SPE Extensions: Conditions on Representations and Defect Driven Rules

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In this paper I propose a new formal theory of iterative rules and demonstrate the advantage of analyzing various prosodic phenomena in terms of the rule format which is introduced. Noteworthy is the extensive use of constraints and well-formedness conditions in the formulation of individual rules. The title “SPE Extensions” was chosen to highlight the fact that, in spite of the fact that extensive use is made of conditions on representations, the proposed theory adheres closely to the traditional framework of sequential application proposed in Sound Patterns of English (Chomsky and Halle, 1968). In the proposed format, the application of iterative rules is driven by defects (along some dimension) in the structure they operate on. This application can be extensively controlled by systems of derivational constraints. The proposed format relies heavily on the schema interpretation and expansion mechanisms proposed in SPE.

The particular set of problems which motivated the development of this theory of iterative rules concerns instances of syllable restructuring to accommodate the demands of building foot structure. In various languages, CVV syllables split into CV.V syllable pairs in certain environments to accommodate the requirements of foot formation. This interaction between footing and syllable structure is difficult to analyze in a theory in which syllables have an X-like structure. If the structural change CVV → CV.V is something along the lines of (1) and feet are constructed on an unrelated tier, it stretches plausibility to imagine that the two operations take place as two aspects of one operation.

(1) \[ \sigma C V \sigma V \rightarrow \sigma C \sigma V \sigma V \]

This paper is devoted to working out a theory of syllable structure which makes restructuring a simple operation and a theory of footing which ties it directly to syllable structure. In the framework which is developed, the accommodation of syllable structure to footing will be virtually transparent. Defect driven iterative rules are crucial in both syllabification and footing. Section 1 develops a formal theory of defect driven iterative rules, using a variety of simple footing rules (Garawa, Southern Paiute, Cayuvava, Hawaiian) to illustrate the idea. Section 2 uses defect driven iterative rules to construct a tier, called the cluster tier, roughly akin to a mora tier. The cluster tier and associations with the timing tier contain all necessary
information about syllable structure. The iterative syllabification rule is worked out in detail for Icelandic and Imdlawn Tashlhiyt Berber. Section 3 brings foot structure and syllable structure together by proposing that footing is carried out by inserting delimiters into the cluster tier. Cairene Arabic is used to illustrate the effect of Syllable Integrity (*Split-× in my reformulation) on delimiter insertion. Section 4 shows that syllable splitting under the demands of footing can be realized as elementary autosegmental delinking and relinking. The phenomenon is illustrated for Fijian, Tongan, Southern Paiute, and Gothic (Siever’s Law).

1. Defect Driven Iterative Rules

Kisseberth (1970) first discussed rules which apply only when the input representation violates some constraint and the output does not. The core idea was further developed and articulated by Sommerstein (1974). The intention in this paper is to make this the organizing principle of iterative rule application. The idea is that iterative rules are driven by defects in the structure they apply to, in the sense that apply if and only if they can remove a defect, iterating until they can no longer apply. Application terminates either because all defects have been removed or because the rule provides insufficient resources to remove any remaining defects.

In order to illustrate the idea, let us start with left to right footing, adopting Idsardi’s view of footing (Idsardi, 1992; Halle and Idsardi, 1995). Footing is delimiter insertion, one at a time. For the moment, I abstract away from what units are footed and call the units stressable elements (SEs when space is at a premium). The traditional account of left to right iterative binary footing is that the rule (2a) applies iteratively, producing derivations like that in (2b).

\[(2)\]
\[
a. \emptyset \rightarrow \ell \circ o \_\_ \text{ (left to right)}
\]
\[
b. \circ \circ \circ \circ \circ \rightarrow \circ \circ \ell \circ \circ \circ \circ \rightarrow \circ \circ \ell \circ \circ \circ \circ \circ
\]

This can be recast as a defect driven rule by imposing the target condition:

\[(3)\]\)
\[
\text{) - Delimited: } \ell \circ \_\_ \Rightarrow \ell \_\_
\]

Condition (3) requires that a stressable element which immediately follows another stressable element must be immediately followed by a right foot delimiter. Note that all the stressable elements in the final representation in (3b) satisfy this condition. Left to right footing will be recast as an iterative rule which brings the stressable elements progressively into line with this target condition. A stressable element which is not )-Delimited is defective (with respect to left to right iterative footing).

Initially, the representation is:

\[
\circ \_\_ \_\_ \_\_
\]

The defective stressable elements have been annotated with an asterisk. Demanding that the defects be progressively removed, from left to right, is not sufficient to
ensure the desired derivation. Along with the desired derivation (4a), many undesired derivations are also possible;

\[
\begin{align*}
\text{(4) } & \quad \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \rightarrow \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \\
& \quad \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \rightarrow \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \\
& \quad \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \rightarrow \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \\
& \quad \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \rightarrow \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \circ \\n\end{align*}
\]

Some factor is needed to prevent delimiters from being inserted too close together. A constraint against unary feet (which I call *Uny) plays a role in many footing systems. If we assume it here, derivations (4b) and (4c) are excluded and (4a) is forced, as desired.

What is required is a rule format which can make all of this explicit. The general format is:

\[
\begin{align*}
\text{(5) Type} & \quad \text{Condition} \quad \text{Order} \quad \text{Rule(s)} \quad \text{Constraint Set} \\
\text{Preamble} & \quad \text{Body} \\
\end{align*}
\]

The condition in the preamble will be called the target condition. The rules in the body will be called repair rules. The metaphor is that violations of the target condition are defects which the rules repair.

The simple left to right binary footing rule discussed above, presented in this format, is:

\[
\begin{align*}
\text{(6) Stressable Element} & \quad ; \quad \text{)}\text{-Delimited} \quad ; \quad \text{Left} \quad \text{::} \quad \emptyset \rightarrow ) \quad ; \quad \{ \text{*Uny} \}
\end{align*}
\]

Now consider a slightly more complex footing rule of this type, this one for right to left to footing. The right to left footing condition is the mirror image of the left to right footing condition.

\[
\begin{align*}
\text{(7) Stressable Element} & \quad ; \quad \langle\text{-Delimited} \quad ; \quad \text{Right} \quad \text{::} \quad \emptyset \rightarrow \langle \quad \{ \text{*Uny, *%\langle} \}
\end{align*}
\]

There are two derivational constraints. *Uny, as above, and *%\langle, whose effect is to force foot alignment with the left edge. Two rules are available for removing defects. The rule schema is interpreted in the usual SPE fashion, the highest ranked rule which can apply, does apply. The highest ranked defect is first chosen, then the highest ranked rule which remove this defect applies.

This gives the derivations in (8). Numbers under arrows are reference points for the discussion that follows (akin to footnote numbering).
In steps 1 and 2, the highest ranked rule, $\emptyset \rightarrow \langle$, cannot remove the highest ranked (rightmost) defect without violating either *Uny or *%$. The next highest ranked rule, $\emptyset \rightarrow \rangle$, therefore applies to remove the rightmost defect, in the only way that it can. Inserting $\rangle$ to the left of the rightmost defect would not remove the defect. This is the footing system in Garawa (see Halle and Idsardi, 1995:422, for discussion and examples).

We now consider another example of this type which shows how the interaction of derivational constraints and the preferences of the rule schema can interact to produce rule alternation. Again, right to left footing of strings of stressable elements is the issue, with the edge-marking rule (9.EM) applying prior to the defect driven iterative footing rule (9.IF).

(9) EM: \( \emptyset \rightarrow \rangle \)

IF: Stressable Element ; \langle-Delimited ; Right :: \[
\begin{align*}
\emptyset \rightarrow \rangle \\
\emptyset \rightarrow \langle
\end{align*}
\]; \{*Uny, *%\}

For two and three element strings, edge marking produces:

(10) a. \( \circ \rangle \circ \)
b. \( \ast \circ \circ \rangle \circ \)

The iterative footing rule cannot remove the defect in (10b) because of the two derivational constraints. It therefore does not apply and the derivation moves on to the whatever tasks come next. This illustrates two important points. The target condition of a defect driven iterative rule cannot always be satisfied. Whether or not it can be depends upon the resources that rule body provides for removing defects. In this case, the resources are inadequate and the representation is not brought into complete satisfaction of the target condition; one stressable element remains in violation of the target condition. The second point is that although the initial element in (10.b) remains defective, it is footed. In fact, if stress is trochaic (assigned to the leftmost stressable element of feet), the defective element get main stress in (10.b). This view of the conditions which drive iterative footing which is adopted here is at odds with Prosodic Morphology, which takes the driving force for the organization of prosodic structure to be membership in prosodic categories of one type or another.

A four element string produces the derivation:

(11) \( \circ \circ \circ \circ \rightarrow \ast \circ \circ \circ \rangle \circ \rightarrow \circ \langle \circ \circ \rangle \circ \)

The first step is edge marking and the second iterative footing (which applies only once). No defective elements are marked in the initial representation because “defective” (with respect to the target condition of the iterative footing rule) has no meaning outside of application of the iterative footing rule. The condition
/___ o ⇒ /⟨___ is not a general condition on representations, but a specific condition used to organize iterative footing. In this, it is more akin to the structural description of a rule than to a constraint on representations. Note at step 1 that the most highly ranked rule cannot apply to remove the rightmost violation. Insertion of ) to the right of the defective element would violate *Uny, while insertion to its left would not remove the violation.

A derivation starting from a longer string of stressable elements is given below:

(12) o o o o o o o o → *o *o *o *o o o o o → *o *o *o o o o o o o o o → *o *o o o o o o o o o o → o o o o o o o o o o o o

Step 1 is edge marking.

If stress is assigned foot left and main stress is assigned word right, the footing rules (9) produce the ternary stress pattern of Cayuvava. See Hayes (1995:309). It is interesting to compare the footing pattern produced by (9) with the footing pattern produced by the almost identical rules (13), in which the only change is that the rankings of the two repair operations have been reversed in the iterative footing rule.

(13) 1. ∅ → ⟨/___ o#

2. Stressable Element ; ⟨-Delimited ; Right :: [∅ → ⟨] ; {*Uny, %⟨}

The footing rules (13) yield binary footing rather than ternary footing.

(14) o o o o o o o o o → *o *o *o *o *o o o o o → *o *o *o *o o o o o o → *o *o *o o o o o → o o o o o o o o o o o o

In fact, (13.2) never calls on ∅ → ⟨ in the derivation (14). The source of ternary footing in (9) is this: Right to left footing, which is driven by the target condition ⟨-Delimited, is naturally paired with the delimiter insertion rule ∅ → ⟨. The rule (9) produces ternary footing because it demotes the natural right to left delimiter insertion rule to secondary status, ranked after ∅ → ⟨.

1.1. Discretionary Constraints

Up to this point, we have assumed that the constraint set consists of only strict constraints on rule application. We will now admit a new class of constraints, called discretionary constraints. In removing a given defect, discretionary constraints can be violated, but only as a last resort. Multiple (ranked) discretionary constraints require a discussion of constraint set schemata and expansion, but for a single discretionary constraint, the idea of violation only as a last resort will suffice. That is sufficient for the examples in this paper.
We can see how this works by considering the iterative footing rule in (15). Discretionary constraints come after the $\parallel$ symbol.

\[(15) \textit{Southern Paiute}\]
\[
\text{Stressable Element} ; )-\text{Delimited} ; \text{Left} :: \emptyset \to ) ; \{ \ast \ast \parallel \ast \text{Uny} \}
\]

The effect of discretionary *Uny is that the creation of unary feet is not absolutely excluded, but is legitimate only if a particular defect cannot be otherwise removed.

A few representative derivations follow.

\[(16) \begin{align*}
a. \ast o \ast o \ast o \ast o & \to o \ast o \ast o \to o \ast o \rightarrow o \ast o \to o \ast o \to o \ast o \\
b. \ast o \ast o \ast o & \to o \ast o \ast o \to o \ast o \to o \ast o \to o \ast o \\
\end{align*}\]

A violation of discretionary *Uny is forced at step 1 because the alternative option for removing the defect is blocked by nondiscretionary *\#). With foot stress right (iambic) and word stress right, this is the stress system of Southern Paiute. Main stress is always penultimate.

As a second example, consider the iterative footing rule (17.IF), which applies after the edge marking rule (17.EM).

\[(17) \textit{Hawaiian}\]
\[
\text{EM: } \emptyset \to )/ _\#.
\]
\[
\text{IF: Stressable Element} ; )-\text{Delimited} ; \text{Right} :: \begin{bmatrix} \emptyset \to ) \\ \emptyset \to ) \end{bmatrix} ; \{ \ast \text{Uny} \parallel \ast \% \langle \}
\]

Some representative derivations follow:

\[(18) \begin{align*}
a. \ast o & \to o \ast o \\
b. \ast o \ast o & \to o \ast o \\
c. \ast o \ast o & \to o \ast o \ast o \to o \ast o \ast o \\
d. \ast o \ast o \ast o & \to o \ast o \ast o \ast o \to o \ast o \ast o \rightarrow o \ast o \ast o \rightarrow o \ast o \ast o \rightarrow o \ast o \ast o \rightarrow o \ast o \ast o \\
\end{align*}\]

At step 1, there is a violation of discretionary *\%\langle, but the alternative ways of removing the rightmost defect violate nondiscretionary *Uny. At step 2, the highest ranked rule, $\emptyset \to )$, is not used because it would violate either nondiscretionary *Uny or discretionary *\%\langle. The second ranked rule, $\emptyset \to )$, therefore applies, since it can remove the defect without violating either *Uny or *\%\langle.

If stress is assigned foot left and word left, this is the stress system of Hawaiian. Main stress is initial, except if there are three stressable elements, in which case it is medial.
1.2. Defectiveness is local to the rule which mentions it

The idea that the most fruitful way to view the structural conditions which trigger rule application, at least certain instances of rule application, is in terms of defects in the structure which rule application can remove, has received ongoing attention since the early work of Kisseberth and Sommerstein (see Singh 1987, Yip 1988, Paradis 1988, Goldsmith 1990, Calabrese 1995). Lacharité and Paradis (1993) give a useful survey.² In all of this work, the concern is for deviation from high-level conditions on phonological structure. The tendency has been to assimilate the idea of “defect” to the idea of violation of an output condition or a surface phonotactic. Only Calabrese (see p. 411, for example) allows well-formedness conditions which trigger repair at some stages of the derivation but are inactive at late stages.³ This tendency to view defects as deviations from surface phonotactics fed Optimality Theory’s preoccupation with surface well-formedness.

The conception of “defect” proposed here much less closely tied to the idea of well-formedness condition imposed on surface structure. It is much more akin to the notion of a “structural description” in SPE terms. A particular notion of defect need only be relevant to the iterative rule in which it appears. There are reasons both from tendencies towards formal simplicity and from learning theory for well-formedness conditions which appear at one place in the grammar to appear at other places as well, perhaps even at the surface, but these reasons are external to the formal constraints on possible grammars and to the online computation which the grammar specifies.

The separation of well-formedness conditions which drive defect-driven iterative rules from surface phonotactics is illustrated, for example, by the condition that drives left to right iterative footing: /o_\_\_ \Rightarrow /_\_\_\_. One of the major advances of prosodic theory was Lieberman’s (1975) discovery that stress placement depended on the abstract computational device of foot formation. The constraint /o_\_\_ \Rightarrow /_\_\_\_ does not even make sense as a phonotactic, since foot delimiters have no immediate phonetic correlate. The computation of foot structure has an effect on surface structure principally because it feeds the computation of stress, which is what is most clearly visible at the surface. The abstractness of foot structure, and therefore of the target condition which drives it, is made particularly clear in a language such as Cyrenacian Bedouin Arabic in which syncope rules applying after foot formation cause widespread deviance from the target condition which directed foot construction. Syncope completely obscures the origin of the foot structure which produces the observable surface stress patterns. (See Frampton, 1999, for an analysis in the present framework.)

It is also worth reminding the reader that defect-driven iterative rules are not necessarily successful in removing all the defects which drive their application. Defects can remain after rule application. There is no guarantee that the array of rules (repair rules) which a defect-driven iterative rule allocates to defect removal is sufficient for the job. The rule operates by doing the best it can, and then moving on. Note also that the notion of “repair rule” used here, like the notion of defect itself, is particular to the defect-driven iterative rule in question. Indeed, we will
see in Section 2 that the array of repair rules which the iterative syllabification rule specifies is a major determinant of syllable structure.

2. Autosegmental Syllabification

Ito’s (1986) templatic theory of syllabification made some advances over earlier theories by integrating well-formedness conditions on syllable structure into a syllabification algorithm built around directional template matching. But Dell and Elmedlaoui’s (1985) study of syllabification in Imidlawn Tashliyt Berber (henceforth ITB) showed that templatic matching was inadequate and proposed a two-stage theory of syllabification for ITB in which core syllables were constructed first, then full syllables built around them. The key innovation was abandoning directional syllabification (left to right, or right to left) and making the order in which syllables are built dependent on the sonority of the phonemes which were to be syllabified.

It is the intention of this section to develop Dell and Elmedlaoui’s idea into a defect driven iterative rule that accomplishes full syllabification, not just core syllabification, and not only in ITB, but (with language particular variation) quite generally. The proposed syllable structure will be autosegmental, which is very natural from the standpoint of iterative rule application. It has the virtue that the kinds of syllable reorganization that occur in response to footing are elementary delinking and relinking processes familiar from autosegmental phonology. We will return to investigate that interaction in Section 4.

Syllabification is a process of grouping timing slots. I propose that it is implemented by the construction of a tier, the cluster tier, and associating elements on this tier, clusters (denoted by $\omega$ below), with timing slots. There are two elementary cluster formation rules, given in (19). They should be understood as operations on $\times$.

\[
\begin{align*}
(19) \quad \text{Form Doublet} & \quad \times' \times \rightarrow \times' \times' \\
\text{Form Singlet} & \quad \times \rightarrow \times
\end{align*}
\]

The asymmetry of Form Doublet is important. The rule operates on the timing slot $\times$ and builds a cluster to the left.

Suppose $\mathcal{L}$ is a simple (hypothetical) language in which vowels cannot be onsets and nonvowels cannot be nuclei. Consider the defect driven iterative rule:

\[
(20) \quad \text{Timing Slot}(x) ; \text{Clustered} ; \left( \begin{array}{c}
\text{Vowel} \\
\text{Left}
\end{array} \right) :: \left[ \begin{array}{c}
\text{Form Doublet} \\
\text{Form Singlet}
\end{array} \right]
\]

$x > y$ with respect to the order (Vowel Left) is $x$ is a vowel and $y$ is not, or if both $x$ and $y$ are vowels or nonvowels, but $x$ is to the left of $y$.\textsuperscript{4} The order component of the footing rules considered in the last section dealt with defects in a directional manner, left to right or right to left. The order here is not primarily directional. The primary determinant of order is the vowel/nonvowel status of a timing slot. Vowels
are targeted for repair first. Directionality is only relevant for distinguishing between timing slots which Vowel does not distinguish between.

The rule (20) produces, for example, the derivation (21). To aid the reader, the highest ranked defect in each representation is annotated with a bullet.

\[
\begin{array}{c}
\text{e} \times \text{t} \times \text{n} \times \text{a} \times \text{t} \times \text{a} \rightarrow \text{i} \text{i} \text{i} \text{i} \text{i} \text{i} \text{i}
\end{array}
\]

At step 1, the highest ranked rule (Form Doublet) cannot apply, so the next highest ranked rule (Form Singlet) applies.

In spite of its unorthodox form, the representation produced in (21) has all the relevant information about “syllable structure” that more orthodox representations have.

We define a syllable to be a maximal connected set of clusters. The leftmost (perhaps only) cluster of a syllable is called its onset cluster. Clusters which are not onset clusters will be called coda clusters. Both clusters and syllables have heads. I assume that: 1) every syllable head is a cluster head, and vice versa; and 2) clusters are right-headed, if possible. It is easy to see that this implies that:

\[
\begin{align*}
(22) \quad & 1. \text{ a syllable can contain at most two clusters;} \\
& 2. \text{ onset clusters are right-headed; and} \\
& 3. \text{ coda clusters are left-headed.}
\end{align*}
\]

The constraint against syllables with more than two clusters will be called *Tri (i.e. no triclusters).

Now consider another derivation, in which *Tri plays a role.

\[
\begin{array}{c}
\text{t} \times \text{a} \times \text{u} \times \text{a} \rightarrow \text{i} \text{i} \text{i} \text{i} \text{i} \text{i} \\
\text{t} \times \text{a} \times \text{u} \times \text{a} \rightarrow \text{i} \text{i} \text{i} \text{i} \text{i} \text{i} \\
\text{t} \times \text{a} \times \text{u} \times \text{a} \rightarrow \text{i} \text{i} \text{i} \text{i} \text{i} \text{i}
\end{array}
\]

Application of Form Doublet is blocked by *Tri at step 1. The lower ranked Form Singlet is therefore used to remove the defect.

The notion of “cluster” introduced here is related to the notion of “demisyllable” used to by Clements (1990) in his study of syllable sonority profiles.5 “Let us refer to syllable halves—overlapping portions of the syllable bounded at one end by the peak—as demisyllables.” The new terminology cluster is justified because in the theory proposed here cluster is the primitive notion and syllable the derived notion. The rule (20) is not a syllabification rule, properly speaking, but a clustering rule.
Simultaneous application at multiple local maxima

In the 5 step derivation (21) above, the global maximum of (Vowel Left) was determined at each step. Suppose instead that the body of the iterative rule applies to all local maxima of (Vowel Left) simultaneously. An unclustered timing slot × is a local maximum if there is no other unclustered timing slot ×’ adjacent to × with ×’ > × with respect to (Vowel Left). The derivations of (21) and (23) in this mode of application of iterative footing are given below, with the local maxima at each step annotated with a bullet.

\[ (24) \]

\begin{align*}
\text{a. } & \quad \text{t n a t a} \quad \text{t n a t a} \quad \text{t n a t a}
\end{align*}

\begin{align*}
\text{b. } & \quad \text{t u a u a} \quad \text{t u a u a} \quad \text{t u a u a}
\end{align*}

The output is identical to the mode of application in which a global maximum is found at each step. In the remaining syllabification examples in this section, simultaneous multiple application at local maxima gives the same output as strictly sequential application at global maxima. Since a formal proof of this equivalence depends upon the clustering rules which apply, their order, and the kinds of constraints allowed, a detailed treatment is beyond what I can do in this paper. Nevertheless, for the sake of minimizing the number of steps that need to be illustrated, I will assume simultaneous application at multiple local maxima throughout. The reader can check in any doubtful case that this mode of application gives the expected results.

The core structural inventory (CSI)

Typically, only a subset of the full phoneme inventory is eligible to be syllabified as syllable nuclei. Of these, some can also occur as onsets. This distribution has a major impact on the iterative syllabification rule. It is the major determinant of the order in which defects are targeted for repair. I suppose, as a parametric choice, that each language establishes a core structural inventory CSI by distinguishing a class of strongly nuclear phonemes, which can be nuclei but cannot be onsets, and a class of semi-nuclear phonemes, which can be either onsets and or nuclei. Remaining phonemes (non-nuclear phonemes) cannot be nuclei.

Given the CSI, we define the precedence relation \( \gg \), “more nuclear than,” between phonemes. \( \alpha \gg \beta \) if \( \alpha \) is strongly nuclear and \( \beta \) is not, or if \( \alpha \) is semi-nuclear and \( \beta \) is non-nuclear, or if \( \alpha \) and \( \beta \) are both semi-nuclear, but \( \alpha \) is more sonorous than \( \beta \). Iterative syllabification targets local maxima of \( \gg \), with directionality deciding the loci of syllable building in case adjacent timing slots are both local maxima of \( \gg \).

As an example, consider a language with the phoneme inventory:

\( \{a, u, i, r, l, m, n, + \text{ nonsonorants}\} \)
Suppose the CSI designates \{a, u, i\} as strongly-nuclear and \{r, l, m, n\} as semi-nuclear. The relation \(\gg\) then partitions the phonemes as follows:

\[
\text{a, u, i} \gg \text{r, l} \gg \text{m, n} \gg \text{nonsonorants}
\]

The partition of the semi-nuclear phonemes by sonority is superimposed on the tripartite partition into nuclear, semi-nuclear, and non-nuclear phonemes.

If we replace Vowel in (20) by \(\gg\), the iterative syllabification rule is:

\[
\text{(25) Timing Slot}(x) \text{; Clustered } \left( \begin{array}{c} \gg \\ \text{Left} \end{array} \right) :: \begin{array}{c} \text{Form Doublet} \\ \text{Form Singlet} \end{array}
\]

If no conditions on syllable shape intervene, we would expect:

\[
\text{(26) a. } x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \\
\text{t a k m r k t a k m r k t a k m r k}
\]

\[
\text{b. } x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \\
\text{t a k m k t a k m k t a k m k}
\]

\[
\text{c. } x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \rightarrow x \cdots x \cdots x \cdots x \cdots x \\
\text{t u a r u t u a r u t u a r u}
\]

Note that the semi-nuclear nasal \(m\) is syllabified as an onset when followed by the more sonorant semi-nuclear liquid \(r\), in (26a), but as a nucleus in (26b). In (26c), on the other hand, \(r\) is syllabified as an onset, since it is followed by the strongly nuclear \(u\). Note also in (26c) that the initial local maxima does not fall on \(a\), even though it is more sonorant than \(u\). The relation \(\gg\) does not distinguish between strongly nuclear phonemes, so \(u\) is chosen over \(a\) on the basis of Left.

- **The default defect driven iterative syllabification rule**

These considerations lead to the proposal that, given the CSI (which establishes the \(\gg\) relation), the default choice for iterative syllabification is (25). The language learner uses the default rule as the starting point and will modify it to suit the particularities (over and above the CSI) of the language. The array of repair rules can be augmented by rules which form complex onsets and complex codas, epenthese onsets or nuclei, and delete otherwise unsyllabifiable elements. Language particular conditions (a constraint on possible codas, for example) can be added to the constraint set. The directionality component of the order in which defects are targeted can be modified.

A thorough exploration of the proposal that syllable structure is autosegmental is beyond the scope of this paper. The discussion will be limited to two languages, ITB and Icelandic. By considering two quite different languages, the hope is that autosegmental syllable structure will be made at least plausible.
2.1. Icelandic

Syllabification in Icelandic is treated in some detail in Ito (1985), from which the examples in this section are taken. The intention here is not to break any new ground, simply to provide a good illustration of iterative autosegmental syllabification for a well-known language and to show how various syllabification phenomena are handled.

The CSI designates the vowels as strongly nuclear and does not designate any semi-nuclear phonemes. The relation $\gg$ is therefore the relation Vowel, viewed as a precedence relation between timing slots. Complex onsets are permitted, but they must have strictly increasing sonority. Certain consonant sequences cannot be broken up into coda and onset. Say that a consonant sequence is an exceptional consonant sequence if the first consonant is one of \{p, t, k, s\} and the second is one of \{r, j, v\}. The phonemes represented as j and v in Icelandic are sonorants, so exceptional consonant sequences have increasing sonority. Lastly, unsyllabified elements are deleted.

The default iterative syllabification rule (25) is modified in several ways.

1. A rule Adjoin Onset is included in the array of repair rules, and constrained so that applies only if the sonorities are appropriate.

\begin{equation}
\text{Adjoin Onset: } \quad \omega \quad \xrightarrow{\text{Adjoin Onset}} \quad \omega, \quad \text{if } \omega' > \omega \text{ wrt Sonority}
\end{equation}

The rule is considered to be an operation on $\times$ and the autosegmental diagram is interpreted nonexclusively (i.e. the requirement is only that the given association exists, not that it is the exclusive association of the items it associates).

2. Form Doublet is restricted so that it does not apply to a timing slot linked to the first consonant of an exceptional consonant sequence.

3. A rule Delete Stray ($\times \rightarrow \emptyset$) is added to the list of repair rules as a last resort option.

4. The CSI is slightly relaxed word-finally: r can head a word-final monocluster.

Given these modifications, the iterative syllabification rule is:

\begin{equation}
\text{TS}(x) ; \quad \text{Clustered} ; \quad \left( \text{Vowel Left} \right) :: \left[ \begin{array}{l}
\text{Form Doublet} \\
\text{Form Singlet} \\
\text{Adjoin Onset} \\
\text{Delete Stray}
\end{array} \right] ; \quad \{\text{CSI, } *\text{Tri}\}
\end{equation}

First, two examples illustrate the behavior of exceptional consonant sequences.

\begin{enumerate}
\item a. $\times \times \times \times \rightarrow \times \times \times \times \rightarrow \times \times \times \times$
\item b. $\times \times \times \times \rightarrow \times \times \times \times \rightarrow \times \times \times \times$
\end{enumerate}
sj is an exceptional consonant sequence, so Form Doublet cannot apply at step 1. Form Singlet is blocked by the CSI, which disallows consonantal nuclei. Adjoin Onset therefore applies.

Multiple onsets are not restricted to exceptional consonant sequences, as shown by (30a).

\[
\begin{array}{c}
\text{(30)} \quad \text{g} \times \text{i} \times \text{l} \times \text{d} \times \text{r} \times \omega \\
\end{array}
\]

Form Doublet is blocked at step 2 by \(*\text{Tri.}\) Form Singlet is blocked by the CSI. So Adjoin Onset applies.

Stray deletion applies in (31):

\[
\begin{array}{c}
\text{(31)} \quad \text{k} \times \text{e} \times \text{m} \times \text{b} \times \text{d} \times \text{i} \\
\end{array}
\]

Form Doublet and Form Singlet are blocked at step 3 as in (30). But here, Adjoin Onset cannot apply because of the restriction to increasing onset sonorities. Therefore, the lowest ranked rule, Delete Stray, applies.

The relaxation of the CSI word-finally to allow monocluster r shows up in:

\[
\begin{array}{c}
\text{(32)} \quad \text{I} \times \text{l} \times \text{r} \\
\end{array}
\]

This is the result of iterative syllabification, which I suppose applies cyclically. Post-cyclically, resyllabification applies. One of the defects which resyllabification is aimed at (in Icelandic and typically) is monoclusters. \(u\)-epenthesis applies in Icelandic to eliminate the final monocluster.

\[
\begin{array}{c}
\text{(33)} \quad \text{r} \times \text{u} \\
\end{array}
\]

The monocluster which is targeted is eliminated, but a new monocluster is created. This is a characteristic of defect-driven iterative rules. Elimination of one defect can create another one. Vowel harmony rules are a clear example; alteration to produce harmony to the left can create disharmony to the right. Iteration eventually removes all the defects, with directionality preventing endless looping. The new monocluster here is eliminated, as is common in resyllabification, by stealing the coda of the preceding syllable to provide an onset.
Resyllabification therefore yields:

\[
\begin{align*}
\omega & \omega & \omega \\
\times & \times & \times & \times & \rightarrow & \times & \times & \times & \times & \rightarrow & \times & \times & \times & \times \\
1 & i & f & r & \rightarrow & 1 & i & f & u & r & \rightarrow & 1 & i & f & u & r
\end{align*}
\]

Ito gets this result by supposing that there is a special template association principle for \( r \) which stipulates that it can associate with the coda position in a syllable with an empty head. It is crucial for her that the nucleus not be realized as \( u \) until the post-cyclic morphology, since this epenthetic \( u \) fails to trigger an umlaut rule that non-epenthetic \( u \) does trigger. In the monocluster account, there simply is no vowel until the post-cyclic morphology, at which point the \( u \)-triggered rule no longer applies. While not a telling difference, the stipulation that \( r \) can head a monocluster word-finally is more straightforward. Final consonantal monoclusters are not uncommon, allowed even at the surface in some languages. We will see an example in Section 3, in Cairene Arabic.

2.2. Imdlawn Tashlhiyt Berber

Before we take up the details of ITB, the interaction of Form Doublet and *Tri must be reexamined. It is commonplace in resyllabification for an unsyllabified vowel to steal the coda of a preceding syllable to provide it with an onset, as we proposed above for Icelandic. Does this happen in iterative syllabification as well? In principle, we can either suppose that Form Doublet is simply blocked by *Tri, as in (35a), or we can suppose that it applies with restructuring (cluster deletion) in order to comply with *Tri, as in (35b), provided of course that the new doublet cluster is permitted by the constraint set.

\[
\begin{align*}
\text{Form Singlet} & \rightarrow \omega & \omega & \omega \\
\text{Form Doublet} & \rightarrow \omega & \omega & \rightarrow & \omega & \omega & \omega \\
\text{Form Singlet} & \rightarrow \omega & \omega & \omega
\end{align*}
\]

ITB gives evidence that Form Cluster applies in the restructuring fashion. The best result would be that this is universal and does not have to be parametrized. Since I know of no evidence to the contrary, I will assume that Form Cluster always applies in the restructuring fashion.

ITB has the three vowel inventory \( \{a, i, u\} \). The only nuclear phoneme is the low vowel. Remarkably, all other phonemes are semi-nuclear. It is easy to check that for this structural inventory \( x \gg y \) iff \( x \) is more sonorous than \( y \). The default syllabification rule is then:

\[
\begin{align*}
\text{TS}(\times) ; \text{Clustered} ; \left( \gg \right) & :: \text{Form Doublet} ; \text{Form Singlet} ; \{\text{CSI, *Tri}\}
\end{align*}
\]

ITB modifies (36) in several ways:
1. The repair rules are augmented by Adjoin Onset, as in Icelandic, and by Adjoin Coda, the mirror image of Adjoin Onset.

2. The directionality component of the rule order is slightly refined by giving precedence to noninitial timing slots.

3. A constraint is added to the constraint set which requires word initial and word final nuclei to be sonorants.

\[
\text{TS}(\times) ; \text{Clustered} ; \begin{pmatrix}
\gg \\
\text{Noninitial} \\
\text{Left}
\end{pmatrix} :: \begin{bmatrix}
\text{Form Doublet} \\
\text{Form Singlet} \\
\text{Adjoin Coda} \\
\text{Adjoin Onset}
\end{bmatrix}
\]

\{ *\text{Nonsonorant edge nuclei, CSI, *Triplet} \}

To illustrate the workings of the iterative syllabification rule, several of the syllabification patterns given by Dell and Elmedlaoui, tabulated in (38), are derived below. I follow Dell and Elmedlaoui in capitalizing nuclei in the surface form.

\[(38) \text{underlying} \quad \text{surface} \quad \text{gloss} \]
\[
\text{txznas} \quad \text{txZ.nAs} \quad \text{‘store’ (3f.sg. perfective, 3m.sg.object)} \\
\text{txznt} \quad \text{txZ.nT} \quad \text{‘store’ (2sg.perfective)} \\
\text{ratlult} \quad \text{rAt.lUlt} \quad \text{‘you will be born’} \\
\text{ttfkt} \quad \text{tF.tKt} \quad \text{‘you suffered a sprain’} \\
\text{haultn} \quad \text{hA.uL.tN} \quad \text{‘make them (m.) plentiful’}
\]

As a quick reference guide, sonority precedence between the phonemes in the examples which follow is:

\[ a > u, i > r, l > m, n > z > f, s, x > b > t, k \]

The first example illustrates nonsonorant nuclei and the restructuring application of Form Doublet.

\[(39) \begin{array}{c}
\times \times \times \times \rightarrow \omega \\
n \times \times \times \times \rightarrow n \times \times \times \times \\
t \times \times \times \times \rightarrow \times \times \times \times \times \\
t \times \times \times \times \rightarrow \times \times \times \times \times
\end{array}
\]

In step 1, Form Doublet restructures the preceding syllable.

In the following, sonority increases from left to right, except for the final timing slot.

\[(40) \begin{array}{c}
\times \times \times \times \times \rightarrow \times \times \times \times \times \\
n \times \times \times \times \times \rightarrow n \times \times \times \times \times \\
t \times \times \times \times \times \rightarrow \times \times \times \times \times \times \\
t \times \times \times \times \times \rightarrow \times \times \times \times \times \times \times
\end{array}
\]

Only Adjoin Onset can apply in step 2 because nonsonorants cannot be nuclei at the word edges.
The first four phonemes in (41) are identical to the first four phonemes in (40). Nevertheless, the syllabification turns out to be entirely different.

\[(41) \quad \times \times \times \times \rightarrow \times \times \times \times \rightarrow \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \rightarrow \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times 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\times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \time
If the leftmost of such a pair is word initial, however, it is not chosen. The following is from their (33).

\[
\begin{array}{c}
\text{ω} \\
\text{x x x x} \rightarrow \text{ω ω} \\
\text{i u r m} \quad \text{i u r m}
\end{array}
\rightarrow \text{yU.rM}
\]

The form \( yUy.yL \) ‘he flew away’ in their (42) makes the same point.

3. Footing the Cluster Tier

The view of syllabification developed in the last section leads directly to certain expectations about footing. I assume that footing groups clusters. I assume further that footing not only groups clusters, but must also induce a grouping of the timing slots. This has a major effect on footing.

(46) *Split-×: Footing delimiters cannot intervene between the two clusters of a bicluster syllable.

If a footing delimiter did intervene, there would be a representation containing one of the following:

\[
\begin{array}{c}
\text{ω} \\
\text{x x x} \rightarrow \text{ω ω} \\
\text{i u r m} \quad \text{i u r m}
\end{array}
\]

But these are impossible, under the assumption that footing must group timing slots. In both cases, the medial timing slot is both inside a foot and outside it. The constraint (46) is obviously related to Syllable Integrity (Prince, 1976). But I do not take *Split-× (or Syllable Integrity) to be a primitive assumption. It is a consequence of the assumption that footing must not only group clusters, but must also induce a grouping of timing slots as well. The effect of *Split-× is that bicluster syllables on the cluster tier distort the footing pattern that would otherwise obtain (i.e. in the case of all monocluster syllables). A good illustration is the footing pattern in Cairene Arabic.

3.1. Cairene Arabic

In his analysis of Cairene Arabic, Hayes (1995:67) points out the “the stress pattern of Arabic as spoken in Cairo has ... played a central role in the development of metrical theory.” I follow that tradition and use Cairene Arabic to illustrate how bicluster syllables effect delimiter insertion. The examples are from Hayes, based on the work of Mitchell (1960), McCarthy (1978), and many others.
The iterative footing rule (47) for Cairene Arabic is identical to the iterative footing rule given earlier for Southern Paiute, except that “stressable element” has been replaced by cluster. As in Southern Paiute, the constraint *Uny is discretionary.

(47) Cluster : /ω __ ⇒ / __ ; Left :: 0 → ; {*)# || *Uny}

For words consisting of monoclusters, footing proceeds just as in Southern Paiute, producing:

(48) a. \[\begin{array}{c}
\omega \\
\omega \\
\omega \\
\end{array}\] \[\begin{array}{c}
k \\
\epsilon \\
\alpha \\
\end{array}\] kātaba  ‘you (m.sg.) wrote’

b. \[\begin{array}{c}
\omega \\
\omega \\
\omega \\
\end{array}\] \[\begin{array}{c}
k \\
\alpha \\
\kappa \\
\end{array}\] katabītu  ‘she wrote it (m.)’

c. \[\begin{array}{c}
\omega \\
\omega \\
\omega \\
\end{array}\] \[\begin{array}{c}
\epsilon \\
\alpha \\
\kappa \\
\end{array}\] safarātu  ‘his tree (nom.)’

Although the footing pattern is identical to the footing pattern in similarly structured Southern Paiute words, the stress pattern is different. Southern Paiute has right foot stress (iambic) and right word stress, so the main stress is invariably on the penultimate cluster. Cairene Arabic has left foot stress (trochaic) and right word stress, so the main stress in words consisting of monoclusters is penultimate if there are an odd number of monoclusters and antepenultimate if there are an even number of monoclusters.

Because *Split-× prevents delimiter insertion between the two clusters of a bicluster syllable (i.e. heavy syllable), heavy syllables in certain positions will distort the pattern of delimiter insertion points. Compare (49a) and (49b) with (48b).

(49) a. katábta, ‘you (m.sg.) wrote’

\[\begin{array}{c}
\omega \\
*\omega \\
*\omega \\
\end{array}\] \[\begin{array}{c}
k \\
\alpha \\
\beta \\
\end{array}\] kataba  ‘you (m.sg.) wrote’

b. bêtak, ‘your (m.sg.) house’

\[\begin{array}{c}
*\omega \\
*\omega \\
\omega \\
\end{array}\] \[\begin{array}{c}
b \\
\alpha \\
\kappa \\
\end{array}\] betak  ‘your (m.sg.) house’

In (49b), there is no way to remove the final defect, which remains. Of course, the defect is forgotten as soon as the iterative footing rule has run its course and the derivation moves on to the next rule.
Now that it is clear how *Split-x* distorts delimiter insertion points, we can write derivations in a more compact manner. The two clusters of heavy syllables will be connected by a “double bond,” indicating that they cannot be broken apart by delimiter insertion. After syllable splitting is discussed in the next section, a “single bond” will be used to indicate the two clusters of splittable syllables. Cairene Arabic does not allow syllable splitting.

A variety of derivations is given below for words that end in a string of monoclusters. Stress alternates between penultimate and antepenultimate.

(50) a. *qattāla*, ‘he killed’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

b. *ţinkásara*, ‘it got broken’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

c. *ţadwiyatuhu*, ‘his drugs (nom.)’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

A penultimate heavy syllable is always stressed. We saw two examples already in (49a) and (49b). Two more follow:

(51) a. *muddárris*, ‘teacher’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

b. *haţdami*, ‘these (m.du.)’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

If the final syllable is heavy, a penultimate monocluster is stressed.

(52) a. *şajrátun*, ‘tree (nom.)’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

b. *şajratuhúma*, ‘their (du.) tree (nom.)’
   
   \[
   \begin{align*}
   \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \to \omega \wedge \omega \wedge \omega \\
   \end{align*}
   \]

Cairene Arabic has what are called “super-heavy syllables.” Word finally, what is usually interpreted as a complex coda consonant can appear, as in *katabt*. I assume that Cairene Arabic syllabification does not form complex codas, but does relax the CSI to allow word-final consonantal monoclusters, just as Icelandic allows word-final r monoclusters.

We can now derive the feet structure and stress pattern of *katabt*.

(53) \[
\begin{array}{cccccccc}
\omega & \omega & \omega & \omega & \to & \omega & \omega & \omega \\
\omega & \omega & \omega & \omega & \to & \omega & \omega & \omega \\
\wedge & \wedge & \wedge & \wedge & \wedge & \wedge & \wedge & \wedge \\
\end{array}
\]

\[
\begin{array}{cccccccc}
k & a & t & a & b & t \\
k & a & t & a & b & t \\
k & a & t & a & b & t \\
\end{array}
\]

‘I wrote’

The final monocluster allows the insertion of } to the right of the bicluster. The result is that if CVC+C is final, stress will always be on the initial cluster of the CVC bicluster.
Aside from needing to clarify the syllable structure for “super-heavy syllables,” the results above follow virtually without comment. There is no notation of “foot inventory,” as in Hayes. Feet are simply what the footing rule produces. There is no notion of extrametricality. Nothing special needed to be said about heavy syllables. Their effect on footing follows entirely from general principles (*Split-×).

3.2. Insensitivity to Weight

It is well known that there are many languages in which footing ignores the distinction between monocluster syllables and bicluster syllables. In other languages, CVV bicluster syllables act as if they have two footing units, but CVC bicluster syllables do not. The theory developed above must be extended to account for these facts.

The topic is extensive and will be more adequately discussed elsewhere, but a sketch of the approach can be given here. A clue as to how this should be treated comes from languages like Central Alaskan Yupik and Malayalam, in which the effective demotion of certain bicluster syllables to “monocluster status” for the purposes of footing cannot be fixed in advance of footing, but is an operation which interacts with other footing operations.

This suggests that there is an operation which can effectively “lighten” heavy syllables, which sometimes takes part in iterative footing. Essentially, the operation must render the second cluster of certain (or all) biclusters invisible with respect to footing. Such clusters cannot simply be deleted, because they have a role to play in prosodic structure even though they do not enter the footing calculation. The most straightforward way to achieve invisibility is by splitting the cluster tier into two tiers; a primary cluster tier and an extrametrical cluster tier. Demotion consists of moving a cluster from the primary cluster tier to the extrametrical cluster tier, preserving all associations. Footing then groups elements on the primary cluster tier. One might imagine that syllable footing, as opposed to cluster footing, arises because a syllable tier is constructed over the cluster tier, and footing takes place on the syllable tier. But splitting the cluster tier is much simpler, involving the introduction of no new elements (i.e syllables) into the representation.

In languages in which syllable weight plays no role, demotion is applied across the board, prior to footing. In some languages, demotion applies only to CVC syllables. In other languages, demotion has complex interactions with other prosodic rules.

3.3. Another way to remove defects: Vowel shortening

Delimiter insertion is the primary device that iterative footing uses to remove defects. But other devices are also used. Since it is a useful bridge to the discussion of syllable splitting in the next section, it is useful to consider one of these devices here.
3.3.1 Fijian

Fijian has only (C)V and (C)VV syllables. Footing is generated by the edge-marking rule (54.EM) and the iterative footing rule (54.IF).

\[(54) \quad \text{EM: } \emptyset \rightarrow / \#\]

\text{IF: Cluster ; -Delimited ; Right : [ } \emptyset \rightarrow ( \] ; \{ *\text{Uny} \}

The data is from Hayes (1995:142), based on Schütz (1985).

Delete-× applies in (55). Neither \( \emptyset \rightarrow \) nor \( \emptyset \rightarrow ( \) can remove the rightmost defect because of *Split-× and *Uny.

\[(55) \quad \text{rdaiDa, ‘I see’}
\]

Stress is foot left and main stress is word right.

Hayes (p. 145) describes other dialects of Fijian in which the result is ráđa, with ai a short diphthong. Instead of deletion of the timing slot and its associated phoneme, only the timing slot deletes, with the phoneme reassociating with the timing slot to the left of the deleted slot. In still other dialects, the CVV bicluster splits into a pair of monoclusters. This will be discussed in Section 4.

The particular configuration in (55), a bicluster followed by a word-final monocluster, is the only environment in which Delete-× is called on to remove a defect. In all other environments, delimiter insertion suffices. The following example shows why.

\[(56) \quad \text{sa:kilá:; ‘she knows it’}
\]

Crucially, \( \emptyset \rightarrow \) is available along with \( \emptyset \rightarrow ( \) (the canonical delimiter insertion rule for right to left footing). Note that the defect driven rule format allows the iterative rule to alternate between three different ways of removing defects as it progresses across the word. This rule alternation, within the context of a containing iterative rule, sets the defect driven rule idea apart from traditional iterative rules, which have no means for such rule alternation.

As in Cairene Arabic, the distribution of secondary stresses resulting from heavy syllables, apart from the special configuration discussed above, follows with no
comment necessary. Some examples follow, with \( ^m \) and \( ^n \) denoting prenasalized consonants.

\[(57)\]
\[
a. \quad \text{par`aimar´ı: } 'primary' \\
\quad *w \ast w \omega \ast w \omega \rightarrow *w \ast w \omega \langle w \omega \rangle \rightarrow *w \ast w \omega \langle w \omega \rangle \rightarrow w \langle w \omega \rangle \langle w \omega \rangle
\]

\[
b. \quad \text{"bèlè-bò:tómù, } 'bellbottoms' \\
\quad *w \ast w \ast w \ast w \omega \rightarrow *w \ast w \ast w \langle w \omega \rangle \rightarrow *w \omega \langle w \omega \rangle \omega \langle w \omega \rangle \rightarrow \langle w \omega \rangle \langle w \omega \rangle \langle w \omega \rangle
\]

\[
c. \quad \text{mì:sìni \( ^n \)agnì, } 'machine gun' \\
\quad *w \ast w \ast w \ast w \omega \rightarrow *w \ast w \ast w \langle w \omega \rangle \rightarrow *w \ast w \langle w \omega \rangle \omega \langle w \omega \rangle \rightarrow \langle w \omega \rangle \langle w \omega \rangle \langle w \omega \rangle
\]

\[
d. \quad \text{pal`asitá: } 'plaster' \\
\quad *w \ast w \ast w \ast w \omega \rightarrow *w \ast w \ast w \langle w \omega \rangle \rightarrow w \langle w \omega \rangle \langle w \omega \rangle
\]

4. Syllable splitting

Above, a dialect of Fijian was analyzed in which vowel shortening was used to eliminate the defect (with respect to right to left footing) of the second cluster of a bicluster preceding a word-final monocluster. We begin by analyzing a different dialect of Fijian which eliminates the defect by splitting the bicluster into a pair of monoclusters.

4.1. Syllable splitting in Fijian and Tongan

*Split-\( \times \) blocks straightforward delimiter insertion between the two clusters of a bicluster syllable. If delimiter insertion is accompanied by delinking, as in (58), there is no violation of *Split-\( \times \). I call the operation local syllable restructuring (LSR).

\[(58)\]
\[
\begin{array}{c}
\ast w \ast w \\
\ast w \langle \ast w \rangle \\
\ast w \ast w \langle \ast w \rangle \\
\ast w \langle \ast w \rangle \langle \ast w \rangle
\end{array}
\]

The operation inserts a delimiter between the two clusters of a bicluster syllable, but avoids a *Split-\( \times \) violation by simultaneously dissociating the second cluster from the syllable nucleus.

If the crucial example (55) is reconsidered, with LSR replacing Delete-\( \times \) in the Fijian iterative footing rule (54b), the result is:

\[(59)\]
\[
\begin{array}{c}
\ast w \ast w \omega \\
\ast w \lambda \omega \\
\ast w \lambda \omega \\
\ast w \lambda \omega \lambda \omega
\end{array}
\]

raíða, ‘I see’

This example, Hayes (1995:145), is from Geraghty (1983).
Tongan is virtually identical to the syllable splitting dialect of Fijian. Edge marking and iterative footing are as in Fijian, with LSR replacing Delete-× in the iterative footing rule (54.IF). Stress is foot left and main stress is word right, as in Fijian. There are differences in secondary stress, which we return to shortly.

Parallel to Fijian (59) is Tongan (60), from Churchward (1953:11).

\[
\begin{align*}
\text{60} & \quad \frac{*\omega *\omega}{\text{LSR}} \quad \frac{\omega}{\omega} \\
\frac{\text{h u f i}}{\text{h u f i}} & \quad \rightarrow \quad \frac{h u f i}{h u f i} \quad \rightarrow \quad \text{huúfa, ‘to open officially’}
\end{align*}
\]

The following examples (Churchward p. 5, 11), parallel the Fijian examples in (57), and demonstrate that only biclusters preceding a word-final monocluster are subject to splitting.

\[
\begin{align*}
61a. & \quad \text{kà:ká}, \ ‘to cheat’ \quad \frac{*a_o o}{*a_o o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \\
b. & \quad \text{mà:lóhi, \ ‘strong’} \quad \frac{*a_o o}{*a_o o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \\
c. & \quad \text{fà:kahùa, \ ‘to sail a zigzag course’} \quad \frac{*a_o o o_o}{*a_o o o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o} \\
& \quad \rightarrow \frac{o_o}{o_o} \rightarrow \frac{o_o}{o_o}
\end{align*}
\]

Assuming that foot stress that is not main stress surfaces as secondary stress, the footing rules above predict secondary stress on biclusters and monoclusters which are separated from a following bicluster or a monocluster with main stress by an odd number of monoclusters. Although there are no clearcut examples given, Churchward (p. 5) indicates that non-penultimate stress only surfaces on long vowels. Is so, secondary stress must be suppressed on short vowels. Note however, that the footing rule (54) requires no modification. The only issue is the possible language particular suppression of certain secondary stresses.

Example (60) was given a prominent place in Prince and Smolensky (1993) as an argument against rule-based phonology. Clearly, in theories which attempt to give an account of how complex phonological representation are computed from simple inputs, syllabification of some form must precede footing. Prince and Smolensky argue that Tongan poses an insoluble “chicken and egg problem” for such theories because the form huúfi shows that syllabification depends upon footing. The confusion in the logic of their argument is revealing. The argument is based on the assumption that later operations cannot modify the work of earlier operations. This is an assumption from OT; the idea that all change works “in the same direction”, towards surface optimality. But it is in no way an assumption of rule-based theories. The only substantive point that Prince and Smolensky make is that rule-based analyses of Tongan stress will be unsuccessful if they adopt the premises of Optimality Theory. But there is no argument about this point.

In any event, the LSR rule above has no difficulty in undoing the work that was done in building a CVV syllable, just as shortening has no difficulty in undoing the
work of associating a long underlying segment with an extra timing slot. That is the way phonology works.

4.2. Gothic (Siever’s Law)

The metrical structure of Old English and Gothic has been the subject of a series of recent studies. The data below are taken from Dresher and Lahari (1991), Halle, O’Neil, and Vergnaud (1993) and Keyser and O’Neil (1985).

If a language has melodic segments which can be either onsets or nuclei, it is at least possible for it to employ local syllable restructuring as in (62).

\[
\begin{array}{llllll}
\omega & \times & \times & \times & \times & \times \\
C & V & C & X & 1 & 1 \\
\end{array}
\rightarrow
\begin{array}{llllll}
\omega & \times & \times & \times & \times & \times \\
C & V & C & X & V & V \\
\end{array}
\]

Formerly nuclear X becomes an onset. (The right delimiter shown above is simply illustrative and could just as well been a left delimiter.)

Gothic employs this footing strategy in one very specific context, which is just the left to right version of the context in which vowel shortening and syllable splitting are used in Fijian and Tongan. Just as in Tongan and Fijian, mixed delimiter insertion allows higher ranked operations to remove footing defects in all other positions, so that resort to LSR can be avoided in those positions. What sets the strategy apart from the Tongan and Fijian footing strategies is that it is employed with only one phoneme, called j in the literature, which alternates between a glide onset and high vowel nucleus, depending on the environment it finds itself in. Local syllable restructuring therefore reduces to:

\[
\begin{array}{llllll}
\omega & \times & \times & \times & \times & \times \\
C & V & C & j & V & V \\
\end{array}
\rightarrow
\begin{array}{llllll}
\omega & \times & \times & \times & \times & \times \\
C & V & C & X & V & V \\
\end{array}
\]

Prior to iterative footing (64.IF), edge marking (64.EM) at the left edge applies.

\[
\begin{array}{llllll}
\omega & \omega & \omega & \omega \\
C & V & C & j & V & V \\
\end{array}
\rightarrow
\begin{array}{llllll}
\omega & \omega & \omega & \omega \\
C & V & C & j & V & V \\
\end{array}
\]

I will assume that syllabification forms complex onsets, but not complex codas. Final unsyllabified consonants are associated with a monocluster, as in Cairene Arabic. Foot and word stress are left.

First, some examples in which the heavy syllables are distributed in such a way that \( \emptyset \rightarrow \) is sufficient to eliminate all the defects in the foot structure.
Note the vowel deletion in several surface forms. Unfooted high vowels delete. Keyser and O’Neil. 1985, discovered the connection between high vowel deletion and foot structure. Their analysis is entirely different, but the basic insight is confirmed.

Biclusters can disrupt footing because of *Split-×, just as in Cairene Arabic.

In (66), biclusters disrupt the footing, but the option of ∅ → ⟨ allows all defects to be eliminated. But there is one (and only one) configuration in which the option of ∅ → ⟨ does not suffice to remove all the defects. If the bicluster immediately follows a word-initial monocluster, *Uny and the edge mark combine to prevent the application of ∅ → ⟨.

Because *Uny is a strict constraint, one of the defects cannot be removed. This configuration is the mirror image of the configuration which forced syllable splitting in Tongan and Fijian; a bicluster immediately preceding a word-final monocluster. *Uny and the edge mark } combined to prevent the application of ∅ → }.

In the same configuration as (67), if the nucleus of the first cluster in the bicluster is j, footing resorts to local syllable reorganization, the bicluster is split, and all defects are removed.

I leave open the question of whether resyllabification applies in the final foot since there is no evidence that can be brought to bear on the question.
The syllabification of *nasjis* ‘save’ as *nas.jis* rather than *na.siis* is an instance of what is called Siever’s Law. Another example, with the same analysis, is the syllabification of *arjis* ‘plow’ as *ar.jis*, not *a.riis*. There is a very long tradition of explanation of Siever’s Law in terms of “exceptional syllabification” of these forms. See the many references in Dresher and Lahiri, starting with Kauffmann (1887). Syllable splitting under accommodation to footing desiderata provides a principled basis for the exceptional syllabification.

4.3. Southern Paiute

Halle and Vergnaud (1987:191) note that long vowels never interrupt the metrical count in Southern Paiute, even though long vowels are always counted as a pair of stressable elements. They conclude that, at least as an option, feet can partition syllables. But Hayes (1995:123), notes that apparent syllable partitioning between two feet is never found with CVC syllables. He further notes that a simple explanation for this is possible if syllables cannot be split between two feet and apparent cases of syllables partitioned between two feet are actually cases of CV.V bisyllabic sequences. Crucially, a C split off from a CVC syllable cannot stand alone as a syllable, so that CV.C is impossible. I find Hayes’ argument convincing, and have adopted *Split-* as a basic principle of foot formation.

In Fijian, Tongan, and Gothic, splitting a bicluster occurred in only in the very limited environment. The reason was that both left and right foot delimiters could be inserted by the iterative footing rule. Syllable splitting was always a last resort, and never needed except in that limited environment. Southern Paiute, which foots left to right, employs only *⟩*-insertion. It therefore is faced with the problem of eliminating the footing defects in biclusters throughout the word. Since recourse to a less desirable rule is always preferable to violating derivational constraints, even discretionary ones, syllable splitting occurs across the word. The following example, Hayes (1995:121), is from Sapir (1930).

\[
\begin{align*}
\langle \omega & \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \omega \\
\times & \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \\
t & i \chi \ i \ n \ a \ t & i \beta & i \zeta & u & \chi \ a & i \ ? & i \eta \ a
\end{align*}
\]

\[
\rightarrow \langle \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \ \omega \\
\times & \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \times \\
t & i \chi \ i \ n \ a \ t & i \beta & i \zeta & u & \chi \ a & i \ ? & i \eta \ a
\]

*tix*’*mâtifiču*’*a*’*i?i*’*η*”a ‘go and ask him to tell a story’
Notes

1. I am grateful to Morris Halle for his guidance, support, and contagious curiosity about how the language faculty does what it does. Thanks also to Sylvain Bromberger, Sam Gutmann, Wayne O’Neil, Eric Rainy, and Moira Yip, as well as audiences at MIT and at the Phonology 2000 Conference, for helpful comments. This paper is a rewriting of part of a longer paper which circulated as “SPE Extensions” 1999.

2. Unaccountably, the work of Calabrese is not mentioned.

3. In more recent work, Calabrese supposes that constraints are associated with particular strata.

4. In general, predicates can be interpreted as precedence relations. If P is a predicate, then we say x > y with respect to P if P(x) and not P(y). We also say x = y with respect to P if not x > y with respect to P and not y > x with respect to P. Predicates over phonemes can be interpreted as predicates over timing slots via association. The complication of timing slots associated with multiple phonemes will be ignored here, since it is irrelevant to what follows. A list of precedence relations is itself interpreted as a precedence relation by saying x > y with respect to (P_1 P_2 ... P_n) if x > y with respect to P_1, or x = y with respect to P_1 and x > y with respect to (P_2 ... P_n). The recursion is terminated by interpreting (P) as P.

5. Clements says: “The demisyllable was first introduced as a linguistic unit in the acoustic and phonological studies of Fujimura and his colleagues (see e.g. Fujimura et al. 1977), but has not previously received explicitly phonological justification.” I have not been able to consult the papers which Clements refers to.

6. The context was criticism of a proposal of Mester (1992), which had suggested that the Tongan phenomenon was “structure-changing imposition of [a] foot.” My conclusion is that Mester was exactly right. Autosegmental syllabification and an analysis of footing as delimiter insertion into the cluster tier provide an analytic framework which allow Mester’s proposal to be directly translated into a sound analysis.

7. The medial high vowel apparently does not delete. Plausibly, this is a consequence of the fact that it would strand the onset m, which could not integrate into either flanking syllable. The problem does not appear to have been noted by Halle, O’Neil, and Vergnaud (1993).

References


