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Rhythmic vowel deletion in Optimality Theory

René Kager
University of Utrecht

1. Introduction[1]

A challenge to any theory of phonology is to reconcile two types of interaction which are exact functional opposites: *conspiracy* and *opacity*. A conspiracy is a situation in which independent processes interact in such a way that they create uniform patterns in surface forms. Opacity is the opposite situation: one process obscures the context of application of another process - rendering the surface form opaque.

One of the principal reasons for which rule-based theory has recently come under attack is that it offers no satisfactory explanation for conspiracies. Rule-based theory fails in this respect since it states generalisations in the form of structural descripions, which are checked against representations at various steps during a serial derivation. All that is relevant for rule application is that some representation matches the context of a rule at the point in the derivation at which that rule applies. In this view the level of the output is no more priviliged than any intermediary level. In contrast, Optimality Theory (Prince & Smolensky 1993, McCarthy & Prince 1993b) defines grammatical well-formedness as the result of an interaction of conflicting constraints on surface forms, thus abandoning the concept of ordered rules. Focussing on the output allows a more principled explanation of conspiracies. In OT, a convergence to surface patterns is the expected situation, since the output is the single level at which of generalisations can be stated.

As compared to its success in capturing conspiracies, OT has up till now at least, not been equally successful in capturing opacities. In rule-based theory, opacity is just the expected situation, since generalisations may hold at intermediary levels, but then be lost in the output, where other rules may have obscured them.[2] Opacity poses a challenge for OT, a theory that, in its standard interpretation at least, is deprived of any intermediate levels that do not correspond to morphological strata. (The issue of opacity and OT is also addressed in three papers by Halle, Idsardi, and Noyer, all in this volume.)

This paper is devoted to one specific type of opacity, the case of rhythmic vowel deletion. This is a cross-linguistically common process that deletes vowels in alternating

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[2] Doug Pulleyblank kindly reminds me of proposals in derivational theory that minimize opacity in rule interactions (e.g. Kiparsky 1971). This is a valid observation, but it leaves unaffected the crucial point: derivational theory, being a theory employing ordered rules, is *in principle* capable of expressing rule opacity, and to that extent it also predicts it. This point has been emphasized by Kisseberth (1970, 1973), Kenstowicz & Kisseberth (1979), and others.

syllables. The standard rule-based analysis attributes the rhythmicity of vowel deletion to its context - weak syllables of iterative disyllabic feet. Opacity is an inherent result of this analysis, for the following reason. Deletion of vowels is followed by a resyllabification of surrounding consonants. Consequently the context of deletion may be irrecoverable from the output. A rule-based scenario typically includes the following ordered rules (i-iv): (i) syllabification, (ii) iterative foot construction, (iii) deletion of vowels in weak syllables of feet, and (iv) resyllabification. The derivations in (1) illustrate these rules by forms from two languages that will figure prominently in this paper, Macushi Carib (iambic, 1a) and Southeastern Tepehuan (trochaic, 1b).

(1)	UR	a.	/wanamari/	b.	/maa-matuʃidʒaʔ/
	Syllabification		wa.na.ma.ri		maa.ma.tu.ʃi.dʒaʔ
	Foot construction		(wa.nàː).(ma.ríː)		(máa.ma).(tù.ʃi).(dʒàʔ)
	Vowel deletion		(w .nàː).(m .ríː)		(máa.m).(tù.ʃ).(dʒàʔ)
	Resyllabification		(wnàː).(mríː)		(máam).(tùʃ).(dʒàʔ)
	PR		[(wnàː).(mríː)]		[(máam).tuʃ.dʒaʔ]

In languages in which the context of deletion correlates with rhythmic stress in surface forms, such as Macushi Carib, deletion is transparent with respect to its metrical context. But in the case of Southestern Tepehuan, where no surface rhythmic pattern is present, deletion cannot be conditioned by surface feet. Here vowel deletion apparently destroys its own context, by deleting the vowel that is the head of the weak syllable in the foot. ‘Metrical opacity’ presents a challenge to surface-oriented Optimality Theory. This paper tackles this challenge by arguing that vowel deletion in Southeastern Tepehuan is not due to iterative feet, but rather to the minimization of the number of unstressed syllables that remain unparsed by a single word-initial foot. This analysis is fully surface-based, thereby removing the opacity problem.

This dual treatment of (what appears to be) a unitary phenomenon may seem to amount to a loss of generalisation: there are now two types of grammars that achieve the same kind of surface result - alternating phonetic loss of underlying vowels. However, this loss of generalisation is apparent only, since there are independent arguments for a distinction between these types of language. Actually, there is no unitary phenomenon of rhythmic vowel deletion, but instead there are two varieties: *gradient* and *categorial*.

Gradient rhythmic vowel deletion is phonologically incomplete, occurring in free variation with vowel reduction. It preserves the syllabicity of the ‘deleted’ vowel, which may be signalled by phonetic cues (open transitions at the deletion site etc.). It preserves the foot-based context in the output, in the form of secondary stresses. Since its context is fully recoverable from the output, gradient reduction/deletion involves no opacity. The language that exemplifies this is Macushi Carib, discussed in Section 2.

Categorial rhythmic vowel deletion is phonologically complete, and has no vowel reduction counterpart. It destroys the syllabicity of the deleted vowel, which is clear from the fact that syllable-governed phonology refers exclusively to the output syllabification. Moreover there is no secondary stress pattern that coincides with the alternating deletion pattern. (As a matter of fact, Southeastern Tepehuan had no secondary stress at all.) OT predicts that categorial deletion cannot be conditioned by iterative feet, since that would involve opacity. In Section 3, I will first argue against an iterative-foot-based analysis on independent grounds. I will then propose an OT analysis which is based on the idea that vowel deletion in Southeastern Tepehuan serves a cross-linguistically well-known output target: exhaustivity of metrical parsing. It minimises the number of syllables outside the single initial foot (e.g. [(máam)] in the output of 1b). The apparent ‘rhythmicity’ of the deletion pattern follows from constraint interaction: input consonants must be preserved, while output consonants must be properly syllabified (“no complex margins”). From this it follows that the optimal strategy to reduce violations of exhaustive metrical parsing, while preserving the input consonantism, is the deletion of alternating vowels.

My conclusion will be that OT (but not rule-based theory) predicts the clustering of properties of rhythmic vowel deletion found in Macushi and Southeastern Tepehuan on a broader typological basis. It is a virtue of OT, rather than a liability, that it makes a distinction between two phenomena that are only apparently identical.

2. Macushi Carib

2.1 Rhythmic vowel deletion preserves syllabicity

The rhythmic pattern of Macushi, a member of the Carib family spoken in Guyana and Brazil, was first described by Hawkins (1950). His paper focusses on the rhythmic vowel deletion rule, without discussing an alternating stress pattern as its conditioning factor. Hawkins reports that vowels in odd-numbered syllables, counting from left to right, are deleted. The last vowel in each stress contour is always retained. Abbott (1991) relates deletion to an alternating stress pattern: “A short unstressed vowel is reduced to open transition [transcribed as [ᵊ],R.K] before stops, and may be completely lost before voiced consonants.” Complementing the rhythmic deletion pattern, Abbott (1991:145) reports a short-long rhythmic pattern in sequences of open syllables within the phrase, with even-numbered syllables long: “The final CV in a phonological phrase (i.e., a phrase bounded by pause) is always long and stressed, but within the phrase, even across grammatical word boundaries, the pattern is that the even numbered V or CV syllable, counting from the left, is long.” Abbott defines ‘long’ as ‘having stress and vowel length’. This pattern is illustrated in (2), where foot boundaries are indicated that will be motivated below:[3]

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[3] Forms below which are taken from Hawkins (1950) are marked by ‘H’, while those from Abbott are marked by ‘A’. In the former I have added length on vowels where this should fall according to Abbott’s description.

Lengthening data reported in Carson (1982) slightly deviate from those in Abbott (1991). Carson describes vowel lengthening as a compensatory process: “when a short vowel is suppressed, the vowel that immediately precedes a stop consonant in its vicinity is lengthened.” Her description differs in various other aspects from Hawkins (1950) and Abbott (1991), in particular in positing lexical tone rather than stress. Because of these rather large differences I suspect that Carson’s description was based on a different dialect than Hawkins’ and Abbott’s. For this reason I have not used any of Carson’s examples.

(2)	2σ	/pa̲ta/	(pᵊtáː)	‘place’	(A:147)
		/pe̲-pɨn/	(pᵊpɨ́n)	‘no, never’	(H:89)
	3σ	/pi̲ripi/	(prìː).(píː)	‘spindle’	(H:89)
		/u̲pata/	(ᵊpàː).(táː)	‘my place’	(A:146)
	4σ	/e̲repa̲mɨ/	(ᵊrèː).(pmɨ́ː)	‘I arrive’	(A:146)
		/pi̲rɔtɔ̲-rɨ/	(pᵊrɔ̀ː).(trɨ́ː)	‘gunshot’	(H:89)
	5σ	/u̲-mana̲ri-rɨ/	(màː).(nrìː).(rɨ́ː)	‘my cassava grater’	(H:89)
		/y-a̲kina̲-tɔʔ-ton/	(yᵊkìː).(nᵊtɔ̀ʔ).(tɔ́n)	‘something to comb him with’	(H:88)
	6σ	/u-wana̲mari̲-rɨ/	(wàː).(nmàː).(rrɨ́ː)	‘my mirror’	(H:87)
	7σ	/a̲rima̲raka̲yamɨ/	(rìː).(mràː).(kyàː).(mɨ́ː)	‘dogs’	(A:146)

Rhythmic vowel deletion may actually produce vowel-zero alternations in stems, due to prefixation, which affects the odd-even count:[4]

(3)	a.	/wa̲nama̲ri/	(wnàː).(mríː)	‘mirror’	(H:87)
	b.	/u̲-wana̲mari̲-rɨ/	(wàː).(nmàː).(rrɨ́ː)	‘my mirror’	(H:87)

In sum, we find that foot parsing is iambic by two converging criteria: rhythmic vowel reduction (or deletion) and rhythmic vowel lengthening. Both indicate the strength of even-numbered syllables, and the weakness of odd-numbered syllables. Moreover, the quantity-sensitivity of iambic feet is apparent from both processes. First, vowels in heavy syllables (Cvv, CvC) are immune to deletion. Second, heavy syllables disrupt the parity count of both lengthening and reduction (below underlying length of vowels has been indicated by gemination):

(4)	a.	/seepɔ̲rɔ/	(sèe).(prɔ́ː)	‘along here’	(A:147)
	b.	/peʔma̲ra/	(pèʔ).(mráː)	‘free’	(A:147)
	c.	/eere̲pamɨ/	(èe).(rᵊpàː).(míː)	‘I arrive’	(A:146)
	d.	/waimu̲yamɨ/	(wài).(myàː).(míː)	‘rats’	(A:147)
	e.	/ʃiʔ-mi̲ri-kɨ̲-pe/	(ʃìʔ).(mrìː).(kᵊpéː)	‘little now’	(H:88)
	f.	/aʔta̲ en-kɔ̲ne-ka-ʔpɨ/	(àʔ)(tèn)(knèː)(kàʔ)(píː)	‘the hammock that he made’	(H:88)
	g.	/u̲-y-en-kuʔ-tɨ̲-saʔ-ya/	(yèː).(kùʔ).(tᵊsàʔ).(yáː)	‘if anyone deceives me’	(H:88)

The contexts of application of reduction and lengthening are stated maximally general by iambic feet, which present the contexts of both processes simultaneously.

Both lengthening and vowel reduction are cross-linguistically common processes in iambic languages, increasing the durational differences which are inherent to the iamb: *a quantitatively unbalanced rhythm unit* (Hayes 1995) of a light plus a heavy

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[4] In fact, without alternations we would not know the underlying values of most vowels.

syllable. From a typological perspective some analysis is preferrable that expresses this connection between foot type and reduction. But then vowel reduction must crucially preserve the weak syllable in the iamb as a degenerate syllable, containing a nucleus that is void of vocalic features (indicated below by ‘• ’):

(5) [Cv.Cv] → [C• .Cvv]

If the vowel were categorially deleted, the disyllabic iambic target would be lost.

There is additional evidence that vowel deletion is an extreme type of reduction, i.e. of a gradient rather than a categorial nature. First, according to Abbott (1991) it is an optional process: reduction need not go all the way to deletion. Since reduced vowel and ‘zero’ seem to be mutually interchangeable realisations, it would be difficult to draw the line between both. The gradient nature of vowel deletion shows its phonetic, rather than phonological, character.

Second, deletion is literally incomplete in certain contexts: before stops, an open transition is retained at the site of the ‘deleted’ vowel. I interpret this to be the phonetic realisation of the empty nucleus:

(6) a. /y-eʔma̲-tan-tɨʔ/ (yèʔ).(mᵊtà**n**).(**t**ɨ́ʔ) ‘you (pl.) go pay it’ (H:88)
b. /y-a̲kina̲-tɔʔ-ton/ (yᵊkìː).(**n**ᵊ**t**ɔ̀ʔ).(tɔ́n) ‘something to comb him with’

Without a phonetic counterpart of syllabicity, the closed versus open transition contrast between [...nt...] (cf. 6a) and [...nᵊt...] (cf. 6b) is not explainable.[5]

Third, if deletion were complete, it would be non-structure-preserving. That is, it would violate otherwise unviolable phonotactic laws of consonant clusters. For example, the word onsets /wn/ and /yk/ that arise across the deletion site in (3a) and (6b) are not otherwise attested initially in roots. Non-structure-perservingness is a typical property of gradient processes.

Fourth, there is corroborating evidence from lengthening that ‘deleted’ vowels still function as empty nuclei in the phonology. We saw earlier that iambic lengthening affects open syllables, but not closed syllables. If vowel deletion were complete, it would trigger re-syllabification of an onset as the coda of the preceding syllable, thereby closing it. Then lengthening would be incorrectly blocked (since closed syllables generally fail to lengthen). For example, we would expect *[wnam.riː] rather than [wnaːmriː] (cf. 3a).

An allophonic process of obstruent voicing provides yet another argument for an empty nucleus. Abbott (1991:140) reports that “Voicing occurs following a long syllable (CVV, CVC or VC) in which there is a long vowel or a final n or ʔ (this does not include all cases of rhythmically long vowels)”. From various examples which she

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[5] Hawkins (1950:88) argues open transition to be “nonsyllabic and nonvocalic (1) because the space between the consonants has no clear vowel quality; (2) because no contrastive vowel qualities are there present; (3) because the transition does not take as much time as the vowels do; and (4) because no vowel phoneme with which this can be phonetically or structurally identified occurs elswehere in the language.” He adds that “[...] the contrast between open and closed transition, however, remains as an unexplained contrastive residue in the phonemic analysis.”

provides it is clear that both ‘underlying’ and ‘derived’ syllable weight may trigger obstruent voicing, see (7a-d). But Abbott never transcribes a voiced obstruent in a position following a site of reduction or deletion, see (7e-f). (Abbott’s transcriptions abstract away from deletion; I have indicated reduction vowels by underlining.)

(7)	a.	/seeporɔ/	[see.**b**ɔ̱rɔː]	‘along here’	(A:147)
	b.	/mɔʔta/	[mɔʔ.**d**a]	‘move’	(A:140)
	c.	/uyapɔnse/	[u.yaː.**b**ɔŋ.**z**e]	‘my bench’	(A:140)
	d.	/yepɔtɔrɨ/	[ye̱.pɔː.**d**ɔ̱.rɨː]	‘lord’	(A:140)
	e.	/sɨrɨrɨpe/	[sɨ̱.rɨː.rɨ̱.**p**eː]	‘today’	(A:144)
	f.	/eraʔmata/	[e̱.raʔ.ma̱.**t**aː]	‘go get it’	(A:147)

If deletion would affect syllabification, it would produce outputs such as *[(srɨːr).(**b**eː)], in which bold-face /**b**/ would be in the position for voicing, following a heavy syllable.

There is yet a third syllable-sensitive process which provides evidence for the lack of resyllabification. Nasals in coda position cannot license place of articulation, and they are homorganic with the following consonant, or realized as [ŋ] at the end of a word and before /r/, see (8a). Now observe that a nasal that precedes a deletion site always retains its place features, see (8b-c):[6]

(8)	a.	/anraʔ/	[a**ŋ**raʔ]	‘heron’	(A:142)
	b.	/peʔmara/	[peʔ**m**a̱ra]	‘free’	(A:147)
	c.	/aimutuŋ/	[ai**m**u̱tuŋ]	‘white’	(A:142)

If deletion would trigger resyllabification, the expected outputs would be *[peʔ**ŋ**.ra] and *[ai**n**.tuŋ]. Crucially all three syllable-sensitive processes point to the same syllabification of consonant clusters that are adjacent to ‘deletion’ sites. This prediction is not made by a derivational analysis with true vowel deletion, given the fact that (in principle at least) a syllable-sensitive rule may be extrinsically ordered before or after vowel deletion.[7]

In sum, there are four arguments that RVD preserves a nucleus in the output - hence is phonologically incomplete. First, its target (the canonical iamb LH) is disyllabic. Second, it is optional, while vocalic traces (open transitions) may remain at the deletion site. Third, phonotactic patterning (creation of otherwise ill-formed consonant clusters). Fourth, three syllable-sensitive processes (vowel lengthening, obstruent voicing and nasal assimilation) show that deletion fails to trigger resyllabification.

2.2 Rule-ordering theory vs. Optimality Theory

Consider first a rule-based analysis of this pattern:

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[6] Form (8b) is actually presented by Abbott with its underlined vowel deleted, while form (8a) is presented in a broader transcription that abstracts away from vowel deletion.

[7] Doug Pulleyblank remarks that resyllabification is not necessarily triggered by vowel deletion in a rule-based approach. However, resyllabification is considered to be ‘automatic rule’ by most derivational analysts.

(9) a. Foot construction: assign iambs from left to right (treating CvC as heavy)
b. End Rule (Right): label the rightmost foot as strong.
c. Iambic lengthening: lengthen the vowel of a syllable in strong position.
d. Iambic reduction: reduce the vowel of a syllable in a weak position.

This analysis is illustrated by sample derivations below:

(10)	UR	/piripi/	/y-akina-tɔʔ-tɔn/	/ʃiʔ-miri-kɨ-pe/
	Iambs	(pi.ri).(pi)	(ya.ki).(na.tɔʔ).(tɔn)	(ʃiʔ).(mi.ri).(kɨ.pe)
	ER(R)	(pi.ri).(pí)	(ya.ki).(na.tɔʔ).(tɔ́n)	(ʃiʔ).(mi.ri).(kɨ.pé)
	Lengthen	(pi.riː).(píː)	(ya.kiː).(na.tɔʔ).(tɔ́n)	(ʃiʔ).(mi.riː).(kɨ.péː)
	Reduce	(priː).(píː)	(y^{ə}.kiː).(n^{ə}tɔʔ).(tɔ́n)	(ʃiʔ).(mriː).(k^{ə}.péː)
	PR	[(prìː).(píː)]	[(y^{ə}kìː).(n^{ə}tɔ̀ʔ).(tɔ́n)]	[(ʃìʔ).(mriː).(k^{ə}.péː)]

Now consider an OT analysis of the Macushi footing pattern. The preservation of input vowels - in the form of empty nuclei - is due to the 'faithfulness' constraint MAX (McCarthy & Prince 1995). This requires input segments to have some *correspondent* in the output. (Correspondence is a relationship between elements in two segment strings, in this case input and output, see McCarthy & Prince 1995.)

(11) **MAX**
Every segment in the input has a correspondent in the output.

MAX does not require a correspondent of an input segment to retain the feature content of that input segment - it only asserts that 'something' be identifiable in the output as a realisation of the input vowel, e.g. an open transition.[8]

Next I assume a 'cover constraint' FT-FORM, merely as a short-hand notation for four undominated constraints that together define the iamb as a foot of the shape (LH) or (H). It includes the constraint responsible for vowel lengthening (STRESS-TO-WEIGHT):

(12) **FT-FORM** (cover constraint)

a.	FTBIN	Feet are binary under moraic or syllabic analysis.
b.	WSP	Heavy syllables are prominent within the foot.
c.	RHTYPE=IAMB	Feet are right-headed.
d.	STRESS-TO-WEIGHT	Stressed syllables are heavy.

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[8] Bill Idsardi objects that null vowels constitute a representational extension of the theory, since "if null vowels are not phonetically present, then the analysis of Carib sneaks a derivation in through the back door. The OT calculation is not calculating surface phonetic forms, but 'end-of-phonology' forms, subject to further phonetic interpretation." I disagree. Under any theory, a borderline should be drawn between phonology and the domain of phonetic interpretation. A well-argued assumption (Keating 1988, Cohn 1990) is that this coincides with the distinction between categorial ('symbolic') and gradient ('temporal and spatial') rules. Since durational reduction of unstressed vowels is a gradient process in Macushi Carib (as it is in many other languages), it must belong to phonetic interpretation.

Vowel reduction (or the loss of vocalic features) in weak syllables is due to undominated REDUCE.

(13) **REDUCE**
Weak syllables dominate no vocalic features.

To obtain an iterative foot parsing, PARSE-σ (14) must dominate ALL-FT-R (15).

(14) **PARSE-σ**
All syllables must be parsed by feet

(15) **ALL-FT-R**
All feet must stand at the right edge of PrWd.

This constraint interaction (McCarthy & Prince 1993) produces exhaustive footing that is oriented towards the right edge of the word. Let us see how this works. First, PARSE-σ must be undominated because of exhaustivity. It must crucially dominate ALL-FT-R, since every foot that is not strictly at the right word edge incurs a violation of ALL-FT-R. But even in its dominated position, ALL-FT-R has two effects. It minimises the number of feet per word. Since feet are maximally disyllabic, the effect is an alternating rhythm. Its second effect is to limit monosyllabic feet to the right periphery - this will become clear immediately below in tableau (18). Notice that the *left-to-right* specification of footing in the rule-based analysis translates into a *right-edge* orientation in the OT analysis.

The fact that vowels are reducible at all is due to an interaction of REDUCE and IDENT. The latter is the faithfulness constraint that militates against loss of input features in the output (McCarthy & Prince 1995).

(16) **IDENT**
If a segment is specified as [αF] in the input, then it must be specified as [αF] in the output.

Clearly REDUCE must dominate IDENT. The last crucial ranking, that of ALL-FT-R above IDENT, will be motivated by the tableaux (18-19).

In sum, the alternating reduction pattern is due to the following hierarchy:

(17) MAX, REDUCE, FT-FORM, PARSE-σ » ALL-FT-R » IDENT

This hierarchy is illustrated in tableaux (18-19). In (18) we see a trisyllabic form:

(18) Input: /piripi/	MAX	REDUCE	FT-FORM	PARSE -σ	ALL-FT-R	IDENT
a. ☞ (p• .ri:).(piː)					piː	*
b. (piː).(r• .piː)					r• .piː!	*
c. (piː).(riː).(piː)					piː, riː.piː!	
d. p• .(r• .piː)				*!		**
e. (p• .ri).(piː)			*!		piː	*
f. (pi.riː).(piː)		*!			piː	
g. (pr• .piː)	*!					*

‘Rightward directionality’ of foot parsing is due to ALL-FT-R, which excludes (18b-c) in favour of (18a). Note that violations of ALL-FT-R are counted by measuring the distance in numbers of syllables between every right foot edge and the right word edge. Of the three candidates (18a-c) that violate none of the undominated constraints, (18c) is the only one that has no reduced vowels, hence no violations of IDENT. However, it is excluded by ALL-FT-R, of which it has three violations, while the optimal candidate (18a) has only one. This establishes the ranking ALL-FT-R » IDENT.

To save space in tableau (19), I have marked violations of ALL-FT-R by asterisks:

(19) Input: /ʃiʔ-miri-kɨ-pe/	MAX	REDUCE	FT-FORM	PARSE-σ	ALL-FT-R	IDENT
a. ☞ (ʃiʔ).(m• .riː).(k• .peː)					**,****	**
b. (ʃiʔ).(m• .riː).(kɨ:).(peː)					*,***,***!*	*
c. (ʃiʔ).(miː).(riː).(kɨ:).(peː)					*,**,***,*!** *	
d. (ʃ• ʔ.miː).(r• .kɨ:).(peː)			WSP!		*,***	**
e. (ʃiʔ).(mi.riː).(kɨ.peː)		*!*			**,****	
f. (ʃiʔ).(mriː).(kpeː)	*!*				*,**	

The activity of WSP now becomes visible: the three-foot candidate (19e) is rejected by it even though this has fewer violations of ALL-FT-R than the optimal candidate (19a).

Let us now summarise the argument. A foot-based analysis of RVD in Optimality Theory requires that feet governing RVD can be inferred from the output on the basis of phonetic cues or phonotactic diagnostics. Arguments given earlier substantiate this: there are phonetic cues (open transitions) for syllabicity at deletion sites, while foot structure is diagnosed by the presence of both secondary stress and vowel length (phonotactically the lengthening pattern shows that no resyllabification takes place, since it is not inhibited by consonant clusters resulting from deletion). More generally, the prediction is that if RVD is foot-based, then it must be gradient. Conversely, if RVD is categorial, then it cannot be foot-based. The latter prediction will be shown correct for Southeastern Tepehuan in Section 3. Before that, I have to point out a refinement in the analysis of Macushi Carib.

2.3 Excursion: Phonotactic restrictions on deletion

Hawkins (1950:88-89) mentions certain phonotactic conditions under which RVD fails to apply. He reports that “a vowel in the basic form is retained if it precedes or follows any cluster of [...] two consonants in which the first consonant is a member of Group I.”

(20) a. /pakra-yamɨnʔ/ pakraymɨnʔ (*pᵊkraymɨnʔ) ‘bush hogs’
b. /ptakay-pe/ ptakaype (*ptᵊkaype) ‘traira-fish now ...’
c. /kratu-pe/ kratᵊpe (*krᵊtupe) ‘alligator now ...’

Group I is the class of obstruents /p, t, k, s, ʃ, r/. Since ternary onsets are disallowed, the obstruent-plus-consonant cluster in the quote from Hawkins defines the (phonotactically well-formed) complex onset in Macushi. We must be careful not to immediately attribute the blocking of vowel deletion in (20) to syllable phonotactics (e.g. ‘no ternary onsets’). We have seen in previous examples that vowel reduction/deletion is *not* phonotactically structure-preserving. (That is, consonant clusters may arise across a deletion site that are not elsewhere attested in morphemes.) Instead we attribute the ill-formedness of vowel deletion in (20) to an undominated constraint *CC:[9]

(21) ***CC**
A complex onset must not be adjacent to an empty nucleus.

This symmetrical constraint rules out pre-cluster reduction (20a), as well as post-cluster reduction (20b-c).

The problem for a rule-based analysis is that the metrical parsing is influenced by phonotactic patterns that arise only *after* vowel reduction. This is illustrated by the forms (22ab). The predicted metrical parsing, resulting from the rightward assignment of iambs, is shown in (22a). The metrical parsing that is required for the attested form, and which is motivated by the reduction of the second vowel, is shown in (22b):

(22) a. (kra̱.tu).(pe) *[krᵊtuːpeː]
b. (kra).(tu̱.pe) [kraːtᵊpeː]

The problem is not so much how to block (22a): this may be due to *CC, interpreted as an output filter on vowel reduction/deletion. Instead, the question is how to derive the foot parsing (22b) that makes correct predictions about reduction/deletion. An ordering paradox is evident: vowel reduction depends on metrical parsing, while metrical parsing in its turn must depend on reduction.[10] Hence foot parsing must have global look-ahead in order to apply properly. This raises a problem for a rule-based analysis, since globality is excluded by most proponents of rule theory.

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[9] A similar situation is disallowed in Dutch, possibly by the same constraint - shwa may not be the head of a syllable that has a complex onset, see Kager (1990), Van Oostendorp (1995). However, there is no evidence for a ban on post-shwa complex onsets in Dutch.

[10] Incidentally, note that these data present evidence for the assumption that reduced vowels are featurally empty due to a phonological constraint. If vowel reduction were completely phonetic, its influence of metrical parsing could not be explained.

The look-ahead of metrical parsing to whatever phonotactic effects it might have in the output is just the kind of situation that one would expect under OT. The 'shift' in position of feet follows from REDUCE, which selects the metrical parsing (kraː).(tu̲.péː) in (23a) over the parsing (kra.tuː).(pé:) in (23c), with a non-reduced initial syllable.

(23) Input: /kratu-pe/	*CC	MAX	REDUCE	FT-FORM	PARSE -σ	ALL-FT-R
a. ☞ (kraː).(t• .peː)						t• .peː
b. (kraː).(tuː).(peː)						peː, tuː.peː!
c. (kra.tuː).(peː)			*!			peː
d. (k• .tuː).(peː)		r!				peː
e. (kr• .tuː).(peː)	*!					peː

The tableau of /ptakay-pe/ minimally differs from the preceding tableau (23). Here WSP rejects the two-foot output (24b), which is due to the heaviness of the second syllable, which in its turn is due to the consonant cluster preceding the final vowel.

(24) Input: /ptakay-pe/	*CC	MAX	REDUCE	FT-FORM	PARSE -σ	ALL-FT-R
a. ☞ (ptaː).(kay).(peː)						peː, kay.peː
b. (ptaː).(k• y.peː)				WSP!		k• y.peː
c. (pta.kay).(peː)			*!			peː
d. (p• .kay).(peː)		t!				peː
e. (pt• .kay).(peː)	*!					peː

This concludes the analysis of Macushi Carib. I now turn to Southeastern Tepehuan.

3. Southeastern Tepehuan

3.1 Patterns of vowel deletion

Southeastern Tepehuan (Willett 1982, Willett 1991) is an Uto-Aztecan language spoken southeast of Durango in Mexico. It has a number of vowel alternations, among which apocope, rhythmic syncope, and shortening. These three alternations occur in a domain identified as the *stem* by Willett (1982). The stem includes the root, plus a reduplicant prefix, plus a number of stem-formation suffixes.

Before we can look into the vowel alternations, we must discuss the place of the accent in the stem. Accent falls on the initial stem syllable when it is heavy (i.e. either long-voweled, diphthongal, or closed), see (25a-c). It falls on the second stem syllable if this is heavy while the first syllable is light, see (25d-f). Note that no stem begins with a sequence of two light syllables - this output gap is due to rhythmic syncope. The accent pattern can be captured by a single iambic foot (H) or (LH) at the left edge:

(25)	a.	(vóo).hi	'bear'	d.	(ta.káa).ruiʔ	'chicken'
	b.	(vát).vi.rak	'went to bathe'	e.	(sa.pók)	'story'
	c.	(táat).pɨʃ	'fleas'	f.	(ta.pɨ́ɨʃ)	'flea'

This non-iterative, iambic foot deviates from the iterative, trochaic parsing required in a rule-based analysis. Both aspects of my analysis will be motivated below.

The first vowel alternation, shown in (26), is due to a *shortening* of long vowels in unstressed syllables. (The reduplicant is marked off the root by '-'):

(26)	a.i	/kooʔ/	(kóoʔ)		'snake'
	a.ii	/koo-k**oo**ʔ/	(kóo).k**o**ʔ	*(kóo).(kòoʔ)	'snakes'
	b.i	/kaam/	(káam)		'cheek'
	b.ii	/kaa-k**aa**m/	(káa).k**a**m	*(káa).(kàam)	'cheeks'
	c.i	/topaa/	(to.páa)		'pestle'
	c.ii	/to-top**aa**/	(tót).p**a**	*(tót).(pàa)	'pestles'
	d.i	/tapɨɨʃ/	(ta.pɨ́ɨʃ)		'flea'
	d.ii	/ta-tap**ɨɨ**ʃ/	(tát).p**ɨ**ʃ	*(tát).(pɨ̀ɨʃ)	'fleas'

The fact that all long vowels shorten except the one that is accented provides additional evidence for the absence of secondary stress - i.e. for non-iterative footing.

The second vowel alternation is due to *apocope*, which, like syncope, minimises the number of unfooted syllables in the stem. Short vowels are deleted word-finally, except when a sequence of consonants (as in 27d), or when /h/ (as in 27e) precedes. All prefixes are outside the stem, as I have indicated by '#', while suffixes are integrated.[11]

(27)	a.i	/hiɲ# nov**i**/	hiɲ# (ɲóv)			'my hand'
	a.ii	/hiɲ# noo-nov**i**/	hiɲ# (ɲóo).nov			'my hands'
	a.iii	/novi-ʔn/	(no.víʔɲ)			'his hand'
	b.i	/tu# huan**a**/	tu# (huán)			'he is working'
	b.ii	/tu# huana-t/	tu# (huá).nat			'he was working'
	c.	/nakasɨɽ**i**/	(nák).sɨɽ			'scorpion'
	d.	/hupna/	(húp).na	*(húpn)	*CC$]_\sigma$	'pull out'
	e.	/voohi/	(voo).hi	*(vóoh)	*h$]_\sigma$	'bear'

The condition that a vowel-consonant sequence must precede for deletion to take place reflects inviolable phonotactics: no process may produce branching codas, or /h/ codas.

Interestingly, neither apocope nor shortening affects final long vowels, e.g.:

(28)	a.i	/gaa/	(gáa)			
	a.ii.	/ga-gaa/	(ga.gáa)	*(ga.gá)	*(gáʔŋ)[12]	'cornfield'
	b.	/ʔaɽii/	(ʔa.ɽíi)	*(ʔa.ɽí)	*(ʔáɽ)	'child'

Here the long vowel can be parsed by the strong syllable of an iamb - I hypothesise that the output goal of apocope/syncope is a reduction of syllables *outside the accent foot.*

The third vowel alternation is due to *syncope*: vowels in even-numbered open syllables are dropped. Examples (29g-j) illustrate that syncope may delete long vowels

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[11] In (27a.i-ii) a 1sg. object prefix /hiɲ-/ occurs, in (27b) an extent prefix /tu-/; (27a.iii) contains a 3sg. possessive suffix, and (27b.ii) a past imperfective suffix.

[12] The de-obstruentization of voiced obstruents in coda position will be discussed below.

and diphthongs following an initial heavy syllable. All examples (except 29a) show that syncope freely applies across a reduplicant-stem boundary, so that the domain must be the stem. Notice that regular prefixes are outside this domain, see (29i-j).

(29)	a.	/tɨr**o**viɲ/	(tír).viɲ	‘rope’
	b.	/tɨɨ-t**ɨ**roviɲ/	(tɨ́ɨt).ro.piɲ	‘ropes’
	c.	/to-t**o**paa/	(tót).pa	‘pestles’
	d.	/taa-t**a**pɨɨʃ/	(táat).pɨʃ	‘fleas’
	e.	/taa-t**a**kaaruiʔ/	(táat).ka.ruiʔ	‘chickens’
	f.	/tu# maa-m**a**tuʃ**i**dʒaʔ/	tu# (máam).tuʃ.dʒaʔ	‘will teach’
	g.	/gaa-g**aa**gaʔ/	(gáaʔŋ).gaʔ	‘he will look around for it’
	h.	/sui-s**ui**maɽ/	(súis).maɽ	‘deer (pl.)’
	i.	/hiɲ# ɲuu-ɲ**uu**tʃiʃ/	hiɲ# (ɲúuɲ).tʃiʃ	‘my brothers-in-law’
	j.	/hiʃ# mai-m**ai**kak/	hiʃ# (máim).kak	‘sweet (pl.)’

The examples in (30) illustrate the lack of syncope after a *light* first syllable. In (30a-d) this is shown for the context #CvCvv and in (30e-f) for the context #CvCv(v)C.

(30)	a.	/tak**aa**ruiʔ/	(ta.káa).ruiʔ	‘chicken’
	b.	/vo-v**oo**hi/	(va.póo).hi	‘bears’
	c.	/va-v**ai**ɲum/	(va.pái).ɲum	‘metals’
	d.	/vi-viad**i**kaiʔ/	(vi.piáʔŋ).kaiʔ	‘lizards’
	e.	/ka-k**a**rvaʃ/	(ka.kár).vaʃ	‘goats’
	f.	/ha-h**aa**nnuɽ/	(ha.háan).nuɽ	‘clothes’

In contexts where both are possible, *apocope* is preferred over *syncope*:

(31)	a.	/hiɲ# noo-novi/	hiɲ#(ɲóo).nov	*hiɲ#(ɲóon).vi	‘my hands’
	b.	/ʃi# ʔomiɲi/	ʃi#(ʔo.míɲ)	*ʃi#(ʔóm).ɲi	‘break it!’
	c.	/naa-nakasɨɽi/	(náan).ka.sɨɽ	*(náan).kas.ɽi	‘scorpions’

So far we have been looking into the context of syncope - let us now look into its *effect*: does it result in full (or partial) vowel deletion? Four independent phonotactic diagnostics indicate that syncope amounts to the complete deletion of the nucleus, i.e. of *syllabicity*.

First, syncope strictly respects the canonical syllable (Cv, Cvv, CvC, CvvC), which has an obligatory non-branching onset and an optional non-branching coda, with either a long or short vowel as its nucleus. Syncope is blocked wherever it would create a complex coda or a complex onset.

(32)	/ka-karvaʃ/	(ka.kár).vaʃ	*(kákr).vaʃ	*(kák).rvaʃ	‘goats’

Second, the language has a *mutation* process (restricted to reduplicated forms) by which intervocalic /v/ changes into [p]. This consonant mutation is conditioned by the output syllabification (i.e. it applies ‘after’ syncope), as shown by the forms (33c-d):

(33) a. /va-**v**aavasi/ (va.**p**áa).vaʃ ‘pheasants’
b. /tɨɨ-tɨ̲ro**v**iɲ/ (tɨ́ɨt).ro.**p**iɲ ‘ropes’
c. /to-to̲**v**aa/ (tót).**v**a *(tót).**p**a ‘turkeys’
d. /noo-no̲**v**iɲ/ (nóon).**v**iɲ *(nóon).**p**iɲ ‘his hands’

Third, a process of *coda de-obstruentization* changes voiced obstruents in codas into pre-glottalised nasals - while agreeing in place of articulation with the following consonant. Again, it is output syllabification that matters here.

(34) a. /gaa-**g**a̲a̲gaʔ/ (gáa**ʔŋ**).gaʔ ‘he will look around for it’
b. /gio-**g**i̲o̲tɨr/ (gió**ʔn**).tɨr ‘plains’
c. /vi-via**d**i̲kaiʔ/ (vi.piá**ʔŋ**).kaiʔ ‘lizards’

Fourth, output syllabification is relevant to another coda weakening process of /h/-*assimilation,* by which /h/ assimilates completely to a following consonant.

(35) /hiɲ# hii-**h**i̲i̲kuɽ/ hiɲ#(híi**k**).kuɽ ‘my uncles’

Observe that syncope is not blocked by a constraint barring /h/ from syllable coda, as we saw earlier for apocope. The difference is that here /h/ can be ‘saved’ by complete assimilation to the following consonant.

In sum, no syllable-sensitive phonology of Southeastern Tepehuan refers to the ‘initial’ syllabification.[13] Instead all such phonology refers to the ‘re-syllabified’ output of apocope and syncope, in a phonologically transparent way. Below I will return this important observation.

3.2 A rule-based analysis

The rule-based analysis expresses syncope as the deletion of vowels in weak syllables of iterative feet. The core of such an analysis has been given by Rice (1992) in the form of the five ordered rules in (36a-d, 36f). To complete the analysis I have added four rules Apocope (36e), De-obstruentisation (36g), Conflation (36h), and Shortening (36i).

(36) a. *Syllabify*. Assign syllable structure.
b. *Metrify*: Build left-headed quantity-sensitive feet from left to right.
c. *Destressing*: Remove the rightmost of two adjacent heads, unless the rightmost head dominates a syllable which is heavier than the leftmost. In that case, delete the left one.
d. *End Rule Left*: Promote the leftmost foot to main stress.
e. *Apocope*: Delete final short vowels (and resyllabify).
f. *Syncope*: Delete vowels in non-head syllables (and resyllabify).
g. *De-obstruentisation*: Nasalise voiced obstruents in coda position.
h. *Stress Conflation*: Remove feet that do not support the main stress.
i. *Shortening*: Shorten vowels in metrically weak syllables.

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[13] There is a rule of palatalisation that ‘precedes’ vowel deletions, but this does not refer to syllable structure, just to adjacency of root nodes.

This analysis is illustrated in (37) by derivations of stems beginning with #HL or #LL:

(37)	UR	a. /maa-matuʃidʒaʔ/	b. /naa-nakasɨɽi/	c. /to-topaa/
	Syllabify	maa.ma.tu.ʃi.d͜ʒaʔ	naa.na.ka.sɨ.ɽi	to.to.paa
	Metrify	(maa.ma).(tu.ʃi).(d͜ʒaʔ)	(naa.na).(ka.sɨ).(ɽi)	(to.to).(paa)
	Destress	---	---	---
	End Rule L	(máa.m**a**).(tu.ʃ**i**).(d͜ʒaʔ)	(náa.n**a**).(ka.sɨ).(ɽi)	(tó.t**o**).(paa)
	Apocope	---	(náa.n**a**).(ka.sɨɽ)	---
	Syncope	(máam).(tuʃ).(d͜ʒaʔ)	(náan).(ka.sɨɽ)	(tót).(paa)
	Deobstruent	---	---	---
	Conflation	(máam).tuʃ.d͜ʒaʔ	(náan).ka.sɨɽ	(tót).paa
	Shortening	---	---	(tót).pa
	PR	[(máam).tuʃ.d͜ʒaʔ]	[(náan).ka.sɨɽ]	[(tót).pa]

Although the analysis derives these forms correctly, it runs into conceptual problems.

First, the complete lack of surface secondary stress must be accounted for by a rule of ‘stress conflation’ (Halle & Vergnaud 1987), eliminating feet that do not support the main stress. This obscures the iterative metrical pattern on which syncope is based, rendering it opaque. From the viewpoint of the language learner, the abstractness of this analysis, as well as the extrinsic rule ordering on which it is based, are problematic.

Second, out of the four trochees that the analysis sets up to define the context of syncope - (LL), (HL), (H) and (L) - three never surface (only (H) does). Two of these abstract trochees, degenerate (L) and unbalanced (HL), are cross-linguistically marginal at best (Hayes 1995). This contributes to the abstractness of the analysis. Even worse, the surface stress contours at the stem’s left edge, #**H** and #L**H**, are easily interpreted as *iambic*, given the fact that foot constituency is inaudible. The trochaic analysis assigns a ‘mis-aligned’ parsing #L(H) to the latter sequence, thereby adding to its abstractness (a mismatch between foot type and surface stress patterns).

Third, iterative unbalanced trochees by themselves do not suffice to predict the syncope and accent pattern. One problematic case are inputs beginning with a sequence #HH - recall that syncope may delete a long vowel or diphthong in the second syllable if the initial syllable is heavy (29g-j). Here the monosyllabic foot on the second syllable must be deleted prior to syncope, see (38c). But now compare such cases to inputs that begin with a sequence #LH. These surface with accent on their second syllable, which must - somehow - be protected against destressing and subsequent syncope, see (38a-b). Rice (1992) proposes a quantity-sensitive destressing rule (36c): if both syllables are of equal weight (#HH, cf. 38c), it deletes the righthand foot, but if the lefthand syllable is lighter (#LH, cf. 38a-b), the lefthand foot is deleted:

(38)	UR	a. /ka-karvaʃ/	b. /vi-viadikaiʔ/	c. /gaa-gaagaʔ/
	Metrify	(ka).(kar).(vaʃ)	(vi).(via.di).(kaiʔ)	(gaa).(gaa).(gaʔ)
	Destressing	ka.(kar).(vaʃ)	vi.(via.di).(kaiʔ)	(gaa).gaa.(gaʔ)
	End Rule L	ka.(kár).(vaʃ)	vi.(viá.di).(kaiʔ)	(gáa).gaa.(gaʔ)
	Syncope	---	vi.(viád).(kaiʔ)	(gáag).(gaʔ)
	Deobstruent	---	vi.(via**ʔŋ**).(kaiʔ)	(gaa**ʔŋ**).(gaʔ)
	Conflation	ka.(kár).vaʃ	vi.(viáʔŋ).kaiʔ	(gáaʔŋ).gaʔ
	PR	[ka.(kár).vaʃ]	[vi.(viáʔŋ).kaiʔ]	[(gáaʔŋ).gaʔ]

The quantity-sensitive destressing rule that compares the relative weight of the first two syllables is a powerful device. Even worse, it misses the generalisation that destressing and syncope conspire toward outputs that begin with iambs: (H) or (LH). Finally, notice that initial light syllables in words beginning with #LH fail to undergo syncope, even though destressing places them in a metrically weak position. Rice does not address this problem, but clearly this situation reflects an *output constraint* on syncope: it must not create syllables with branching onsets or codas. Output constraints on serial rules defeat the strictest version of rule-based theory.

In sum, the rule-based analysis identifies iterative feet as the context of syncope. This metrical structure arises only momentarily as an intermediary step in the derivation but it is lost in the output - due to syncope, resyllabification and conflation. *Opacity* of syncope is the result - a situation that is highly compatible with the serial point of view, but a potential embarrassment to OT. Yet, rule-based analysis, in order to be able to set up syncope as the result of an opaque metrical structure, was forced to accept various types of flaws: an odd foot typology, output constraints on syncope, quantity-sensitive destressing, etc. Moreover, a rule-based analysis fails to express various *conspiracies* in the phonology of Southeastern Tepehuan: the accented syllable is heavy, no rule leads to an output violating the canonical syllable, etc. Let us now consider an OT analysis of these data.

3.3 An OT analysis

The rule-based analysis given above cannot be translated into an OT analysis, since the metrical context (iterative feet) does not occur in the output in the form of a secondary stress pattern. In the rule-based analysis, this metrical context is destroyed by syncope plus resyllabification, while conflation wipes out any traces of secondary stress feet.

3.3.1 Basic ideas

The intuition behind an OT analysis is that syncope and apocope serve ‘exhaustivity’ of metrical parsing. They serve this goal by minimising the number of syllables that are not parsed by the initial foot - a (H) or (LH) iamb. This effect is shown schematically in the Cv-skeletal forms in (39). The outputs in the middle column are ‘better’ than those in the rightmost column because they contain a smaller number of unparsed syllables. In the rightmost column, non-application of apocope (39a), syncope (39b), or of neither (39c), would result in outputs that contain a larger number of unparsed syllables:[14]

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[14] These skeletal structures correspond to actual examples that have been presented above, as follows: (39a.i) to (28b) /ʃi# ʔomiɲi/; (39a.ii) to (24c.i) /tu# huana/; (39b.i) to (27b) /hiɲ# noo-

(39)	*Inputs*	*Optimal outputs*	*Less-than-optimal outputs*
a.i	/CvCvC**v**/	(Cv.CvC)	*(Cv.Cv).Cv
a.ii	/CvvC**v**/	(CvvC)	*(Cvv).Cv
b.i	/CvvC**v**CvC/	(CvvC).CvC	*(Cvv).Cv.CvC
b.ii	/CvvC**v**CvC**v**CvC/	(CvvC).CvC.CvC	*(Cvv).Cv.Cv.Cv.CvC
c.i	/CvC**v**CvC**v**/	(CvC).CvC	*(Cv.Cv).Cv.Cv
c.ii	/CvvC**v**CvCvC**v**/	(CvvC).Cv.CvC	*(Cvv).Cv.Cv.Cv.Cv

The optimal forms in (39) cannot be compressed any further by deletion of additional vowels *without violating rigid syllable phonotactics*: syllables must have non-branching margins. Forms in the rightmost column in (40), even though they are preferrable over those in the middle column for exhaustivity, are ruled out by syllable shape constraints:

(40)	*Inputs*	*Optimal outputs*	*Less-than-optimal outputs*
a.i	/CvvC**v**CvC/	(CvvC).CvC	*(CvvCCC)
a.ii	/CvC**v**CvC**v**/	(CvC).CvC	*(Cv.CvCC)

We already begin to see the outlines of an explanation for the alternating character of vowel deletion. Syncope of vowels in adjacent syllables necessarily leads to consonant clusters that cannot be parsed by canonical syllables. And we also see a connection now between syncope and apocope: both improve metrical parsing. The explanation for why apocope applies ‘more generally’ than syncope is that final vowels happen to be ‘easier’ targets for deletion: no consonants follow that might phonotactically interfere. (There is some independent pressure for apocope in the phonology as well, as we will see later.)

If the ‘target’ of vowel deletion is exhaustive parsing of syllables into feet, then we predict that no deletion will take place when nothing can be gained by it - that is, when deletion would yield no progress in terms of syllable parsing. This is exactly what we find. In (41) apocope/syncope fails to reduce the number of syllables outside the foot. Everything else being equal, it is always better to be ‘faithful’ to input segments:[15]

(41)	*Inputs*	*Optimal outputs*	*Less-than-optimal outputs*
a.	/CvCvv/	(Cv.Cvv)	*(CvC)
b.	/CvCvvCvC/	(Cv.Cvv).CvC	*(CvC).CvC

A second output target of syncope is related to quantity-sensitivity: *the stressed syllable must be heavy* (i.e. CvC, Cvv, or CvvC) in the output (compare Macushi Carib, discussed earlier). This means that syncope affects all inputs beginning with #CvCv, to prevent a (LL) foot.

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novi/; (39b.ii) to (29f) /tu# maa-matuʃidʒaʔ/; (39c.i) to (27a) /nakasɨɽi/; and (39c.ii) to (31c) /naa-nakasɨɽi/.

[15] Actual examples corresponding to (41a-b) are (28b) /ʔaɽii/ and (30c) /va-vaiɲum/. I have not found any examples whose input shape is /CvCvvCv/. These are predicted to undergo apocope into (Cv.CvvC).

(42)

	Inputs	Optimal outputs	Less-than-optimal outputs
a.	/CvC**v**CvC**v**/	(CvC).CvC	*(Cv.Cv).CvC, *(CCv.CvC)
b.	/CvC**v**CvC/	(CvC).CvC	*(Cv.Cv).CvC, *(CCv.CvC)

It is correctly predicted that the second vowel in such sequences is deleted. Phonotactics ('no branching onsets') rule out the deletion of the first vowel, which would produce an ill-formed output *(CCv.CvC). Unlike the rule-based analysis, no abstract intermediate trochee (LL) is needed to obtain this result.

Could a rule-based analysis be based on the same idea, setting up a single foot at the left edge, then apocopate, and finally syncopate?[16] Perhaps, but it is immediately clear that it would be very difficult to deal with 'rhythmic deletion' in examples such as (39b.ii). Without iterative foot structure, what sets syllables to be syncopated apart from those that are immune? A solution would be to write the 'double-sided CV context' into the syncope rule V→ Ø / CV ___ CV, and to apply this rule from left to right through the domain, resyllabifying its output after each application. Even then, a major problem arises with respect to quantity: since both short and long vowels are deletable, why syncopate CvvCvvCvC, but not CvCvvCvC? Although perhaps such an analysis may be feasible, it would be uninsightful to an extreme degree.

3.3.2 The constraints and their ranking

The idea of an OT analysis is that exhaustivity of metrical parsing, and heaviness of the accented syllable, are both given priority over realising underlying vowels in the output. However, the forces that lead to vowel deletion are counterbalanced by phonotactics: syllables must not have branching onsets.[17]

To implement all this, we start by fixing the metrical constraints that account for the shape and position of the accent foot. Southeastern Tepehuan, like Macushi Carib, has an iambic foot inventory (H) and (LH). Accordingly, we adopt Ft-Form as a cover constraint:

(43) **Ft-Form** (cover constraint)

a.	FtBin	Feet are binary under moraic or syllabic analysis.
b.	WSP	Heavy syllables are prominent within the foot.
c.	RhType=Iamb	Feet are right-headed.
d.	Stress-to-Weight	Strong syllables are heavy.

Southeastern Tepehuan truly differs from Macushi Carib in having maximally one foot per word, rather than iterative feet. This difference is due to a re-ranking, as compared to Macushi Carib, of foot alignment and Parse-σ (McCarthy & Prince 1993). Since All-Ft-L takes precedence over Parse-σ, every foot is adjacent to the left PrWd edge:

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[16] The idea of such a rule-based analysis was suggested to me by Doug Pulleyblank.

[17] As we will see in Section 3.3.4 on reduplicated forms, we must also recognise morphological forces opposing deletion.

(44) **All-Ft-L**
Align (Ft, L, PrWd, L)

(45) All-Ft-L, Ft-Form » Parse-σ

The interaction All-Ft-L and Parse-σ, which produces non-iterative footing, is illustrated in tableaux (46-47):[18]

(46) /ka-karvaʃ/	All-Ft-L	Ft-Form	Parse-σ
a. ☞ (ka.kár).vaʃ			*
b. (ka.kár).(vàʃ)	ka.kar!		

(47) /vatvirak/	All-Ft-L	Ft-Form	Parse-σ
a. ☞ (vát).vi.rak			**
b. (vát).(vi.ràk)	vat!		

Next, the set of syllable shapes that are well-formed in Southeastern Tepehuan is {Cv, Cvv, CvC, CvvC}, i.e. an obligatory non-branching onset (48a-b), and an optional non-branching coda (48b). Moreover, the fact that CvC syllables cannot occur in weak positions of iambs (LH) shows that such syllables must be heavy (48c).

(48) **σ-Form** (cover constraint)

a.	Onset	Syllables must have onsets.
b.	*Complex	Syllables must not have complex margins.
c.	Weight-by-Position	Codas must be moraic.

Next consider that all three vowel alternations involve deletion or shortening. More generally Southeastern Tepehuan allows neither epenthesis nor lengthening, of any segment type. For example Stress-to-Weight cannot be satisfied by lengthening the second vowel in stems beginning with #CvCv. That is, we never find inputs such as /tɨroviɲ/ realised as *(tɨróː).viɲ, rather than (tɨ́r).viɲ. The avoidance of vowel epenthesis and lengthening motivates undominated Dep (McCarthy & Prince 1995):

(49) **Dep**
Every segment in the output has a correspondent in the input.

Dep is another ‘faithfulness constraint’ - one that sees to it that the input and output are maximally identical. It penalises any output segment that cannot be traced back to a segment of lexical representation - ruling out epenthesis. It is the logical counterpart of Max, which requires that input segments have correspondents in the output.

Unlike vowels, consonants remain generally unaffected - they may participate in alternations of place, but they are never deleted nor inserted under pressure of metrical

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[18] The violation of WSP due to the CvC syllable outside the accent foot in candidates (46a) and (47a) will be discussed below. The preservation of input vowel quality in unstressed vowels is due to the ranking Ident » Reduce, which I have not indicated here.

constraints. For example, the stem /karvaʃ/ might surface as a single (LH) iamb without any violation of PARSE-σ, if only one of its medial consonants were deleted: *(ka.váʃ), or *(ka.ráʃ). This apparently never occurs - all outputs must preserve the consonants of their inputs. Therefore MAX-C must be undominated as well:[19]

(50) **MAX-C**
Every consonant in the input has a correspondent in the output.

DEP and MAX-C limit the options of Southeastern Tepehuan to accomodate its word shapes to metrical constraints to the *deletion of vowels* (e.g. syncope, apocope), or parts of vowels (e.g. shortening). This means that vowel-zero alternations must be due to a constraint interaction in which MAX-V is crucially dominated by metrical constraints.

(51) **MAX-V**
Every vocalic element in the input has a correspondent in the output.

What constraints must dominate MAX-V such that apocope and syncope arise? Clearly PARSE-σ is among these constraints, since it forces vowel deletion. By transitivity, all constraints dominating PARSE-σ must dominate MAX-V as well:

(52) FT-FORM, ALL-FT-L, σ-FORM, DEP, MAX-C » PARSE-σ » MAX-V

The ‘rhythmicity’ of the syncope pattern follows from this ranking - there is no need to set up an intermediate representation of iterative trochees, as in the rule-based analysis.

A major ‘rhythmic’ property of syncope follows directly from (52): the fact that adjacent syllables do not both syncopate. If they would, the outcome would collide with syllable shape constraints, since this would stack up consonants that cannot be parsed as onsets or codas due to *COMPLEX. There is no remedy in simplifying such clusters by deletion of consonants: this escape route is effectively shut off by MAX-C. Another fact of syncope (that the rule-based analysis attributed to trochaic feet) now follows as well: vowels in initial syllables are immune from syncope, since vowel deletion in #C**v**Cv would produce an output #CCv, again in violation of *COMPLEX. Furthermore syncope may never affect a closed syllable, since that always results in violations of *COMPLEX. Again, this is attributed to abstract intermediate deletion feet in the rule-based analysis. Finally, it is correctly predicted that syncope/apocope are blocked in vowels preceded by more than one consonant - the maximum that can be accomodated as a coda in the preceding syllable. Actually, the rule-based analysis does not make this prediction at all.

3.3.3 Non-reduplicated stems

I will first illustrate, and develop, the analysis for non-reduplicated stems. Reduplicated stems will be treated in Section 3.3.4, since they involve interaction with morphology-based constraints. Due to relative shortness of unreduplicated stems, it turns out that the activity of the constraint PARSE-σ cannot be motivated on the basis of such stems, since

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[19] I assume that consonants are distinguished from vowels segmentally, by [±consonantal].

other constraints obscure its effects. However, PARSE-σ (and its ranking above MAX-V) will be motivated later on the basis of reduplicated stems.[20]

Tableau (53) shows the effect of undominated constraints: ALL-FT-L, FT-FORM, σ-FORM, DEP AND MAX-C. The optimal output (53a) cannot be improved with respect to PARSE-σ without violating any of these.

(53) /tɨroviɲ/	ALL-FT-L	FT-FORM	σ-FORM	DEP	MAX-C	PARSE-σ	MAX-V
a. ☞ (tír).viɲ						*	o
b. (tɨ.víɲ)					r!		o
c. (tɨ.róo).viɲ				o!		*	
d. (tro.víɲ)			*!				ɨ
e. (tírvɲ)			*!				o, i
f. (tɨ.ró).viɲ		*!				*	
g. (tɨr.víɲ)		*!					o
h. (tír).(vìɲ)	tɨr!						o

Next, tableau (54) shows the role of the faithfulness constraint MAX-V, which blocks vowel deletion by rejecting candidate (54b). Both the optimal candidate and its competitor (54b) have one unparsed syllable, and both contain a well-formed foot. That is, vowel deletion does not apply when nothing is gained by it in terms of foot shape or metrical parsing.

(54) /takaaruiʔ/	ALL-FT-L	FT-FORM	σ-FORM	DEP	MAX-C	PARSE-σ	MAX-V
a. ☞ (ta.káa).ruiʔ						*	
b. (ták).ruiʔ						*	aa!
c. (ta.káarʔ)			*!				ui
d. (tak.rúiʔ)		*!					aa
e. (ta.káa).(rùiʔ)	ta.kaa!						

When we consider a vowel-final input such as /nakasɨɾi/, we find that PARSE-σ and MAX-V make the incorrect prediction that its output should be *(na.kás).ɾi, rather than the actual attested form (nák).sɨɾ. Both outputs have identical numbers of unparsed syllables, but the former is slightly more faithful to its input vocalism (since it preserves all but one vowel, rather than all but two). The ill-formedness of the output *(na.kás).ɾi must therefore be due to another factor: it ends in a vowel, and hence violates a cross-linguistically common requirement that the stem must end in a consonant. This is stated as STEM CLOSURE (Prince 1990:381):

(55) **STEM CLOSURE**
All stems end in C.

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[20] As a service to the interested reader, I refer ahead to the tableaux of [(ɲúuɲ).tʃiʃ] in (67), [(táat).pɨʃ] in (79), [(tɨ́ɨt).ro.piɲ] in (80), and [(máam).tuʃ.dʒaʔ] in (81).

Stem Closure is the functional analogue of apocope in a rule-based analysis. Tableau (56) shows that it ranks above Max-V, since the output candidate (56a) that is selected by Stem Closure is less faithful to its input vocalism than its competitor (56b). Notice that the indicated ranking Parse-σ » Stem Closure cannot be motivated by this tableau. (However, we will find indirect evidence for this ranking directly below.)

(56) /nakasɨɽi/	All-Ft-L	Ft-Form	σ-Form	Dep, Max-C	Parse -σ	Stem Closure	Max-V
a. ☞ (nák).sɨɽ					*		a, i
b. (na.kás).ɽi					*	*!	ɨ
c. (nák).sɨ.ɽi					**!	*	a
d. (nak.sɨ́ɽ)		*!					a, i
e. (na.ká).sɨ.ɽi		*!			**	*	
f. (nák).(sɨ̀ɽ)	*!						a, i

Tableau (57) again shows that apocope is favoured over syncope, for a vowel-final stem that is slightly shorter.

(57) /ʃi# ʔomiɲi/	All-Ft-L	Ft-Form	σ-Form	Dep, Max-C	Parse -σ	Stem Closure	Max-V
a. ☞ ʃi#(ʔo.míɲ)							i
b. ʃi#(ʔóm).ɲi					*!	*	i
c. ʃi#(ʔo.míi).ɲi				i!		*	
d. ʃi#(ʔo.mí).ɲi		*!				*	

Next we must reconsider disyllabic stems ending in a long vowel, whose input shape is CvCvv, e.g. /topaa/ 'pestle'. Due to the ranking Stem Closure » Max-V the analysis (incorrectly) predicts that such stems lose their final vowel. Only consider two output forms [(to.páa)] and *[(tóp)] to see this. These candidates are evaluated equally by all higher-ranking constraints, as both have a well-formed, left-aligned foot, and no unparsed syllables. Therefore Stem Closure selects *[(tóp)], the candidate that ends in a consonant, over the more faithful candidate [(to.páa)].

The blocking of apocope in such words must be due to an independent factor, which I identify as a 'minimality' effect. Specifically, apocope fails since the resulting output [(tóp)] would violate the constraint that a Prosodic Word is minimally disyllabic. This constraint is stated as Disyll below, minimally adapting a constraint of the same name in McCarthy & Prince (1993):

(58) **Disyll**
The PrWd is minimally disyllabic.

Note that we cannot identify the disyllabicity requirement as a foot, since the minimal foot equals a single heavy syllable. There is cross-linguistic support for a disyllabicity constraint from quantity-sensitive languages which have bimoraic feet (e.g., Japanese, Itô 1990; Axininca Campa, McCarthy & Prince 1993; Guugu Yimidhirr, Kager 1995a).

In Southeastern Tepehuan Disyll must be ranked above Stem Closure, as the following tableau shows:

(59) /topaa/	All-Ft-L	Ft-Form	Dep, Max-C	Parse-σ	Disyll	Stem Closure	Max-V
a. ☞ (to.páa)						*	
b. (tóp)					*!		aa

Note that Disyll is ranked below Parse-σ, since /CvvCv/ input stems surface without their final vowel, e.g. /tu# huana̲/ [tu# (huán)] (27b.i). This interaction is shown in (60):

(60) /huana/	All-Ft-L	Ft-Form	Dep, Max-C	Parse-σ	Disyll	Stem Closure	Max-V
a. ☞ (huán)					*		a
b. (huá).na				*!		*	
c. (huá.na)		*!				*	

Since Disyll dominates Stem Closure, but is in its turn dominated by Parse-σ, we find a ranking Parse-σ » Disyll » Stem Closure. By transitivity, we now find evidence to rank Parse-σ with respect to Stem Closure, a ranking that was so far unestablished.

We have seen that apocope is blocked by the disyllabic minimality requirement. We may then ask whether disyllabicity is enforced by epenthesis as well, for example in monosyllabic stems. The answer is negative. Southeastern Tepehuan has monosyllabic stems, but none undergoes vowel epenthesis. This motivates the ranking Dep » Disyll. Tableau (61) illustrates this ranking for the monosyllabic stem /ban/ 'coyote', where the epenthetic vowel appears in capital:

(61) /ban/	All-Ft-L	Ft-Form	Dep, Max-C	Parse-σ	Disyll	Stem Closure	Max-V
a. ☞ (bán)					*		
b. (ba.nÁA)			AA!			*	

Since Disyll is dominated by Parse-σ, which is itself dominated by Ft-Form and Dep, we predict that Ft-Form and Dep both dominate Disyll. This prediction is correct. Stems of the shape /CvCv/ undergo apocope, falling below the disyllabic minimum, for example /novi̲/ [(nóv)] 'my hand' (cf. 27a.i). In tableau (62) a faithful candidate (62b), which preserves the final input vowel, is ruled out by Ft-Form. This 'bad' double-light iamb cannot be improved upon by final lengthening as in (62c), due to Dep:

(62) /novi/	ALL-FT-L	FT-FORM	DEP, MAX-C	PARSE-σ	DISYLL	STEM CLOSURE	MAX-V
a. ☞ (nóv)					*		i
b. (no.ví)		*!				*	
c. (no.víɪ)			ɪ!			*	

This concludes the basic analysis of apocope and syncope. An analysis of the third vowel alternation, shortening, will be given in Section 3.3.5.

3.3.4 Reduplicated stems

Let us now turn to reduplicated stems. Southeastern Tepehuan uses reduplication for a number of morphological categories, of which plurality in nouns is the most important. Two types of reduplicant prefix occur: Cv- (short) and Cvv- (long). The choice between both cannot be predicted from the stem's quantitative (or segmental) make-up, although certain interesting tendencies can be observed.[21] The idiosyncratic nature of the type of reduplicant (short vs. long) is shown in the pairs (63a-c) below, for stems that have the skeletal structure CvC, CvvC, and CvvCvC:

(63)				
	a.i	/Cv - huk/	(hu.húk)	'pines'
	a.ii	/Cvv - ban/	(báa).ban	'coyotes'
	b.i	/Cv - gaat/	(ga.gáat)	'bows'
	b.ii	/Cvv - kaam/	(káa).kam	'cheeks'
	c.i	/Cv - haaraʃ/	(ha.háa).raʃ	'crabs'
	c.ii	/Cvv - ɲuutʃiʃ/	(ɲuuɲ).t͡ʃiʃ	'brothers-in-law'

I assume that stems select length of the reduplicant by lexical specification. Moreover, this length requirement must be respected in the output. To see what is at stake we must look into vowel shortening.

The current constraint ranking falsely predicts that a long reduplicant shortens to Cv in order to form a maximal foot (Cv.CvX) together with the stem-initial syllable. In (64a), this false prediction is due to PARSE-σ, while in (64b), it is due to MAX-V:

(64)		*Input*	*Predicted output*	*Actual output*
	a.i	/RED - ban/	*(ba.bán)	(báa).ban
	a.ii	/RED - novi/	*(no.nóv)	(nóo).nov
	a.iii	/RED - tɨroviɲ/	*(tɨ.tɨ́r).viɲ	(tɨ́ɨt).ro.piɲ
	a.iv	/RED - nakasiɽɨ/	*(na.nák).siɽ	(náan).ka.siɽ
	b.i	/RED - ɲuutʃiʃ/	*(ɲu. ɲúu).tʃiʃ	(ɲúuɲ).tʃiʃ
	b.ii	/RED - matuʃidʒaʔ/	*(ma.mát).ʃi.d͡ʒaʔ	(máam).tuʃ.d͡ʒaʔ

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[21] For example, polysyllabic stems that begin with a closed syllable always select a short reduplicant, so that the reduplicated stem starts with a (LH) foot. Although this suggests control by the constraint system, I have not been able to fully predict it by ranked constraints.

Non-shortening of long reduplicants cannot be attributed to Max-V, since this is ranked below Parse-σ. Moreover, Max-V fails to explain the actual output form [(ɲúuɲ).tʃiʃ] in (64b.i), since this is less faithful to input vocalism than its competitor [(ɲu. ɲúu).tʃiʃ].

Rather, the generalisation is that the (stem-specific) requirement on the length of the reduplicant vowel must always be respected in the output. To capture this, I assume that the reduplicant's nucleus can be required to be bimoraic (Shaw 1992). Southeastern Tepehuan places this constraint under control of specific stems:

(65) **Red=Nuc$_{\mu\mu}$**
The reduplicant must be a syllable with a bimoraic nucleus (for specific stems).

Red=Nuc$_{\mu\mu}$ must rank above Parse-σ, as tableau (66) shows:

(66) /Red - ban/	All-Ft-L	Ft-Form	Red=Nuc$_{\mu\mu}$	Parse-σ	Disyll	Stem Closure	Max-V
a. ☞ (báa).ban				*			
b. (ba.bán)			*!				
c. (bán).ban			*!	*			
d. (báa).(bàn)	*!						

Tableau (67) shows that, as predicted by transitivity, Red=Nuc$_{\mu\mu}$ ranks above Max-V. This is the first of a series of tableaux presenting firm evidence for Parse-σ. The optimal output (67a) is less faithful to its input vocalism than candidate (67b), but is selected on the grounds of its smaller number of unparsed syllables.

(67) /Red - ɲuutʃiʃ/	All-Ft-L	Ft-Form	Red=Nuc$_{\mu\mu}$	Parse-σ	Disyll	Stem Closure	Max-V
a. ☞ (ɲúuɲ).tʃiʃ				*			uu
b. (ɲúu).ɲu.tʃiʃ				**!			u
c. (ɲu.núu).tʃiʃ			*!	*			
d. (ɲúu).(ɲu.tʃìʃ)	*!						u

Note that syncope may obscure the identity of the reduplicant and the *base*. An example is the vowel [uu] in the reduplicant of (ɲúu-ɲ).t͜ʃiʃ, which has no correspondent in the output, but depends on the vowel [uu] in the input. In terms of constraint ranking, the prosodic constraints of foot shape and foot position, syllable-shape, and Parse-σ, must dominate constraints on reduplicant-base correspondence.[22]

(68) *Ft-shape, Ft-position, σ-shape* » Parse-σ » *R-B Identity*

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[22] This may appear as a case of a reduplicant that is more faithful to the input than the base is. McCarthy & Prince (1995) suggest that no languages rank reduplicant-base-faithfulness above reduplicant-input-faithfulness. Actually the Southeastern Tepehuan data do not unambiguously counterexemplify this, since all we know is that R-B identity must be dominated by prosodic constraints.

I will not pursue the issue of the correspondence relationship between reduplicant and input here.

3.3.5 Vowel shortening and WSP

Next let us turn to unstressed vowel *shortening*. This is exemplified for open syllables in (69a), and for closed syllables in (69b).

(69) a.i /taa-tak**aa**ruiʔ/ (táat).k**a**.ruiʔ *(táat).k**aa**.ruiʔ ‘chickens’
a.ii /to-top**aa**/ (tót).p**a***(tót).p**aa** ‘pestles’

b.i /kaa-k**aa**m/ (káa).k**a**m *(káa).k**aa**m ‘cheeks’
b.ii /taa-tap**ɨɨ**ʃ/ (táat).p**ɨ**ʃ *(táat).p**ɨɨ**ʃ ‘fleas’

Actually the tools for shortening in unstressed open syllables are already in our hands, in the form of the ranking WSP » MAX-V. This predicts that unstressed vowels shorten ‘in order to’ avoid a violation of WSP (Cvv being heavy, and Cv light). But we must sharpen this initial analysis quite a bit. So far we have tacitly assumed that heavy syllables outside the accent foot do *not* constitute violations of WSP. If they would do so, WSP would incorrectly block every vowel deletion that results in a closed syllable outside the accent foot. See (56a) vs. (56b-c), which I repeat below for convenience:

(70) (nák).sɨɽ > (na.kás).ɽi, (nák).sɨ.ɽi

This indicates that WSP must be ranked below both PARSE-σ and STEM CLOSURE. But that sets up a ranking paradox: WSP must also be undominated to keep closed syllables from weak positions of iambs. I will break this paradox by introducing a distinction between two logically possible interpretations of quantity-sensitivity, both of which are found in the metrical literature. On the one hand, any heavy syllable (CvC, Cvv, CvvC) must be banned from weak positions of feet (this interpretation of quantity-sensitivity is due to Hayes 1980, and occurs in much later work on foot typology, for example Hayes 1995). Let us refer to it as WSP-FT:

(71) **WSP-FT**
Bimoraic syllables must not occur in weak positions of feet.

As stated above, this constraint does not distinguish degrees of syllable weight, e.g. Cvv and CvC from CvvC. Violations of it are counted absolutely, rather than gradiently.

On the other hand, an interpretation of quantity-sensitivity that does not depend on the foot has been proposed in Prince (1983). This Weight-to-Stress Principle simply requires that ‘heavy syllables must be stressed’ (Prince & Smolensky 1993):

(72) **WSP**
Heavy syllables must be stressed.

As I will argue below, this constraint measures violations in a gradual fashion, so that a violation that is due to an unstressed CvC syllable is less severe than a violation that is due to an unstressed CvvC syllable. This will then predict vowel shortening.

This dual interpretation of the Weight-to-Stress Principle allows us to rank WSP (72) below PARSE-σ, while we can maintain WSP-FT (71) as a part of the undominated cover constraint FT-FORM, thus guaranteeing quantitatively well-formed iambs. That is, the effects of both constraints are empirically distinguishable in Southeastern Tepehuan since WSP-FT (the specific constraint) dominates WSP (the general constraint), while two other constraints (PARSE-σ, STEM CLOSURE) are ranked in between.

The new (now complete) ranking is given below:

(73) ALL-FT-L, FT-FORM (*including* WSP-FT), σ-FORM, DEP, MAX-C » RED=NUC$_{\mu\mu}$ » PARSE-σ » DISYLL » STEM CLOSURE » WSP » MAX-V

An illustration of this analysis is provided by tableau (74). All three candidates (74a-c) have no violations of undominated constraints, and violate PARSE-σ to the same degree. The shortening of the long stem vowel is due to WSP, which rules out candidates (74b) and (74c), both of which have one additional heavy syllable as compared to the optimal candidate (74a). Candidate (74e), which would be an improvement over (74a) in terms of PARSE-σ and MAX-V, is excluded by WSP-FT.

(74) /RED - takaaruiʔ/	ALL-FT-L	FT-FORM	RED=NUC$_{\mu\mu}$	PARSE-σ	STEM CLOSURE	WSP	MAX-V
a. ☞ (táat).ka.ruiʔ				**		*	a, a
b. (táat).kaa.ruiʔ				**		**!	a
c. (táa).tak.ruiʔ				**		**!	aa
d. (ta.ták).ruiʔ			*!				aa
e. (taat.káa).ruiʔ		WSP-FT!		*		**	a
f. (táa).(ta.kàa).(rùiʔ)	*!**						

In (74) I have indicated violations of WSP on a binary basis since we still have not seen the evidence for a gradual interpretation.

The analysis of reduplicated CvCvv stems involves a final vowel shortening that is due to WSP. Again we find that WSP must dominate MAX-V:

(75) /RED - topaa/	ALL-FT-L	FT-FORM	RED=NUC$_{\mu\mu}$	PARSE-σ	STEM CLOSURE	WSP	MAX-V
a. ☞ (tót).pa				*	*		o, a
b. (tót).paa				*	*	*!	o
c. (tot.páa)		WSP-FT!			*		o
d. (tót).(pàa)	*!				*		o

Observe that RED=NUC$_{\mu\mu}$ is not violated since /topaa/ is not a stem that triggers it. There is yet another plausible candidate to be considered, [(to.tóp)]. The fate of this ill-formed output form will be discussed in Section 3.3.6.

In the following tableau, we find additional evidence that WSP is dominated by STEM CLOSURE:

(76) /RED - novi/	ALL-FT-L	FT-FORM	RED= NUC$_{\mu\mu}$	PARSE-σ	STEM CLOSURE	WSP	MAX -V
a. ☞ (nóo).nov				*		*	i
b. (nóon).vi				*	*!		o
c. (nóo).no.vi				**!	*		
d. (no.nóv)			*!				i
e. (nóo).(nòv)	*!						i

So far we have been looking into vowel shortening in unstressed open syllables - this could still be captured by the binary weight distinction between Cv and Cvv/CvC. But gradual evaluation by WSP is relevant for shortening in unstressed closed syllables, e.g. /RED-k**aa**m/ [(káa).k**a**m], (63b.ii). Such forms tell us that CvC must be *lighter* than CvvC. If not, vowel shortening would not yield any gains in terms of WSP.[23]

We thus find that WSP (66) uses a gradual interpretation of syllable weight, one based on ‘intrinsic prominence’. Interestingly this precisely matches the heaviness scale which Prince & Smolenky (1993:40) give for ‘prominence-driven’ stress systems:

(77) CvvC > Cvv, CvC > Cv

Prince & Smolensky (1993) and Hayes (1995) argue that weight scales typically occur in languages whose stress assignment is not strictly foot-based (cf. PKPROM in Prince & Smolensky’s analysis of Kelkar’s Hindi). Southeastern Tepehuan confirms this picture: *gradual* syllable weight is relevant *outside* the foot (WSP), and a *binary* moraic weight distinction (Cv versus bimoraic syllables) *within* the foot (WSP-FT). The shortening of CvvC into CvC which we find outside the foot follows from the gradual evaluation by WSP: unstressed CvC incurs one violation, and unstressed CvvC two.[24]

This is illustrated in tableau (78). The optimal candidate (78a) violates WSP to a smaller degree than candidate (78b), even though the latter is more faithful to the input. This motivates the ranking WSP » MAX-V.

(78) /RED - kaam/	ALL-FT-L	FT-FORM	RED= NUC$_{\mu\mu}$	PARSE -σ	STEM CLOSURE	WSP	MAX -V
a. ☞ (káa).kam				*		*	a
b. (káa).kaam				*		**!	
c. (ka.káam)			*!				
d. (kaa.káam)		WSP-FT!					
e. (káa).(kàam)	*!						

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[23] Of course we cannot assume that CvC is light; CvC must be heavier than Cv as judged from various types of evidence, in particular accentability and stem minimality: stems are minimally CvC or Cvv, never Cv.

[24] WSP is never enforced by vowel lengthening in stressed syllables. As was explained in Section 3.3.2, lengthening is absolutely disallowed due to undominated DEP.

Tableau (79) proves the same point (compare 79a and 79b), and also presents additional evidence for a ranking Parse-σ » Max-V (compare 79a and 79c)

(79) /Red - tapɨɨʃ/	All-Ft-L	Ft-Form	Red=Nuc$_{\mu\mu}$	Parse-σ	Stem Closure	WSP	Max-V
a. ☞ (táat).pɨʃ				*		*	a, ɨ
b. (táat).pɨɨʃ				*		**!	a
c. (táa).ta.pɨʃ				**!		*	ɨ
d. (tát).pɨʃ			*!	*		*	a, a, ɨ!
e. (táa).(ta.pɨ̀ɨʃ)	*!						

As expected, there is independent evidence for the role of WSP from syncope. In some cases the choice of which vowel will be deleted depends on whether the output contains an open or a closed syllable. In such cases the output is selected that has the fewest violations of WSP. In tableau (80), two candidates (80a) and (804b) occur which equally violate Parse-σ, but the optimal output (80a) has one fewer violation of WSP (it has one unstressed heavy syllable only).

(80) /Red - tɨroviɲ/	All-Ft-L	Ft-Form	Red=Nuc$_{\mu\mu}$	Parse-σ	Stem Closure	WSP	Max-V
a. ☞ (tɨ́ɨt).ro.piɲ				**		*	ɨ
b. (tɨ́ɨ).tɨr.viɲ				**		**!	o
c. (tɨ́ɨ).tɨ.ro.piɲ				***!		*	
d. (tɨ.tɨ́r).viɲ			*!	*		*	o
e. (tɨ́ɨt).(ro.pìɲ)	*!						ɨ

Observe again that Parse-σ must dominate Max-V, so as to exclude candidate (80c).

The next tableau shows rhythmic vowel deletion in the longest form seen so far. The optimal candidate is the one that has the minimal number of unparsed syllables that is possible without violating undominated constraints. The ‘rhythmicity’ of the deletion pattern is captured by an interaction of output constraints, and requires no iterative feet.

(81) /Red -matuʃidʒaʔ/	All-Ft-L	Ft-Form	Red=Nuc$_{\mu\mu}$	Parse-σ	Stem Closure	WSP	Max-V
a. ☞ (máam).tuʃ.dʒaʔ				**		**	a, i
b. (máa).mat.ʃi.dʒaʔ				***!		**	u
c. (máa).ma.tu.ʃi.dʒaʔ				***!*		*	
d. (ma.mát).ʃi.dʒaʔ			*!	**		*	u
e. (maam.túʃ).dʒaʔ		*!		*		*	a, i
f. (máa).(ma.tùʃ).(dʒàʔ)	*!***						i

Note that this tableau represents all key aspects of the analysis: the domination of input faithfulness (Max-V) by exhaustive metrical parsing (Parse-σ), and the domination of the latter by a complex of constraints that enforce a single left-aligned iamb.

3.3.6 Vowel deletion and output-to-output correspondence

Finally I return to the question of what excludes the candidate [(to.tóp)] in tableau (75), with a complete deletion of the final vowel. Given the constraint ranking established so far, this candidate is incorrectly predicted to be optimal, since it has no violations of the constraints that are violated by the attested output [(tót).pa] in (75a), Parse-σ and Stem Closure. What makes [(to.tóp)] less optimal than [(tót).pa]? I suggest that the presence of the final [a] in the reduplicated form correlates with its status as a stressed vowel in the non-reduplicated form [(to.páa)]. This *output-to-output* correspondence relationship between the head of the basic form and a vowel in the output has been stated as the correspondence constraint HeadMax (McCarthy 1995, Alderete 1995):

(82) **HeadMax** (B/O)
Every segment in the base prosodic head has a correspondent in the output.

The notion of ‘base’ is used here in a more general sense than is usually assumed in the analysis of reduplication. Following Benua (1995), Alderete (1995) and Kager (1995b), I assume that the ‘base’ of an affixed form is the word (an output form itself) to which it is morphologically related by means of affixation. Here the independently existing form [(to.páa)] is the base of the prefixed form [(tót).pa], in which the prefix happens to be a reduplicant. As I will show below, HeadMax is not crucially dominated by any other constraint in Southeastern Tepehuan.

Tableau (83) illustrates its effect in the reduplicated stem [(tót).pa]:

(83) /Red-topaa/ B: (to.páa)	All- Ft-L	Head Max	Red= Nuc$_{\mu\mu}$	Parse -σ	Disyll	Stem Closure	WSP	Max -V
a. ☞ (tót).pa				*		*		o, a
b. (to.tóp)		*!						aa

Finally, we must ask whether HeadMax has any harmful consequences for the analysis of reduplicated forms that were discussed earlier in this paper. Upon closer inspection, this happens not to be the case. The vowel that is stressed in the base always reoccurs in the reduplicated stem, either in its ‘proper’ position in the stem (84a), in the reduplicant prefix (84b), or even in both positions (84c).

(84)		*Input*	*Base*	*Reduplicated stem*	
	a.i	/topaa/	(to.p**áa**)	(tó-t).p**a**	‘pestle(s)’
	a.ii	/novi-ɲ/	(no.v**í**ɲ)	(nóo-n).v**i**ɲ	‘his hand(s)’
	a.iii	/tapɨɨʃ/	(tap.**ɨ́ɨ**ʃ)	(táa-t).p**ɨ**ʃ	‘flea(s)’
	b.i	/ɲuutʃiʃ/	(ɲ**úu**).tʃiʃ	(ɲ**úu**-ɲ).tʃiʃ	‘brother(s)-in-law’
	b.ii	/tɨroviɲ/	(t**ɨ́**r.viɲ)	(t**ɨ́ɨ**-t).ro.piɲ	‘rope(s)’
	c.i	/karvaʃ/	(k**á**r).vaʃ	(k**a**-k**á**r).vaʃ	‘goat(s)’
	c.ii	/novi/	(n**ó**v)	(n**óo**)-n**o**v	‘hand(s)’

This concludes the analysis of rhythmic vowel deletion in Southeastern Tepehuan.

3.4 Metrical opacity in Southeastern Tepehuan: Conclusions

In sum, rhythmic vowel deletion in Southeastern Tepehuan is ‘categorial’ in the sense that no traces of deleted vowels appear in the output. Consonants across the deletion site are phonologically adjacent, as we inferred from various syllable-sensitive phonotactic patterns. Moreover, rhythmicity of the vowel deletion pattern finds no surface correlate in the form of secondary stress. The opacity of the metrical context of deletion makes that it is analyseable as foot-based only within a rule-based model. But as I have shown, the derivational foot-based analysis is suspect for independent reasons. It must set up feet (quantity-sensitive trochees) that never surface and whose single role is to ‘explain’ the syncope pattern, producing circularity. Moreover, the rule-based analysis has no real explanation of the fact that all syllable-sensitive rules in Southeastern Tepehuan refer to surface (‘post-syncope’) syllabification rather than to pre-syncope syllables. In contrast, an OT analysis has no intermediate stage of abstract iterative ‘syncope’ feet. Instead, it rationalises syncope as a means of minimizing the number of syllables unparsed by the initial foot. The foot is an iamb, i.e. a surface-true foot. It also explains why phonotactic constraints refer to surface syllabification. In sum, derivational theory seems to be too rich in its descriptive possibilites, since it places no inherent limitations on the abstract intermediate representations that condition vowel-zero alternations in surface forms. OT is descriptively more conservative, and also adequately captures the distinction between ‘gradient’ and ‘categorial’ types of RVD.

4. Conclusions: A typological perspective

I have shown that OT makes the prediction of two types of rhythmic vowel deletion, i.e. gradient and categorial. Gradient deletion is actually extreme reduction which preserves syllabicity. This may be foot-based, applying to rhythmically weak syllables in surface feet. In contrast, categorial rhythmic deletion (rhythmic syncope) involves full deletion, with loss of syllabicity, and ‘resyllabification’. It is not conditioned by iterative feet, but by other factors. For example, in Southeastern Tepehuan ‘rhythmicity’ of RVD follows from the ranking All-Ft-L, Parse-σ » Max-V. This ranking says that exhaustivity of metrical parsing and the shape and position of feet have higher priority than faithfulness to input vocalism. That is, the phonology may delete input vowels in order to get closer to the ideal of a single initial foot, with no unparsed syllables.

These typological predictions require careful checking against more languages. Languages that I know from the literature seem to fall into one or the other class by the majority of criteria. Into the first class (of ‘gradient deletion’) fall a number of iambic languages that are discussed in Hayes (1995). For example, Unami and Munsee (both Algonquian languages) have vowel reduction up to the point of deletion, which seems to be remarkably free of phonotactic restrictions, while secondary stress is preserved. More examples may be found in the historical phonology of Romance languages. Late Latin (Jacobs 1989) had a process of post-tonic vowel reduction/deletion which was not phonotactically conditioned, since it led to consonant clusters that were otherwise ruled out in the language. It was only in Gallo-Romance, a later stage at which alternations between reduced vowel and zero had been lost altogether, that the ‘illegal’ clusters were repaired to match canonical syllables (e.g. Latin *dormitorium* > Late Latin [dɔrm.torju] > Gallo-Romance [dɔr.tojr]). Into the second class (‘categorial deletion’) fall syncope patterns found in various Arabic dialects (Levantine and Palestinian Arabic syncope and metrical structure are analysed in an OT framework in Kager 1995b). Also, several Uto-

Aztecan languages (genetically related to Southeastern Tepehuan), such as Cupeño (Hill & Hill 1968), Hopi (Jeanne 1982), and Luiseño (Munro & Benson 1973). Here syncope tends to be conditioned phonotactically (since it is 'repaired' by epenthesis), while the secondary stress pattern (if any) does not signal the site of deletion.[25]

Finally I wish to point out a general point of this paper which may bear on the debate between (rule-based) derivational phonology and (constraint-based) OT. This is that one cannot, and should not, directly transfer the conceptual categories of rule-based theory into OT. As I have shown, 'surface opacity with respect to metrical structure' is not a *categorical* problem to a constraint-based theory which views the surface form as the primary level at which generalisations interact. Rather, for independent reasons that have nothing to do with theoretical viewpoint, the derivational notion 'metrical opacity' should be broken down into two separate cases.[26] Each of these requires a different type of analysis, and each analysis can be stated strikingly well in optimality theoretic-terms.

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[25] Bill Idsardi (this volume) argues that an opaque interaction of spirantisation and syllabification in Tiberian Hebrew is problematic to OT.

[26] Another type of metrical opacity, involving 'output-to-output' correspondence', is discussed in Kager (1995b).

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