ⌣ –
$\mathrm{GF}_{\mathrm{LH}}$	does not apply
GB	《⌣ –〉⌣ –
GB	《⌣ –〉⌣ –〉
	(⌣́ –)(⌣́ –)

6. The Finnish data in this section is from Karttunen (2006), taken from Elenbaas (1999) and Kiparsky (2003)

Both heavy beats follow light beats in (21d), but GF_{LH} applies to neither. In spite of the fact that GF_{LH}-marking biases the system towards situating heavy beats in foot initial position, hence a position in which they would be stressed, neither heavy syllable is stressed.

4.3. The Once and Done Principle[7]

How does the derivation proceed step by step? The Finnish system illustrates that marking rules can apply at multiple positions away from the edges. This raise a problem for keeping track of the place where the iterative rule applies. It is more complicated than simply introducing multiple cursors, because it is necessary to keep track of where rules have already applied. If there is a single cursor, the compution cannot target the same beat twice. But if there are multiple cursor which steps after each application of a subrule of the iterative rule, more care must be taken. I will assume that initially all the beats are *active*; that is, potential targets.

(22) *Once and Done Principle*: Each application of a marking rule renders the beats it applies to inactive. Each instance in which the iterative rule targets a beat renders it inactive, whether or not any of the subrules of the iterative rule are applicable.[8]

The Once and Done Principle means that the set of potential targets of the delimiter insertion rules progressively narrows as the computation proceeds. This makes the computation more efficient. But there are empirical consequences as well. Latin provides a good example. The footing system is (23).

(23) Latin footing system

$$\left.\begin{array}{l} \times \rightarrow \rangle \times \;/\; \_\_\# \\ [\times \rightarrow \langle \times]_{\mathrm{RL}} \end{array}\right\} ;\ {*}\textsc{Deg} \qquad \begin{array}{l} (GF_{\#}) \\ (GB) \end{array}$$

*Deg is violated only by light beats which violate *Unary.

Without the Once and Done Principle we get the derivation (24a), with it we get the derivation (24b). Stress in Latin is trochaic, with only the rightmost foot stress surfacing.

---

7. This was renamed the Free Beat Condition in later work.

8. One could assume that the iterative rule always includes a last resort ‘do nothing’ option, whose application does not insert a delimiter but does change the representation by moving the cursor.

(24) a.

$$\begin{array}{ll} & \smile\ \smile\ - \\ \mathrm{GF}_{\#} & \smile\ \smile\rangle - \\ \mathrm{GB} & \smile\ \smile\rangle\langle - \\ \mathrm{GB} & \langle\smile\ \smile\rangle\langle - \\ & \textit{*si.mu.lá:} \end{array}$$

b.

$$\begin{array}{ll} & \smile\ \smile\ - \\ \mathrm{GF}_{\#} & \smile\ \smile\rangle - \\ \mathrm{GB} & \langle\smile\ \smile\rangle - \\ & \textit{sí.mu.la:} \end{array}$$

The Once and Done Principle is also responsible for a similar phenomenon in Manam; as well as otherwise puzzling stretches of unstressed syllables in Winnebago; as well as well as an unexpected gap between stressed syllables in Indonesian when a suffix is concatenated.

The transformation of the current state has no access to the history of the derivation other than what that history has contributed to the current state. Some way is needed to mark the inactive beats. Inactivity is a property which will be indicated by an asterisk below the beat. The *current targets* of the iterative rule, if the direction is LR, are all the active beats which do not have an active beat immediately to their left. They are often indicated by cursors. If we redo (24b) to indicate inactivity, the derivation is (25). Marking the inactive beats explicitly makes it much easier to follow the course of a derivation.

(25)

$$\begin{array}{ll} & \smile\ \smile\ \underset{\blacktriangle}{-} \\ \mathrm{GF}_{\#} & \smile\ \underset{\blacktriangle}{\smile}\rangle\underset{*}{-} \\ & \underset{\blacktriangle}{\smile}\ \underset{*}{\smile}\rangle\underset{*}{-} \\ \mathrm{GB} & \langle\underset{*}{\smile}\ \underset{*}{\smile}\rangle\underset{*}{-} \\ & \textit{sí.mu.la:} \end{array}$$

We can redo some of the derivations in (21) to more clearly specify inactivity.

(26) a. *vói.mis.te.lùt.te.le.màs.ta*

$$\begin{array}{ll} & -\ -\ \smile\ -\ \smile\ \smile\ -\ \smile \\ \mathrm{GF}_{\#} & \langle\!\langle\underset{*}{-}\ -\ \smile\ -\ \smile\ \smile\ -\ \smile \\ \mathrm{GF}_{\mathrm{LH}} & \langle\!\langle\underset{*}{-}\ \underset{\blacktriangle}{-}\ \smile\langle\!\langle\underset{*}{-}\ \underset{\blacktriangle}{\smile}\ \smile\langle\!\langle\underset{*}{-}\ \underset{\blacktriangle}{\smile} \\ \mathrm{GB} & \langle\!\langle\underset{*}{-}\ \underset{*}{-}\rangle\underset{\blacktriangle}{\smile}\langle\!\langle\underset{*}{-}\ \underset{*}{\smile}\rangle\underset{\blacktriangle}{\smile}\langle\!\langle\underset{*}{-}\ \underset{*}{\smile}\rangle \\ & \langle\!\langle\underset{*}{-}\ \underset{*}{-}\rangle\underset{*}{\smile}\langle\!\langle\underset{*}{-}\ \underset{*}{\smile}\rangle\underset{*}{\smile}\langle\!\langle\underset{*}{-}\ \underset{*}{\smile}\rangle \\ & (\acute{-}\ -)\smile(\acute{-}\ \smile)\smile(\acute{-}\ \smile) \end{array}$$

b. *rá.vin.tò.lat*

$$\begin{array}{ll} & \smile\ -\ \smile\ - \\ \mathrm{GF}_{\#} & \langle\!\langle\underset{*}{\smile}\ \underset{\blacktriangle}{-}\ \smile\ - \\ \mathrm{GB} & \langle\!\langle\underset{*}{\smile}\ \underset{*}{-}\rangle\underset{\blacktriangle}{\smile}\ - \\ & \langle\!\langle\underset{*}{\smile}\ \underset{*}{-}\rangle\underset{*}{\smile}\ \underset{\blacktriangle}{-} \\ \mathrm{GB} & \langle\!\langle\underset{*}{\smile}\ \underset{*}{-}\rangle\underset{*}{\smile}\ \underset{*}{-}\rangle \\ & (\acute{\smile}\ -)(\acute{\smile}\ -) \end{array}$$

Cursors are not introduced until after all the marking rules have applied since they are only relevant to iterative footing.

The locations of the cursors can be inferred from the locations of the inactive beats. In an LR system, the current targets (indicated by cursors) are the active beats which do not have an active beat to their left. Cursors can be viewed as either an aid to the reader with the grammar figuring out what the current targets are at each step, or as an aspect of the current state of the system. The former view minimizes the complexity of the representation, the latter minimizes complexity of the computation which must be done. Rather than determine the cursor locations at each stage from scratch, a simple rule relocating the cursors in each step is sufficient; move it to the right if that beat is active, otherwise eliminate it.

After the marking rules apply, before the iterative rule applies, the state of the beat line will be

$$\delta_0 \times \cdots \times \delta_1 \times \cdots \times \delta_2 \times \cdots \times \delta_{n-1} \times \cdots \times \delta_n$$

where all of the $\times$ are active, there are no active beats in any of the δ_j, and δ_j is nonempty for $1 < j < n$. Each of the nonempty δ_j must contain a juncture or a delimiter which has been inserted by a marking rule. Call the $\times \cdots \times$ strings 'active islands'. Since they are separated by delimiters, the operation of the iterative rule on one active island is independent of what happens in another of the active islands. Each active island will contain a current target at one of its edges; which edge is determined by the directionality of the system. I will assume that at each stage the iterative rule applies simultaneously to all of the current targets, as in (26a) in which GB applies to 3 different targets in one step

5. Locality and periodicity

This section proves an important result about schemes of LDIRs; they produce either binary or ternary footing. It is quite technical and some readers may chose to skip it. It will not compromise their ability to understand the sections which follow.

I will assume in this section that iteration is LR, left to right. The RL result is entirely analogous. We start with an infinite string of propertyless beats in a given left context and try to show that as R iterates across the string the derivation produces a periodic pattern. We start with (27).

(27) $\alpha\, \underset{\blacktriangle}{\times}_1 \times_2 \times_3 \cdots \quad \overset{R}{\rightarrow} \quad \alpha\, \psi_1 \underset{\blacktriangle}{\times}_2 \times_3 \cdots \quad \overset{R}{\rightarrow} \quad \alpha\, \psi_1 \psi_2 \underset{\blacktriangle}{\times}_3 \cdots \quad \overset{R}{\rightarrow} \quad \alpha\, \psi_1 \psi_2 \psi_3 \cdots$

We would like to show that $\psi = \psi_1 \psi_2 \psi_3 \cdots$ fits one of the following patterns. Exactly what 'fits' means will be made precise shortly.

(28)	*name*	*pattern*
a.	aperiodic	$\times\times\times\cdots$
b.	LR binary	$\times\times\rangle\times\times\rangle\times\times\rangle\cdots$
c.	RL binary	$\times\times\langle\times\times\langle\times\times\langle\cdots$
d.	2-sided binary	$\times\times\rangle\langle\times\times\rangle\langle\times\times\rangle\langle\cdots$
e.	gapped binary	$\times\times\rangle\times\langle\times\times\rangle\times\langle\times\times\rangle\times\langle\cdots$

It is too much to ask that ψ be exactly one of the patterns in (28) because α can influence the application of R close to the left edge. But we can prove Theorem 1 below. Two preliminary lemmas will be needed to prove the theorem..

Theorem 1: Given R, there is a pattern P in (28) such that $\psi_1\psi_2\psi_3\cdots$ can be written as uP, where u has at most 2 beats.

The key to proving (29) is to focus on those pairs of beats $\times_{i-1}\times_i$ whose adjacency persists in the output. Call such pairs *persistent pairs* and $\times_i$ a *pivot*. There must be many persistent pairs because a persistent pair must follow any occurrence of $\langle$ and a persistent pair must precede any occurrence of $\rangle$. If $\times_i\times_{i+1}\times_{i+2}$ is in ψ, both $\times_{i+1}$ and $\times_{i+2}$ are pivots.

Let r_j be the subrule of R which is applied at $\times_j$ or Shift in case R is not applicable at $\times_j$.

Lemma 1: If $\times_i$ and $\times_j$ are pivots, then $\psi_i = \psi_j$, $\psi_{i+1} = \psi_{j+1}$, $\psi_{i+2} = \psi_{j+2}$, ...
Proof: If $\times_j$ is a pivot, then r_j must be a right rule, otherwise the $\times_{j-1}$ and $\times_j$ would not remain adjacent. Therefore r_j it is the highest ranked right subrule of R which is applicable in the context $\times\_\_\times\times$, or Shift in case there is no such rule. The same is true of r_i, so $r_i = r_j$ and therefore $\psi_i = \psi_j$.

r_{i+1} applies in the context $\times\psi_i\_\_\times\times$ and r_{j+1} applies in the context $\times\psi_j\_\_\times\times$. $\psi_i = \psi_j$, so the extended neighborhood of $\times_{i+1}$ at the point that R applies to it is the same as the extended neighborhood of $\times_{j+1}$ at the point that R applies to it. So $r_{i+1} = r_{j+1}$. For $k > 1$, at the stage in the derivation at which they apply, r_{i+k} and r_{j+k} apply in the same context, $/\,\psi_{i+k-2}\psi_{i+k-1}\_\_\times\times = /\,\psi_{j+k-2}\psi_{j+k-1}\_\_\times\times$. This proves the lemma.

How far apart can persistent pairs be? It can happen that they overlap. In that case $\times_i\times_{i+1}\times_{i+2}$ is persistent. Since both $\times_{i+1}$ and $\times_{i+2}$ are pivots, $\psi_{i+k} = \psi_{i+1+k}$ for $k \geq 1$. Since $\psi_{i+1} = \times$, it follows that $\psi_{i+k} = \times$ for all $k \geq 1$. In this case we will say that ψ is *aperiodic*.

Lemma 2: Suppose $\times_i$ is a pivot and $\times_j$ is the leftmost pivot to the right of $\times_j$. If the persistent pairs $\times_{i-1}\times_i$ and $\times_{j-1}\times_j$ do not overlap, then they are separated by a string in $\Gamma = \{\rangle\ , \langle\ , \rangle\langle\ , \rangle\times\langle\ \}$.
Proof: Let u be the string that separates the two persistent pairs. $\times$ cannot be at either edge of u or adjacent to another $\times$. Since $\langle$ must be followed by $\times\times$, $\langle$ can occur only at the right edge of u. Similarly, $\rangle$ can only occur at the left edge of u. The only possibilities for u are the strings in Γ.

Using the two lemmas, we can prove Theorem 1. Let $\times_i$ be the leftmost pivot and $\times_j$ be the leftmost pivot to the right of $\times_i$. What follows the second persistent pair must be equivalent to what follows the first persistent pair. We conclude that if ψ is not aperiodic, then $\psi = u\times\times\gamma\times\times\gamma\times\times\gamma\cdots$, with γ in Γ. u cannot end with a beat and cannot contain a persistent pair. The only possibilities for u is one of the string in Γ , or $\times\gamma$ with $\gamma \in \Gamma$ or ε, the empty string. This proves Theorem 1.

We now consider finite strings of propertyless beats. Suppose R iterates across a string of propertyless beats in the context $/\,\alpha \_\_ \beta$,

$$\alpha\, \underset{\blacktriangle}{\times_1}\times_2\cdots\times_n\beta \;\rightarrow\; \alpha\,\psi_1\underset{\blacktriangle}{\times_2}\cdots\times_n\beta \;\rightarrow\; \cdots \;\rightarrow\; \alpha\,\psi_1\psi_2\cdots\underset{\blacktriangle}{\times_n}\beta \;\rightarrow\; \alpha\,\psi_1\psi_2\cdots\psi_n\beta$$

Theorem 2: $\psi_1\cdots\psi_n$ can be written as uvw, where u and w have at most 2 beats and v is a substring of one of the patterns (28).

We compare $\psi_1\psi_2\cdots\psi_n$ with what is produced in the unbounded case.

$$\alpha\, \underset{\blacktriangle}{\times_1}\times_2\times_3\cdots \;\rightarrow\; \alpha\,\phi_1\underset{\blacktriangle}{\times_2}\times_3\cdots \;\rightarrow\; \alpha\,\phi_1\phi_2\underset{\blacktriangle}{\times_3}\cdots \;\rightarrow\; \alpha\,\phi_1\phi_2\phi_3\cdots$$

$\phi_k = \psi_k$ if $k < n-1$ because the extended neighborhood of $\times_k$ in the finite case is the same as the extended neighborhood of $\times_k$ in the unbounded case. Consequentially,

$$\phi_1\phi_2\ldots\phi_{n-2}\phi_{n-1}\phi_n = \psi_1\psi_2\ldots\psi_{n-2}\phi_{n-1}\phi_n$$

$\phi_{n-1}\phi_n$ has 2 beats. If we combine this with Theorem (29), we have a proof of (32).

6. The core iterative footing rules

Much attention has been given to the various ways in which footing systems are sensitive to beats which have a heaviness property. This is the focus of the next section. The particularities of the stress system which are related to heaviness can be viewed as modifications of more basic systems which are motivated by improvement in the alignment of metrical stress with inherent stress.

But there is a range of choices which do not seem to have any ‘motivation’. No reason can be given for why a language has iambic versus trochaic stress, or is LR versus RL, of footing is binary versus ternary, or whether if has rhythmic or arhythmic stress. These characteristics of the stress systems simply have to be stipulated. The approach to this matter in this section is to assume that if the choice is made to have rhythmic stress, the basic rule is straightforward binary stress. There are 4 core rules, either the basic rule, or the basic rule modified by 2 choices, ternary/binary, persistent/non-persistent.

What I call the core rules are variations in the more basic rule, simple binary footing. There are two common variations, a ternary variation and a non-persistent variations, so there are 4 possible core iterative rules; 8 if we view LR/RL as a variation. (33) has the 4 varieties of the LR iterative rule.

(33)

	Binary	*Ternary*
Persistent	$[\times\rightarrow\times\rangle]_{LR}$; *Unary	$\begin{bmatrix}\times\rightarrow\times\rangle \\ \times\rightarrow\times\langle\end{bmatrix}_{LR}$; *Unary
Non-persistent	$[\times\rightarrow\times\rangle\ /\ \_\_\times]_{LR}$; *Unary	$\begin{bmatrix}\times\rightarrow\times\rangle\ /\ \_\_\times \\ \times\rightarrow\times\langle\end{bmatrix}_{LR}$; *Unary

6.1. The ternary variant

The validity of viewing ternary footing as a variant of binary footing is supported by the stress systems of several languages which alternate between binary and ternary stress patterns. Estonian is the most prominent example. Hayes (1995) used that metrical system as a model for his theory of weak local parsing, which proposed that there is a parametric choice in a parsing algorithm which in the ternary setting, feet had to be separated by an unfooted beat. I ignore here complications of heavy beats. In the present framework, the footing system is (34).

(34) Estonian footing (light beats only)

$\times \rightarrow \langle\times\ /\ \#\_\_$ ($GF_{\#}$)

$\begin{bmatrix}\times \rightarrow \times\rangle \\ \times \rightarrow \times\langle\,\dagger\end{bmatrix}_{LR}$ (GB) (GF^{x}) the dagger † indicates optionality

Stress is trochaic with main stress left.

(35) illustrates the variation. On the left is straightforward binary footing, GF^{x} does not apply. On the right, GF^{x} does apply.

(35)

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$GF_{\#}$ ⟪× $\underset{\blacktriangle}{\times}$ × × × ×

GB ⟪× ×⟩$\underset{\blacktriangle}{\times}$ × × ×

↙ binary ↘ ternary

binary		ternary	
	⟪× ×⟩× $\underset{\blacktriangle}{\times}$ × ×	GF^{x}	⟪× ×⟩×⟨$\underset{\blacktriangle}{\times}$ × ×
GB	⟪× ×⟩× ×⟩$\underset{\blacktriangle}{\times}$ ×		⟪× ×⟩×⟨× $\underset{\blacktriangle}{\times}$ ×
	⟪× ×⟩× ×⟩× $\underset{\blacktriangle}{\times}$	GB	⟪× ×⟩×⟨× ×⟩$\underset{\blacktriangle}{\times}$
GB	⟪× ×⟩× ×⟩× ×⟩		⟪× ×⟩×⟨× ×⟩×
	ó.sa.và.ma.lè.ki		*ó.sa.va.mà.le.ki*

There must be at least 5 beats in order to give GF^{x} a chance to apply. GF^{x} is always applicable in the context ⟩__×× , but is never applicable in the context ⟩__×# because it would create a unary foot.

6.2. The non-persistent variant

6.2.1. Binary systems

Compare the system (36a) with persistent binary rule and (36b) with the non-persistent binary rule.

(36) a. *Persistent*

$$\left.\begin{array}{l} \times \rightarrow \langle \times \;/\; \#\_\_ \\ [\times \rightarrow \times\rangle]_{LR} \end{array}\right\} ;\ {}^{*}\textsc{Unary}$$

b. *Non-persistent*

$$\left.\begin{array}{l} \times \rightarrow \langle \times \;/\; \#\_\_ \\ [\times \rightarrow \times\rangle \;/\; \_\_\times]_{LR} \end{array}\right\} ;\ {}^{*}\textsc{Unary}$$

Both systems have the LR binary characteristic pattern $(\times\times\rangle)^{\infty}$, but there are different right edge effects. In words with 3, 5, 7, ... beats, they produce exactly the same footing. But compare (37a), generated by (36a), with (37b), generated by (36b).

(37) *Persistent* ⟪× ×⟩× ×⟩$\underset{\blacktriangle}{\times}$ × →⟪× ×⟩× ×⟩× $\underset{\blacktriangle}{\times}$ →⟪× ×⟩× ×⟩× ×⟩

Non-persistent ⟪× ×⟩× ×⟩$\underset{\blacktriangle}{\times}$ × →⟪× ×⟩× ×⟩× $\underset{\blacktriangle}{\times}$ →⟪× ×⟩× ×⟩× ×

GB, with no structural condition, applies at the right edge but GB restricted by the structual condition / __× does not. In words with 4, 6, 8, ... beats, 2 unfooted beats are left at the right edge if footing uses the non-persistent variant.

A comparison of Cairene Arabic (CA) and Palestinian Arabic (PA) illustrates the difference between persistent and non-persistent binary footing. Both systems have trochaic stress and in both systems the leftmost beat in the rightmost foot gets main stress;

with no secondary stress. There is some common vocabulary, which makes a comparison striking.

(38) CA PA

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$$
\begin{array}{ll}
\mathrm{GF}_{\#} & \langle\!\langle \smile \underset{\blacktriangle}{\smile} \smile \smile \\
\mathrm{GB} & \langle\!\langle \smile \smile\rangle \underset{\blacktriangle}{\smile} \smile \\
 & \langle\!\langle \smile \smile\rangle \smile \underset{\blacktriangle}{\smile}
\end{array}
$$

$\swarrow$ binary $\searrow$ non-persistent binary

GB $\langle\!\langle \smile \smile\rangle \smile \smile\rangle$ $\langle\!\langle \smile \smile\rangle \smile \smile$

ba.ka.rí.to *bá.ka.ri.to*

If the word has an odd number of syllables, GB does not apply to the last beat in the CA derivation. Consequently, there is no alternation. Stress is *sa.ǰa.rá.tu.hu* in both Cairene and Palestinian Arabic.

Many accounts of the 3 final unstressed beats analyze PA stress by introducting the notion 'extrametrical foot'. It is stipulated that word-final feet in PA, if there are multiple feet, is extrametrical. Non-persistence in those accounts is supposed to be only a phenomenon of ternary footing, as in the next example. This

6.2.2. Gapped binary (ternary) systems

There is a similar contrast between systems with a gapped binary patterns that exclude the far edge as a potential target of GB and those that do not.

(39) a. *Persistent* b. *Non-persistent*

$$
\left.\begin{array}{l}
\times \rightarrow \langle \times \ / \ \#\_\_ \\
\left[\begin{array}{l} \times \rightarrow \times\rangle \\ \times \rightarrow \times\rangle \end{array}\right]_{\mathrm{LR}}
\end{array}\right\} ; {}^*\textsc{Unary}
\qquad
\left.\begin{array}{l}
\times \rightarrow \langle \times \ / \ \#\_\_ \\
\left[\begin{array}{l} \times \rightarrow \times\rangle \ / \ \_\_\times \\ \times \rightarrow \times\rangle \end{array}\right]_{\mathrm{LR}}
\end{array}\right\} ; {}^*\textsc{Unary}
$$

Both systems have the characteristic pattern $(\times\times\rangle\times\langle)^{\infty}$, but there are different far edge effects. Compare (40), generated by (39a), with (41), generated by (39b).

(40) Persistent ternary footing using (39a)

$$
\begin{array}{lll}
[3] & \langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times & (\times\ \times)\times \\
[4] & \langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times}\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times\ \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times\ \times\rangle & (\times\ \times)(\times\ \times) \\
[5] & \langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times}\ \times\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times \langle \underset{\blacktriangle}{\times}\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times \langle \times\ \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times \langle \times\ \times\rangle & (\times\ \times)\times(\times\ \times)
\end{array}
$$

(41) Non-persistent ternary footing using (39b)

[3]	$\langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times$	$(\times\ \times)\times$
[4]	$\langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times}\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times\ \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times\ \times$	$(\times\ \times)\times\ \times$
[5]	$\langle\!\langle \times\ \times\rangle \underset{\blacktriangle}{\times}\ \times\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times\langle \underset{\blacktriangle}{\times}\ \times \rightarrow \langle\!\langle \times\ \times\rangle \times\langle \times\ \underset{\blacktriangle}{\times} \rightarrow \langle\!\langle \times\ \times\rangle \times\langle \times\ \times$	$(\times\ \times)\times(\times\ \times)$

The feet above which are generated are the same except in the case of 4 beats. Non-persistence manifests itself only if there are 4, 7, 10, . . . beats.

The stress rules of the much discussed Cayuvava stress system is a variant of (39b), iterated from right to left. Only the edge marking rule is altered. It keeps the right edge beat out of the initial foot and is not subject to *Unary. The effect of the alteration is to exclude the right edge beat from the initial foot. Dropping the derivational constraint on the edge-marking rule is crucial in accounting for (43a).

(42)

$$\begin{array}{ll} \boxed{\times \rightarrow \rangle\times\ /\ \_\_\#} & (\mathrm{GF}^{\mathrm{x}}_{\#}) \\ \left.\begin{bmatrix} \times \rightarrow \langle\times \\ \times \rightarrow \rangle\times \end{bmatrix}_{\mathrm{RL}} \right\}\ ;\ {}^{*}\textsc{Unary} & \begin{array}{l}(\mathrm{GB}) \\ (\mathrm{GF}^{\mathrm{x}})\end{array} \end{array}$$

The last line in the derivations below show what the result of later trochaic stress assignment will be. In Cayuvava, beats are in 1-1 correspondence with syllables. In (43a) it is crucial that $\mathrm{GF}^{\mathrm{x}}_{\#}$ is not restricted by *Unary. (43d,g), with multiple unfooted syllables at the left edge, are particularly interesting.

(43)

a.
$$\begin{array}{ll} & \times\ \underset{\blacktriangle}{\times} \\ \mathrm{GF}^{\mathrm{x}}_{\#} & \underset{\blacktriangle}{\times}\rangle\!\rangle\times \\ & \times\rangle\!\rangle\times \\ & (\acute{\sigma}\ \sigma) \end{array}$$

b.
$$\begin{array}{ll} & \times\ \times\ \underset{\blacktriangle}{\times} \\ \mathrm{GF}^{\mathrm{x}}_{\#} & \times\ \underset{\blacktriangle}{\times}\rangle\!\rangle\times \\ & \underset{\blacktriangle}{\times}\ \times\rangle\!\rangle\times \\ & \times\ \times\rangle\!\rangle\times \\ & (\acute{\sigma}\ \sigma)\sigma \end{array}$$

c.
$$\begin{array}{ll} & \times\ \times\ \times\ \underset{\blacktriangle}{\times} \\ \mathrm{GF}^{\mathrm{x}}_{\#} & \times\ \times\ \underset{\blacktriangle}{\times}\rangle\!\rangle\times \\ & \times\ \underset{\blacktriangle}{\times}\ \times\rangle\!\rangle\times \\ \mathrm{GB} & \underset{\blacktriangle}{\times}\langle\times\ \times\rangle\!\rangle\times \\ & \times\langle\times\ \times\rangle\!\rangle\times \\ & \sigma(\acute{\sigma}\ \sigma)\sigma \end{array}$$

d.
$$\begin{array}{ll} & \times\ \times\ \times\ \times\ \underset{\blacktriangle}{\times} \\ \mathrm{GF}^{\mathrm{x}}_{\#} & \times\ \times\ \times\ \underset{\blacktriangle}{\times}\rangle\!\rangle\times \\ & \times\ \times\ \underset{\blacktriangle}{\times}\ \times\rangle\!\rangle\times \\ \mathrm{GB} & \times\ \underset{\blacktriangle}{\times}\langle\times\ \times\rangle\!\rangle\times \\ & \underset{\blacktriangle}{\times}\ \times\langle\times\ \times\rangle\!\rangle\times \\ & \times\ \times\langle\times\ \times\rangle\!\rangle\times \\ & \sigma\ \sigma(\acute{\sigma}\ \sigma)\sigma \end{array}$$

e.
$$\begin{array}{ll} & \times\ \times\ \times\ \times\ \times\ \underset{\blacktriangle}{\times} \\ & \vdots \\ \mathrm{GB} & \times\ \times\ \underset{\blacktriangle}{\times}\langle\times\ \times\rangle\!\rangle\times \\ \mathrm{GF}^{\mathrm{x}} & \times\ \underset{\blacktriangle}{\times}\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \underset{\blacktriangle}{\times}\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & (\acute{\sigma}\ \sigma)\sigma(\acute{\sigma}\ \sigma)\sigma \end{array}$$

f.
$$\begin{array}{ll} & \times\ \times\ \times\ \times\ \times\ \times\ \underset{\blacktriangle}{\times} \\ & \vdots \\ \mathrm{GB} & \underset{\blacktriangle}{\times}\langle\times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \times\langle\times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \sigma(\acute{\sigma}\ \sigma)\sigma(\acute{\sigma}\ \sigma)\sigma \end{array}$$

g.
$$\begin{array}{ll} & \times\ \times\ \times\ \times\ \times\ \times\ \times\ \underset{\blacktriangle}{\times} \\ & \vdots \\ \mathrm{GB} & \times\ \underset{\blacktriangle}{\times}\langle\times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \underset{\blacktriangle}{\times}\ \times\langle\times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \times\ \times\langle\times\ \times\rangle\times\langle\times\ \times\rangle\!\rangle\times \\ & \sigma\ \sigma(\acute{\sigma}\ \sigma)\sigma(\acute{\sigma}\ \sigma)\sigma \end{array}$$

The persistent versus non-persistent terminology derives from the explanation that Hayes (1995) gave for the contrast between (40a) and (40b) in terms of ‘persistent footing’. The idea was that the algorithm that grouped beats into feet in the ternary case produced (40a), but in (40b) footing was persistent, so the algorithm applied a second time (persistently) and grouped the two unfooted beats in (40b) into a foot. The account here is quite different, extending to binary footing. The terminology has been retained for historical reasons.

The two more or less complete analyses of Chugach and Tripura Bangla which follow have gapped binary systems. Chugach is mora-counting (beats project from moras) and Tripura Bangla is syllable-counting (beats project from syllables). Both are trochaic. The Chugach system has persistent GB; the Tripura Bangla system has non-persistent GB.

7. Heaviness

LDIRs can be sensitive to the properties of the target and/or its neighbors. It is well-known that in some languages the foot structure is distorted in way that favors putting heavy syllables in a position where they will be stressed.[9]

7.1. Alignment of inherent syllable stress and metrical stress

I follow the conclusion of Prince (1983, p. 58) that “the light-heavy distinction is really one of sonority.” Alongside the inherent sonority of heavy syllables, which is one kind of prominence, there is the another kind of prominence that comes from metrical structure. There is a tension between these two kinds of prominence, which is resolved if the footing process puts heavy beats in positions in which they will be assigned metrical stress. I call this *alignment*; heavy syllable sonority/prominence aligned with metrical prominence. It is natural to speculate that confusion between inherent heavy syllable stress and metrical stress on the part of the language learner might lead to the diachronic drift of stress systems in the direction of better alignment of inherent and metrical prominence. The consequence of this is that we expect that many systems will depart from the basic binary or ternary system in ways that increase the chances that heavy syllables end up in positions that receive metrical stress.

9. It is more accurate to say that in some syllable-counting languages there is subclass of the possible syllable shapes and a beat property which reflects that subclass, and the footing rules are sensitive to that property.

I explicitly assume that *the delimiter insertion rules conspire with the stress assignment rules*, which come later in the derivation, to promote the alignment of inherent heavy syllable stress with metrical stress. Although ‘conspiracy’ has gotten a bad name, it is commonplace for different submodules of a biological system to conspire. Think about the muscles in the arm. The design of each muscle is shaped to mesh with the design of other muscles. It would be ludicrous to question the conspiracy between the design of the triceps and the biceps. The reason that the conspiracy is to be expected is that the two designs work together to satisfy properties that are external to the muscles themselves. The pressure for alignment is external to the stress computation itself, presumably involving stable learnability. So it should be no surprise that the delimiter insertion rules conspire with the stress assignment rules.

The stance here is related to the stance of OT. Prince (1990), in the period immediately before launching the OT program, said “there is a substantial class of rules whose *mode of operation* [my italics] is to increase well-formedness of representations.”[10] What we claim here is not that derivational steps are directly under the influence of well-formedness considerations, but that the design of rule systems is under that influence.

The Finnish stress system (§10) provided a particularly simple example of how the basic binary system adapts to promote alignment. Below are two more examples which show how the basic ternary systems can be modified to promote alignment. One is in a language, Tripura Bangla, which projects beats from syllables (a ‘syllable-counting’ language). The other is in a language, Chugach, which projects beats from moras (a ‘mora-counting’ language).

7.2. Tripura Bangla, a syllable counting language

The thesis of Das (2001) analyzes the stress system of Tripura Bangla (TB), a dialect of Bengali. In the examples below, the foot structure is conjectural, but will soon be justified.

We start with words with only light syllables. All the examples, here and it what follows, except as noted, are from Das’ thesis, pp. 200-203.

10. It is a short step from thinking that what controls derivational steps is well-formedness to abandoning derivational steps and relying on well-formedness alone to determine outcomes.

(44)
a.	*gó.ra*	(◡́ ◡)	‘root’
b.	*bá.ta.ʃa*	(◡́ ◡)◡	‘type of candy’
c.	*kɛ́.ra.mo.ti*	(◡́ ◡)◡ ◡	‘ingenuity’
d.	*ϕó.ri.sa.lɔ̀.na*	(◡́ ◡)◡(◡́ ◡)	‘direction’
e.	*ϕró.yo.zo.nɪ̀.yɔ.ta*	(◡́ ◡)◡(◡́ ◡)◡	‘necessity’
f.	*ó.no.nu.ʃɔ̀.ro.ni.yɔ*	(◡́ ◡)◡(◡́ ◡)◡ ◡	‘unfollowable’

This is one of the basic LR ternary patterns, the non-persistent variety (see §6.2.2), with trochaic stress. So we start from (45).

(45)
$$\left.\begin{array}{l} \times \rightarrow \langle \times \ / \ \_\_\# \\ \left[\begin{array}{l} \times \rightarrow \times\rangle \ / \ \_\_\times \\ \times \rightarrow \times\langle \end{array}\right]_{\mathrm{LR}} \end{array}\right\} ;\ {*}\textsc{Unary} \qquad \begin{array}{l} (\mathrm{GF}_{\#}) \\ (\mathrm{GB}) \\ (\mathrm{GF}^{\mathrm{x}}) \end{array}$$

Some illustrative derivations follow.

(46)
a. *gó.ra*	b. *kɛ́.ra.mo.ti*	c. *ϕó.ri.sa.lɔ̀.na*	d. *ϕró.yo.zo.nɪ̀.yɔ.ta*
◡ ◡	◡ ◡ ◡ ◡	◡ ◡ ◡ ◡ ◡	◡ ◡ ◡ ◡ ◡ ◡
$\mathrm{GF}_{\#}$ 《◡ ◡	$\mathrm{GF}_{\#}$ 《◡ ◡ ◡ ◡	$\mathrm{GF}_{\#}$ 《◡ ◡ ◡ ◡ ◡	$\mathrm{GF}_{\#}$ 《◡ ◡ ◡ ◡ ◡ ◡
《◡ ◡	GB 《◡ ◡〉◡ ◡	GB 《◡ ◡〉◡ ◡ ◡	GB 《◡ ◡〉◡ ◡ ◡ ◡
	《◡ ◡〉◡ ◡	GF^{x} 《◡ ◡〉◡〈◡ ◡	GF^{x} 《◡ ◡〉◡〈◡ ◡ ◡
	《◡ ◡〉◡ ◡	《◡ ◡〉◡〈◡ ◡	《◡ ◡〉◡〈◡ ◡ ◡
		《◡ ◡〉◡〈◡ ◡	GB 《◡ ◡〉◡〈◡ ◡〉◡
			《◡ ◡〉◡〈◡ ◡〉◡

Beats projected from bimoraic syllables, heavy beats, distort the pattern (44) in various ways. Some examples are given below.

(47)
a.	*ʃɔ́ŋ.rɔk.kɔ̀n*	(–́ –)(–́)	‘reservation’
b.	*ϕó.ri.bɛ̀ʃ*	(◡́ ◡)(–́)	‘environment’
c.	*ó.nu.kɔ̀m.pa*	(◡́ ◡)(–́ ◡)	‘compassion’
d.	*ó.β’i.nɔ̀n.dɔn*	(◡́ ◡)(–́ –)	‘congratulations’
e.	*ó.nu.bòt.ti.ta*	(◡́ ◡)(–́ ◡)◡	‘obedience’
f.	*ϕá.rɔ.dɔ̀ʃ.ʃi.kɔ.ta*	(◡́ ◡)(–́ ◡)◡ ◡	‘expertness’

There are two things to be noted. First, final unary feet must be permitted if they consist of a single heavy beat. Second, heavy syllables are always footed in the context / $\acute{\sigma}\sigma$__.

The first issue is simply dealt with by suitably weakening the derivational constraint to exempt final heavy syllables from the constraint. Call the revised constraint *Unary$_{\text{T}}$. In a trochaic system, allowing final unary feet does not lead to stress clash.[11] One can speculate that the benefit of aligning the final heavy syllable motivates a departure from the default, given that no stress clash results. The cost of relaxing *Unary in the TB system is small, but it makes a significant contribution to improving alignment.

The second issue is most straightforwardly dealt with by assuming that there is a subrule of the iterative rule scheme $- \rightarrow \langle -$ which is ordered before GB. Call it GF$_{\text{H}}$. Unlike Finnish, it cannot be a marking rule in TB because examples like (47d) show that is directional. The iterative rule is strongly biased in favor of alignment. It makes every heavy beat it encounters foot initial, unless *Unary prevents it.

(48)
$$
\begin{array}{ll}
\times \rightarrow \langle \times \;/\; \_\_\# \;\; ; \text{*Unary} & (\text{GF}_{\#}) \\
\left.\begin{bmatrix} - \rightarrow \langle - \\ \times \rightarrow \times \rangle \;/\; \_\_\times \\ \times \rightarrow \times \langle \end{bmatrix}_{\text{LR}} \right\} ; \text{*Unary}_{\text{T}} & \begin{array}{l} (\text{GF}_{\text{H}}) \\ (\text{GB}) \\ (\text{GF}^{\text{x}}) \end{array}
\end{array}
$$

*Unary has been relaxed as a constraint on the iterative rule, but the edge-marking rule is subject to the stronger *Unary. TB does not have monosyllabic words, even if the syllable is heavy. *Unary constraining GF$_{\#}$ prevents it from footing such a word. But an explanation is still needed for why a word consisting of a single heavy syllable is not footed by GF$_{\text{H}}$. The simplest explanation is to assume that edge-marking is obligatory in TB.

Some worked derivations.

11. The fact that Finnish, for example, has a similar trochaic system but does not relax *Unary to *Unary$_{\text{T}}$, shows that the explicit introduction of *Unary$_{\text{T}}$ into the system is needed; its effect does not follow from stress clash avoidance.

(49)

a. *ó.nu.bɔ̀t.ti.ta*	b. *ɸó.ri.bɛ̀ʃ*	c. *ɔ́.ma.no.ʃìk*
◡ ◡ – ◡ ◡	◡ ◡ –	◡ ◡ ◡ –
GF$_{\#}$ ⟪◡ ◡ – ◡ ◡	GF$_{\#}$ ⟪◡ ◡ –	GF$_{\#}$ ⟪◡ ◡ ◡ –
GB ⟪◡ ◡⟩– ◡ ◡	GB ⟪◡ ◡⟩–	GB ⟪◡ ◡⟩◡ –
GF$_{H}$ ⟪◡ ◡⟩⟨– ◡ ◡	GF$_{H}$ ⟪◡ ◡⟩⟨–	GF^{x} ⟪◡ ◡⟩◡⟨–
GB ⟪◡ ◡⟨– ◡⟩◡		GB ⟪◡ ◡⟩◡⟨–⟩
⟪◡ ◡⟨– ◡⟩◡		

Below are further examples which (45) accounts for. Glosses are in footnote 12.

(50) a.	*aít.na, ʃɔ́r.kar, ɸá.til*	⟪× ◡
b.	*ɸák.na.mi, ʃɔ́m.pot.ti*	⟪– ×⟩◡
c.	*dúr.gɔ.ʈɔ.na, ʃɔ́m.por.ki.tɔ*	⟪– ×⟩◡ ◡
d.	*ɔ́.ma.no.ʃìk*	⟪◡ ◡⟩◡⟨–
e.	*ʃán.bi.da.nìk, dúr.bit.ta.yɔ̀n*	⟪– ×⟩◡⟨–
f.	*ɸɔ́dʒ.dʒa.lɔ.sɔ̀.na, ɸɔ́k.kɔ.ɸa.tìt.tɔ*	⟪– ◡⟩◡⟨× ◡
g.	*ɔ́.ɸo.ri.hàidʒ.dʒɔ, ɔ́.nɔ.bɔ.lɔ̀m.bɔn*	⟪◡ ◡⟩◡⟨– ×
h.	*ɔ́.ɸo.ri.bɔ̀t.ti.tɔ*	⟪◡ ◡⟩◡⟨– ◡⟩◡
i.	*ɔ́.ɸo.ri.bɔ̀t.to.ni.yɔ*	⟪◡ ◡⟩◡⟨– ◡⟩◡ ◡

Footing in these examples is essentially the same as if there were all light syllables. In the various place that GF$_{H}$ applies, GF^{x} would have produced the same outcome.

There are a few more examples from Das (p.c.) that are instructive.

(51) a.	*ɸɔ́ɟ.ɟa.lʊ.sɔ̀.nar*	⟪– ◡⟩◡⟨◡ –⟩	'of deliberation'
b.	*ʃá.rɔ.ma.nʊ̀.bɪk*	⟨◡ ◡⟩◡⟨◡ –⟩	'atomic'
c.	*ʃɔ́.ma.lʊ.sɔ̀.nar*	⟨◡ ◡⟩◡⟨◡ –⟩	'of criticism'

In each example, there is an unstressed final heavy syllable. Compare (50d,e) with (51a–c).

There is a plausible footing of the (51) examples in which the heavy final syllable would be stressed, namely $\langle\sigma\sigma\rangle$◡ ◡⟩⟨– . It is worth seeing why the derivation does not take the path.

11. (50a) 'veranda', 'government', 'earthen pot' [201]; (50b) 'precocity', 'wealth' [201]; (50c) 'accident', 'related' [202]; (50d) 'inhuman' [202]; (50e) 'constitutional', 'criminalization' [202]; (50f) 'deliberation', 'partisanship' [202]; (50g) 'inevitable', 'partisanship' [202]; (50h) 'unchanged' [203]; (50i) 'unchangeable' [203]

(52) GF$_{\#}$ 《× $\underset{\blacktriangle}{\times}$ ◡ ◡ –

GB 《× ×〉$\underset{\blacktriangle}{\smile}$ ◡ –

GF^{x} 《× ×〉◡〈$\underset{\blacktriangle}{\smile}$ –

《× ×〉◡〈◡ $\underset{\blacktriangle}{-}$ GF^{x} is blocked by *Unary$_{T}$ (on the left); *⋯ ◡〈◡〈–

《× ×〉◡〈◡ – GB requires /__×

What this shows is that although there are some modifications of the core rules which are made in order to promote metrical stress on heavy syllables, there is not a global computation which is done in order to determine where delimiters should be inserted.

H&I attempt to explain heavy syllable effects by supposing that there is a rule, perhaps iterative, which inserts delimiters at the edges of heavy syllables and applies prior to binary or ternary rhythmic footing. The contrast between the (51) examples and (50d,e) shows that this approach is not sufficient. Whatever rule foots the heavy beat must wait until the iterative rule reaches that beat. Allowing the rhythmic delimiter insertion rule to be a scheme of rules allows precisely that.

There is one further modification of (45) that is needed, again to promote alignment. Words of the form ◡ –×⋯ use a special marking rule to shift stress from the initial light syllable to the following heavy syllable.

(53)	a.	*ɸo.rík.ka, bi.ʃɔ́j.jɔn*	◡《– ×	‘examination’, ‘immersion’
	b.	*a.bɔ́r.zɔ.na*	◡《– ◡	‘garbage’
	c.	*ɔ.ʃáb.da.nɔ.ta, ɔ.ʃɔ́ŋ.rok.ki.tɔ*	◡《– ×〉◡ ◡	‘carelessness’, ‘unreserved’

There must be a special marking rule in these cases, GF^{x} / # $\underline{\smile}$ –, which will be called GF$^{x}_{\#LH}$. Again, the motivation for modifying (45) in this way is to promote alignment; otherwise the second syllable could not be put in a foot initial position. Some example derivations are given below. (54a) shows that GF$^{x}_{\#LH}$ is subject to *Unary, not to *Unary$_{T}$, otherwise GF$^{x}_{\#LH}$ would apply and produce ◡ $\acute{-}$.

(54)

	a.	b.	c.
	ɸá.til	*ɸɔ.rík.ka*	*ɔ.ʃáb.da.nɔ.ta*
	◡ –	◡ – ◡	◡ – ◡ ◡ ◡
	$GF_{\#}$ ⟪◡ –†	$GF^{x}_{\#LH}$ ◡⟪– ◡	$GF^{x}_{\#LH}$ ◡⟪– ◡ ◡ ◡
	⟪◡ –	◡⟪– ◡	◡⟪– ◡ ◡ ◡
		◡⟪– ◡	◡⟪– ◡ ◡ ◡
			GB^{x} ◡⟪– ◡⟩◡ ◡
			◡⟪– ◡⟩◡ ◡

† $GF^{x}_{\#LH}$ is blocked by *Unary.

The full system, with the 3 modifications of (45) introduced above is (55). The modifications consist of an added marking rule and an added subrule of the iterative rule, both promoting alignment, and a weakening of *Unary, which also promotes alignment. The modifications are highlighted by dotted frames in order to emphasize that the TB system is just a perturbation of the non-persistent ternary system.

(55)

$$\left.\begin{array}{l}\boxed{\smile \;\rightarrow\; \smile\langle \;/\; \#\_\_-} \\ \times \;\rightarrow\; \langle\times \;/\; \#\_\_\end{array}\right\}\text{; *Unary} \qquad \begin{array}{l}(GF^{x}_{\#LH})\\(GF_{\#})\end{array}$$

$$\left[\begin{array}{l}\boxed{- \rightarrow \langle -} \\ \times \;\rightarrow\; \times\rangle \;/\; \_\_\times \\ \times \;\rightarrow\; \times\langle\end{array}\right]_{LR}\text{; *Unary}\boxed{\underset{\cdots}{T}} \qquad \begin{array}{l}(GF_{H})\\(GB)\\(GF^{x})\end{array}$$

7.3. The Chugach dialect of Alutiiq, a mora-counting language

Before we consider Chugach directly, the motion ‘mora-counting language’ needs comment.

7.3.1. Moraic beats

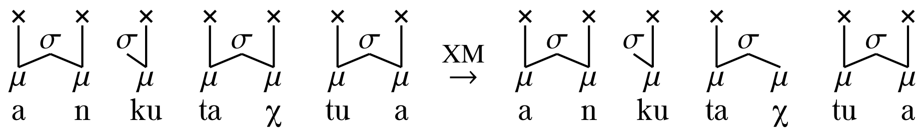
In Tripura Bangla, beats were projected from syllables. In many languages beats are projected from moras. The relation between beats and moras is not straightforward. Both moras of CVV syllables typically project beats, but in many mora-counting systems certain moras do not project a beat. There must be a distinction beteen syllabic moras and moriac beats. The most straightforward way to represent this is to assume that initially every mora is automatically projected to a beat, so that initially the beat line simply mirrors the line of moras. Then, by a language particular rule XM, certain beats are deleted.[12] The moras

12. It is equivalent to suppose that beats are naturally colored green, but a painting operation colors certain ones red; and that the delimiter insertion rules can only see green beats.

that they originally projected from remain unscathed, but no longer project beats. If a beat projected from a mora is deleted, the mora will be called *extrametrical*.

(56) Typical instances of XM. It can delete:
   a. Final consonantal moras.
   b. Coda moras of non-initial CVC syllables.
   c. All consonantal moras.

In Chugach, consonantal codas of non-initial CVC syllables are extrametrical. For example, (57) shows the operation of XM, the extrametricality operation, on the initial prosodic structure of the Chugach word *an.ku.taχ.tua*.

(57) 

In Tripura Bangla, alignment of inherent heavy syllable stress with metrical stress was promoted by making certain subrules of the iterative rule sensitive to the weight of beats, which is inherited from the weight of the syllables they project. In mora-counting languages, there is no beat weight. But there are special pairs of beats on the beat line; those projecting cosyllabic moras. Such pairs will be called *cosyllabic pairs*. I assume that 'onset beat of a cosyllabic pair' (denoted ×‿) and 'coda beat of a cosyllabic pair' (denoted ‿×) are beat properties that DIRs can be sensitive to. Although moras are assigned stress (i.e., project a beat to a higher beat line), stress is realized on syllables. So there is no surface difference between the realization of ×́‿× and ×‿×́. For the word in (57), the delimiter insertion system applies after XM. What it 'sees' is the result of the XM operation, the right side of (57).

×‿× × × ×‿×

The ‿ symbols on the beat line above are only *diacritics* to represent properties of the beats the join. They are not items (beats, delimiters, and junctures) which enter into adjacency relations.

That cosyllabicity is a beat property is crucial in restricting delimiter insertion in mora-counting languages because footing systems only rarely split cosyllabic moras between feet. Footing systems, for the most part, are designed so that they avoid inserting delimiters between cosyllabic beats. This can be done by explicitly imposing a *SplitSyl constraint or indirectly by a marking rule which inserts a delimiter at the edge of each cosyllabic beat pair, leaving it to *Unary to ensure that pairs are not split.[13] The effect is to promote stress on the bimoraic syllables whose moras both project a beat.

7.3.2. Chugach stress system

The data is from Leer (1985a), as is the understanding of the extensive phonological changes that follow footing and stress projection. See also Leer (1985b, 1985c) for discussion of the diachronic development of stress in Chugach and some related languages and for analysis. All the examples I use are in Hayes (1995, pp. 335–36), which is more accessible. There are several complex phonological rules which apply after footing which depend on the foot structure that delimiter insertion creates. A complete analysis of the Chugach stress system would detail those rules and show how the stress system proposed provides the basis for those rules to correctly apply. The analysis here will fall short of that, but Hayes' (1995) analysis of the stress/phonology interaction can be adapted to the present framework.

The light syllable data indicates that footing is persistent ternary footing, with iambic stress and iambic lengthening of stressed nonfinal CV syllables.

(58) Light syllables

			surface
a.	*(a.ta)ka*	(× ×)×	*a.táː.ka*
b.	*(a.ku)(ta.mək)*	(× ×)(× ×)	*a.kúː.ta.mə́k*
c.	*(a.tu)qu(ni.ki)*	(× ×)×(× ×)	*a.túː.qu.ni.kí*
d.	*(pi.su)qu(ta.qu)ni*	(× ×)×(× ×)×	*pi.súː.qu.ta.qúː.ni*
e.	*(ma.ŋaχ)su(qu.ta)(qu.ni)*	(× ×)×(× ×)(× ×)	*(ma.ŋáχ)su(qu.táː)(qu.ní)*

Glosses: a. 'my father' [16], b. 'kind of food (abl.sg.)' [84], c. 'if he (refl.) uses them' [113], d. 'if he (refl.) is going to hunt' [113], e. 'if he (refl.) is going to hunt porpoise' [113]

In (58b,e) I use the assumption that non-initial CVC syllables are associated with a single beat. More evidence for this will accumulate as we proceed.

13. The Winnebago footing system does split word-initial bimoraic syllables. The cost is small because the syllable is CVV (easily split) and the gain is substantial, main stress is then uniformally on the 3rd mora, the dominant Winnebago pattern. Splitting is in response to a marking rule, which are generally less constrained than the subrules of the iterative rule.

On the basis of (58), we conclude that in the absence of heavy syllable effects the footing is LR persistent ternary footing (see § 6.2.2) and stress is iambic. So we start from the core persistent ternary system (33).

(59)
$$\left.\begin{array}{l} \times \rightarrow \langle \times \;/\; \#\_\_ \\ \begin{bmatrix} \times \rightarrow \times\rangle \\ \times \rightarrow \times\langle \end{bmatrix} \end{array}\right\} ;\ {*}\textsc{Unary} \qquad \begin{array}{l} (\mathrm{GF}_{\#}) \\ (\mathrm{GB}) \\ (\mathrm{GF}^{\mathrm{x}}) \end{array}$$

If we turn to see what the alignment effects are, the salient fact is that underlying CVV and initial CVC syllables are *always* stressed. In the examples below, the second column ‘feet’ is the most plausible footing which will yield the surface form. Except for (60d,h), all feet are binary. In those examples, a unary foot is unavoidable. The last column anticipates the results of the delimiter insertion rules (61).

(60) Heavy syllables

		feet	*surface*	*delimiters inserted*
a.	*kal.maː.nuq*	(×‿×)(×‿×)×	*kál.mˈáː.nuq*	⟪×‿×⟩⟪×‿×⟩×
b.	*an.ku.taχ.tua*	(×‿×)(× ×)(×‿×)	*án.ku.táχ.tˈuá*	⟪×‿×⟩× ×⟩⟪×‿×⟩
c.	*at.max.či.qua*	(×‿×)(× ×)(×‿×)	*át.max.číˑ.qˈuá*	⟪×‿×⟩× ×⟩⟪×‿×⟩
d.	*nu.yai*	(×)(×‿×)	*núy.yái*	⟪×⟪×‿×⟩
e.	*u.lua*	(×)(×‿×)	*úl.luá*	⟪×⟪×‿×⟩
f.	*mu.lu.kuːt*	(× ×)(×‿×)	*mu.lúˑ.kˈúːt*	⟪× ×⟩⟪×‿×⟩
g.	*naː.qaː*	(×‿×)(×‿×)	*náː.qˈá*	⟪×‿×⟩⟪×‿×⟩
h.	*u.ɬú.tə.ku.tá.ʁáː*	(× ×)×(× ×)(×‿×)	*u.ɬúː.tə.ku.táˑ.ʁˈá*	⟪× ×⟩×⟨× ×⟩⟪×‿×⟩
i.	*u.xa.či.maːn*	(× ×)×(×‿×)	*u.xáː.či.máːn*	⟪× ×⟩×⟪×‿×⟩
j.	*an.či.qua*	(×‿×)×(×‿×)	*án.či.qˈua*	⟪×‿×⟩×⟪×‿×⟩

Glosses: a. ‘pocket’ [103], b. ‘I’m going out now’ [116], c. ‘I will backpack’ [115], d. ‘her hair’ [102], e. ‘its tongue’ [87], f. ‘if you take a long time’ [87], g. ‘she’s reading it’ [115], h. ‘he is going to watch her’ [104], i. ‘you must be good at it’ [112], j. ‘I’ll go out’ [84]

There is a simple modification of (59) which accounts for the (60) data. In Chugach, all heavy syllables are stressed. The Chugach system achieves this by marking every bimoraic pair of beats. The rule is $\times \rightarrow \langle \times \;/\; \_\_\smile\times$. I will call this GF_{H}. GF_{H} means one thing in mora-counting systems and another in syllable-counting systems. The name does double-duty in order to minimize the number of rule names.

The complete stress system is:

(61) Chugach word stress system

$$\times \rightarrow \langle \times \;/\; \#\_\_ \;;\; {*}\textsc{Unary} \qquad (\mathrm{GF}_{\#})$$

$$\times \rightarrow \langle \times \;/\; \_\_\smile\times \qquad (\mathrm{GF}_{\mathrm{H}})$$

$$\left[\begin{array}{l} \times \rightarrow \times\rangle \\ \times \rightarrow \times\langle \end{array}\right] ;\; {*}\textsc{Unary} \qquad \begin{array}{l} (\mathrm{GB}) \\ (\mathrm{GF}^{\mathrm{x}}) \end{array}$$

Note that GF_{H} is not subject to *Unary. This is important in explaining the stress pattern in (60d,e). Note also that $\mathrm{GF}_{\#}$ must be subject to *Unary because monosyllabic words consisting of a single light syllable are absent in Chugach.

(61) is very close to Leer's original proposal, virtually a restatement of it in the present framework. He proposed that heavy syllables were footed first, in monosyllabic feet. In the terms of this paper, it is essentially a marking rule. Then iterative iambic footing filled in what remained unfooted. In his words (p. 160), he said that he "ordered the foot definition rules so that monosyllabic feet were defined first, leaving the definition of the default case, the iambic foot, until last."

(61) account for the righthand column in the (60) examples. Some full derivations are given in (62). Since there can be multiple current targets of the iterative rule, an indication of inactivity is given rather than cursors at the current targets. The current targets are the active beats which do not have an active beat on their left.

(62) a. *an.či.qua*

$$\times\smile\times \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\#}\;\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times} \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\mathrm{H}}\;\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times} \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times}$$

$$\mathrm{GB}\;\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle \underset{\blacktriangle}{\times}\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle \underset{*}{\times}\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

án.či.quá

b. *an.ku.taχ.tua*

$$\times\smile\times \;\; \times \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\#}\;\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times} \;\; \times \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\mathrm{H}}\;\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times} \;\; \times \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times}$$

$$\mathrm{GB}\;\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle \underset{\blacktriangle}{\times} \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle \underset{*}{\times} \;\; \underset{\blacktriangle}{\times}\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\mathrm{GB}\;\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle \underset{*}{\times} \;\; \underset{*}{\times}\rangle\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

án.ku.táχ.tuá

c. *u.ɬu.tə.ku.ta.ʁaː*

$$\times \;\; \times \;\; \times \;\; \times \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\#}\;\langle\!\langle \underset{*}{\times} \;\; \underset{\blacktriangle}{\times} \;\; \times \;\; \times \;\; \times \;\; \times\smile\times$$

$$\mathrm{GF}_{\mathrm{H}}\;\langle\!\langle \underset{*}{\times} \;\; \underset{\blacktriangle}{\times} \;\; \times \;\; \times \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{\blacktriangle}{\times}$$

$$\mathrm{GB}\;\langle\!\langle \underset{*}{\times} \;\; \underset{*}{\times}\rangle \underset{\blacktriangle}{\times} \;\; \times \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\mathrm{GF}^{\mathrm{x}}\;\langle\!\langle \underset{*}{\times} \;\; \underset{*}{\times}\rangle \underset{*}{\times}\langle \underset{\blacktriangle}{\times} \;\; \times\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\langle\!\langle \underset{*}{\times} \;\; \underset{*}{\times}\rangle \underset{*}{\times}\langle \underset{*}{\times} \;\; \underset{\blacktriangle}{\times}\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

$$\mathrm{GB}\;\langle\!\langle \underset{*}{\times} \;\; \underset{*}{\times}\rangle \underset{*}{\times}\langle \underset{*}{\times} \;\; \underset{*}{\times}\rangle\langle\!\langle \underset{*}{\times}\smile\underset{*}{\times}\rangle$$

u.ɬú.tə.ku.tá.ʁáː

→ *u.ɬúː.tə.ku.táˑ.ʁˑá*

	d. *nu.yai*	e. *naː.qaː*
	$\times\quad\times\smile\times$	$\times\smile\times\quad\times\smile\times$
$GF_{\#}$	$\langle\langle\underset{*}{\times}\quad\underset{\blacktriangle}{\times}\smile\times$	$\langle\langle\underset{*}{\times}\smile\underset{\blacktriangle}{\times}\quad\times\smile\times$
GF_{H}	$\langle\langle\underset{*}{\times}\langle\langle\underset{*}{\times}\smile\underset{\blacktriangle}{\times}$ [1]	$\langle\langle\underset{*}{\times}\smile\underset{\blacktriangle}{\times}\langle\langle\underset{*}{\times}\smile\underset{\blacktriangle}{\times}$
GB	$\langle\langle\underset{*}{\times}\langle\langle\underset{*}{\times}\smile\underset{*}{\times}\rangle$	$\langle\langle\underset{*}{\times}\smile\underset{*}{\times}\rangle\langle\langle\underset{*}{\times}\smile\underset{*}{\times}\rangle$
	nú.yái	*náː.qáː*
	→ *núy.yái*	→ *náː.qˑá*

1. GF_H is not constrained by *Unary.

8. Summary

8.1. What has been done

This paper has explored the idea that only very simple rewriting rules are needed to carry out rhythmic footing; rules of the form $\times \rightarrow \times D$ or $\times \rightarrow D\times$, $\times$ a beat and D a foot delimiter, perhaps restricted to certain contexts and/or subject to certain derivational constraints. There are several advantages to the fact that such rules target individual beats: 1) they can be combined into schemes, with the highest ranked applicable subrule actually applying, 2) iterated directional iteration is straightforward, the target stepping one beat at a time as the iteration precedes through the metrical form, and 3) it is possible to impose strict locality conditions on the possible rules of this kind.

Importantly, it was shown that assuming that rhythmic footing which is carried out by such rules, or schemes of such rules, subject to natural locality conditions, must produce either binary or ternary footing in strings of propertyless beats (light syllables), at least away from the edges of such strings.

Showing that a particular class of stress systems is only capable of generating binary or ternary stress patterns is not impressive unless it can be shown that this class of stress systems is empirically adequate. Some steps in that direction were taken in the analyses of Tripura Bangla and Chugach, two moderately complex ternary systems.

8.2. What remains to do

The *Unary constraint has been ubiquitous and the only other constraint on interative footing that has been introduced (for Tripura Bangla) is a weakened version of *Unary which exempted final heavy syllables from the *Unary requirement. Bani-Hassan Arabic is syllable-counting with a light-heavy weight distinction. It imposes a weak derivational constraint on delimiter insertion; only light beats are subject to *Unary. Remember that the subrules of the iterative rule can have structural conditions, so their applicability can depend on the local context of the target. It is likely the case that the iterative rule is never subject to a derivational constraint stronger than *Unary.

Restricting the possible constraints on iterative footing narrows the class of possible footing systems. But this is on the purely formal side of restricting the class of possible footing system; it pays no attention to the content of beat properties. Suppose we take the view that footing systems are necessarily formed by perturbing one of the 4 basic systems. We want to understand what kind of perturbations are natural, and which are not. Essentially, some theory of markedness is needed. Unfortunately, the residue of what were natural changes historically can appear much less natural in the present, so consistent 'naturalness' is too much to hope for. But there are some things to be said.

As discussed earlier, it is natural for perturbations to be made which increase the alignment of metrical stress and inherent heavy syllable stress. The Tripura Bangla stress system, for example, has three modifications of the basic non-persistent ternary system, all of which improve alignment. One is to a marking rule, but the others affect the iterative rule. Although there are possibilities of anomalies from historical residues, this is the kind of perturbations that we should expect. Chugach perturbs the basic persistent ternary system by introducing a single marking rule, GF_H, with no derivational constraint, ensuring that heavy syllables are always stressed, even in (60d,e), where *Unary is violated and stress clash results.

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