Subsegmental Syllabification

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1. Introduction

I begin by demonstrating that gradient subcategorical syllable weight hierarchies can be extracted from parsed metrical corpora. For example, in both Sanskrit and Finnish, VC and VV rimes are categorically heavy. Nevertheless, statistically significant distributional asymmetries in metrical corpora reveal that poets in both languages treated VC as lighter than VV. I then discuss how gradient weight effects can be used to probe the finegrained nature of syllable structure. For instance, Steriade (2008b, 2009) claims that onsets are parsed into metrical intervals with the preceding nucleus, but not the following one. I argue to the contrary that evidence from gradient weight suggests that an onset is at least partially parsed into the weight-bearing syllabic constituent headed by the following nucleus. Finally, I consider two independent pieces of evidence from distributional asymmetries in Epic Sanskrit meter suggesting that syllable boundaries are not crisply aligned to segment edges. Phonologists already assume this in the case of (most) geminates. I propose that singletons can also be split between syllables. Unlike most ambisyllabicity proposals, this splitting would not involve two syllables sharing a segment in its entirety, but must rather, to explain the effects in question, be treated as a gradient bifurcation.

2. Extracting gradient weight hierarchies from metrical corpora

Most of the material in this talk is based on analysis of an Epic Sanskrit corpus. The corpus, harvested from two epics and seven *purāṇas* downloaded from the Göttingen Register of Electronic Texts in Indian Languages (GRETIL), comprises 586,593 octosyllabic lines (*pādas*) of the *śloka* meter. A metrical filter ensured that only *ślokas* were harvested from the texts. The meter, being quantitative, exhibits a categorical distinction between light ($C_0\breve{V}$) and heavy syllables. We can distinguish three basic types of metrical position: ictus (crucially heavy), breve (crucially light), and anceps (more or less freely permits heavy or light). Analysis of the meter is outside the scope of this paper (see Arnold 1905, Oldenberg 1888, Macdonell 1927:232, Velankar 1949, and Coulson 1992:250,310), but the general distribution of ictuses, breves, and ancipitia in odd *vs*. even *pādas* is given by the finite-state machines in table 1 (H = ictus, L = breve, X = anceps). For the present purposes, it is only important to note that a position's status as regulated or anceps can often only be determined in the context of its line. For example, the second position is crucially heavy if followed by a light, but otherwise anceps.

I now describe a novel technique for extracting gradient syllable weight hierarchies from metrical corpora, which I term the WEIGHT PREFERENCE METHOD. First, we find two different contexts in a given meter which both permit the same weight category of interest (heavy or light) but which differ in their general heaviness propensities. For Epic Sanskrit, I take as my heavier set all heavies in ictuses ($n = 1.5$ million) and as my lighter set all heavies in preferentially light ancipitia (i.e. any anceps filled by a heavy less often than chance; $n = 0.6$ million). I code each syllable token for its position in the word and word template (e.g. H_LH). Finally, for each syllable subtype of interest (e.g. rime skeleton

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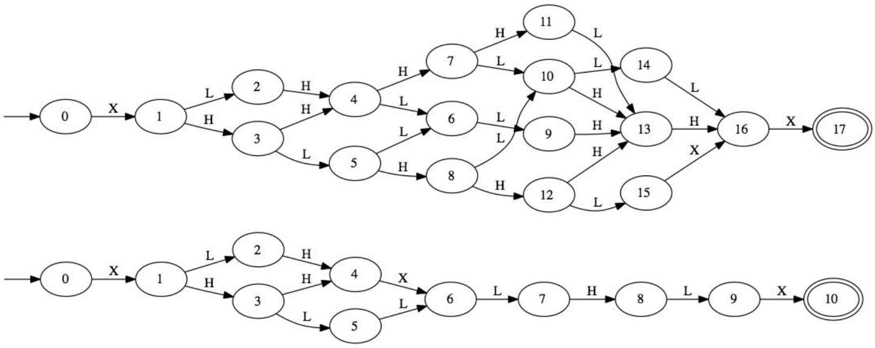

Table 1: Directed graphs representing metrically licit lines in odd (top) and even (bottom) *pādas*.

VC *vs*. VV, etc.), I find the skew between the two metrical contexts. To control for word context (to avoid any possible confounds from lexical asymmetries in the distribution of subtypes), the algorithm randomly pairs ictus and anceps tokens with matching word context specifications (without resampling any token). As it does so, it counts how many times a each syllable subtype occurs in the two context-balanced samples. The more skewed the ratio is towards ictuses, the heavier the subtype can be inferred to be. The paired-sampling process is repeated many times (100 here) to ensure that the results hold across samples and to assess a Monte Carlo p for each contrast.[1]

For example, the following skeletal rime structure hierarchy emerges for Sanskrit: VC $<$ VV $<$ VVC $<$ VVCC (VCC, not shown, is intermediate between VC and VV but, in part because of its infrequency, not significantly different than either). All three contrasts are significant (highest $p < 1.5 \times 10^{-6}$ based on Fisher's exact test two-tailed on the contingency table of average counts for each comparison; cf. Monte Carlo $p < .01$, as there were no reversals in 100 iterations). 207,419 context-controlled pairings were made each run. The box plot in table 2 shows ictus-to-anceps ratio on the x-axis for each of four rime subtypes on the y-axis. Thicker bars correspond to more frequent subtypes (which, it follows, also exhibit less variance from one Monte Carlo trial to the next). In sum, the set of heavies found in preferentially lighter positions skews towards the lighter side. Because VC is the lightest heavy rime type, it is the most overrepresented in preferentially light ancipitia.[2]

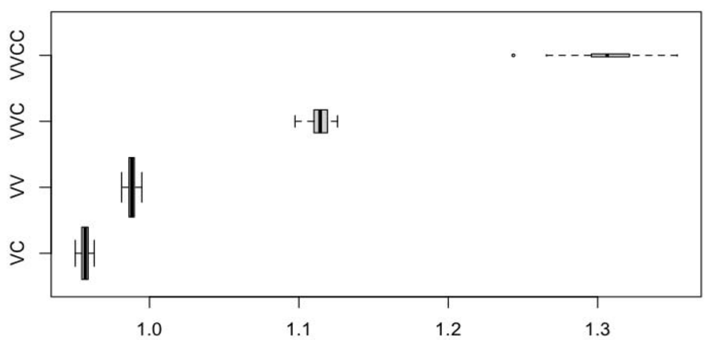

Table 2: Box plot showing controlled ictus::anceps ratios for four rime types in Sanskrit.

Incidentally, the same hierarchy is also found for Finnish, as based on the Kalevala corpus. On the Kalevala meter, a trochaic tetrameter, see, e.g., Sadeniemi (1951), Kiparsky (1968), and Leino (1986). My Kalevala corpus comprises 17,890 octosyllabic lines. I take the set of heavies in downbeats as the

[1] Another means of controlling for word shapes which I have adopted in subsequent work is to employ a mixed effects regression model with the syllable subtypes as fixed effects and the word shape specifications as random effects (see Ryan 2010).

[2] Previous work on intracategory weight distinctions in metrics includes Maas (1962), Irigoin (1965), West (1970), and Devine & Stephens (1976, 1977, 1994), all on Ancient Greek.

heavier context and the set of heavies in (nonfinal) upbeats as the lighter context. The resulting hierarchy, controlling for word shape and position in the word as before, is: VC $<$ VV $<$ VVC (3,427 pairs per run, highest $p < .02$).

To summarize so far, then, in both Sanskrit and Finnish, C_0VC and C_0VV are both categorically heavy. Nevertheless, C_0VC is significantly overrepresented in preferentially light positions in both languages relative to C_0VV. This and similar effects can be explained by the hypothesis that poets preferentially avoid heavier heavies in preferentially light positions. Moreover, the heavier the subtype, the more they avoid it. Preferences such as VC $<$ VV align with the crosslinguistic typology of categorical weight distinctions, in which VC is almost always lighter than VV if their weights are distinguished (Gordon 2006). Unlike categorical contrasts, however, my methodology reveals a ratio scale of weight, in which differences are matters of quantifiable degree. This is unlike the more usually assumed ordinal scale of weight, in which each contrast, e.g. that between heavy and light, is a matter of strict separation.

3. Using gradient weight to probe syllable structure

I now turn to the second part of the paper, in which I discuss how evidence from gradient weight can be used to probe syllable structure. It is well known that the placement of syllables in meter reveals facts about their constituency. For example, one might ask whether Sanskrit *tatra* 'there' is parsed as *tat.ra* or *ta.tra*. Since *tr* is a possible (word-initial) onset in Sanskrit, one might guess that it is the latter. But metrics demonstrates that it is in fact the former: σ_1 cannot be placed in a breve (i.e. crucially light position) in Sanskrit; it can only be placed in an ictus or anceps. Therefore, it must be a closed syllable: *tat.ra*. So the traditional reasoning goes.

A novel finding of this paper is that gradient weight can also be used to probe syllable structure, assuming that the weight of a syllable is a function of elements of that syllable. For example, we might ask whether onset complexity contributes to syllable weight in Sanskrit. If we stopped at the categorical metrics/phonology, the answer would be negative. Onset complexity has no bearing on categorical weight in the language. Nevertheless, given the ability to uncover gradient weight preferences from distributional asymmetries in verse, we can now check whether (increasingly) complex onsets are (increasingly) avoided in crucially light positions (breves) in favor of heavier ones (ancipitia), all else being equal.

It turns out that onset complexity is indeed significantly correlated with weight. In fact, the longer the interlude preceding a light syllable is in Cs, the more strongly that syllable is avoided in breves in favor of ancipitia. The hierarchy illustrated in table 3 is monotonic: C $<$ CC $<$ CCC $<$ CCCC (all contrasts significant, highest $p < .03$; 112,528 pairings per iteration), where C_1 in each level is the full vowel-to-vowel interlude preceding the light nucleus in question. I use interlude length rather than onset length to be neutral on questions of how precisely complex interludes are divided between codas and onsets (e.g. is *saṃskṛtam* 'Sanskrit' parsed *saṃ.skṛ.tam* or *saṃs.kṛ.tam*?). For the present purposes, it is only necessary to demonstrate that material preceding the nucleus has a significant effect on how that syllable is distributed (controlling for confounds from the preceding syllable; see next paragraph). If an onset played no role in the weight of the syllable headed by the following vowel, we would not expect to find any effect of the preceding interlude, regardless of how it is syllabified.

In pairing off syllable tokens, I controlled for two aspects of the preceding syllable, namely, its categorical weight (heavy or light) and its vowel length (short or long), in addition to the word shape controls described above. If I had not enforced these additional controls, the effect of interlude length on the previous syllable might have been a confound. Because of the tendency of the meter to alternate in rhythm, a breve is most frequently preceded by an ictus or preferentially heavy position, which, if it had its way, would prefer a longer following interlude, possibly canceling out or reversing any effect of the interlude on the weight of the following syllable. In the hierarchy in table 3, progressively longer interludes are increasingly strongly avoided before breves, a fact that cannot be explained by any confound from preceding syllables, since preceding syllables, which tend to be ictuses and preferentially heavy ancipitia, would, if anything, *prefer* a longer interlude, not eschew one. The increasing avoidance exhibited in table 3 must be motivated by the syllable headed by following (breve) nucleus.

Independent support for the onset complexity effect on weight comes from the effect of preceding

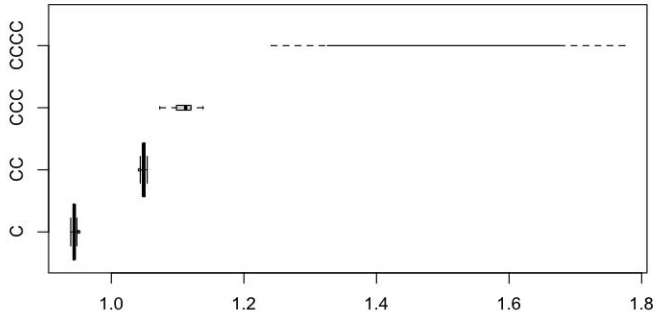

Table 3: Box plot showing controlled breve::anceps ratio (x-axis) as a function of the length of the preceding interlude in Cs (y-axis) in Sanskrit.

interlude length in Cs on the skew of heavy syllables between ictuses (heavier) *vs.* preferentially light ancipitia. Though more compressed in this case, the same hierarchy is obtained (same controls as before): C < CC < CCC(C) (the contrast between interlude CCC and CCCC is nonsignificant, $p = .16$; all other $p < .02$; 207,413 pairs per run). In sum, onset complexity significantly effects the weights of both light and heavy syllables, making both pattern as gradiently heavier.

The point of this case study is that these sorts of distributional asymmetries matter not just for our theory of syllable weight, but also for our theory of syllable structure. The question of weight-bearing onsets is obviously relevant for assessing rime-based and moraic theories of syllable weight. But it is also relevant for assessing a recent proposal about constituency structure in metrics, namely, Steriade's Interval Theory of Weight (2008ab, 2009). Under this theory, an onset is not part of the same metrical interval as the following vowel (e.g. VCVCCVC is parsed [VC][VCC][VC]). Interval Theory thus predicts that onsets could affect weight, but only of the interval headed by the preceding nucleus, not the following one. The evidence presented in this section, though preliminary (see Ryan 2010 for a more thorough appraisal), favors a more traditional syllable theory, in which an onset adjoins a following vowel within a prosodic constituent (the syllable), over Interval Theory.

This evidence regarding statistical effects of onsets on weight corroborates possible evidence for weight-contributing onsets from several other domains of phonology, including stress systems (e.g. Everett & Everett 1984, Everett 1988, Gordon 2005 and references therein, Nanni 1977, Davis 1988 [cf. Gahl 1996], Kelly 2004, Topintzi 2005, 2008, etc.), word minimality (e.g. Topintzi 2005), possibly binomial ordering (cf. Cooper & Ross 1975, Benor & Levy 2006), possibly compensatory lengthening (cf. Kiparsky to appear), findings in the p-center literature in which the downbeat anticipates the vowel onset under heavy-onset conditions, and so forth.

4. A problem for segmental syllabification: T^h

I now turn to the first of two case studies for which the assumption of categorical syllabification of singletons proves problematic. In this case, intervocalic voiceless aspirated singleton stops (abbreviated T^h) are shown to contribute more weight to both the preceding and following syllables than all other intervocalic stops. First, onset T^h, which in Sanskrit covers $\{p^h, t^h, \underset{.}{t}^h, c^h, k^h\}$, is preferentially avoided (relative to all stops) after breve nuclei (schematically, $\underline{C_0\breve{V}}.T^{\neq h}V... < \underline{C_0\breve{V}}.T^hV...$). This is a robust result, true not only for T^h pooled, but for all five members of T^h individually, as table 4 illustrates.

The problem is that, under traditional assumptions, VT^hV must be parsed as $V.T^hV$, since the preceding syllable cannot occupy a crucially heavy position in Epic Sanskrit (only geminate $T{:}^h$, which contrasts with T^h, can close the preceding syllable). Thus, under the traditional categorical parse, T^h is wholly parsed into the onset of the following syllable. If this is the case, how can a short syllable preceding the T^h onset ($\underline{C_0V}.T^hV$) be treated as heavier by the poets than a short syllable preceding any other stop onset ($\underline{C_0V}.TV$)?

One logically possible solution that can be fairly confidently dismissed on both typological and internal grounds is to assume that T^h has a lengthening effect on the preceding vowel. First, typology suggests that any such lengthening effect would be unlikely. Lengthening before T^h, one of the longest

onset type	T^h anceps::breve	T anceps::breve	$p <$
p^h	1.5	0.90	.001
t^h	0.97	0.90	.03
$\underset{.}{t}^h$	1.4	0.90	.08
c^h	6.9	0.90	3.1×10^{-7}
k^h	1.6	0.90	1.4×10^{-19}
T^h (pooled)	1.06	0.90	1.3×10^{-9}

Table 4: Voiceless aspirate stops are consistently avoided after breves relative to other stops.

and most complex of the stops in Sanskrit, but not before other, shorter stops, would be as unnatural as lengthening a vowel in closed syllables (which remain closed) but not in open syllables. It is thus not only the case that such lengthening is unlikely; it is actually the opposite of what one would expect. If a long consonant has any effect on the preceding vowel, shortening, not lengthening, would be natural. Second, internal Indo-Aryan evidence also argues against this hypothetical solution. Vaux (1992) adduces various evidence that T^h is treated as geminate-like (i.e. long) in related Prakrit dialects. Moreover, while a preceding long vowel shortens in some dialects, a short vowel never lengthens. Thus, T^h's contribution to the weight of the preceding syllable appears to be a reflex of the intrinsic length of T^h, not an effect mediated by vowel length.

A second possible explanation for the effect of singleton T^h on the previous open syllable is Steriade's Interval Theory. The vowel-to-vowel interval parse of VT^hV is $[VT^h][V]$, in which T^h is affiliated entirely with the preceding interval. If this is the case, it follows straightforwardly that the initial of $[\underline{VT^h}][V]$ might be treated as gradiently heavier than the initial of $[\underline{VT}][V]$, since T^h is longer than T. So far so good.

Nevertheless, there is also a third logical possibility, that of subsegmental syllabification. Imagine that the perceptual division of interludes is gradient as opposed to crisply aligned to segmental edges. (Phonologists already assume something along these lines for at least one type of long segment, the geminate.) In the present case, an intervocalic stop would be gradiently divided between the two flanking syllables. Because T^h is longer than T, more of it would have a tendency to be perceived as part of the preceding syllable, albeit never enough to make the preceding syllable count as categorically closed/heavy.

Interval theory and subsegmental syllabification, though they can both potentially explain the effect of intervocalic T^h on the preceding light syllable, make different predictions about the effect of T^h *vs.* T on the *following* syllable. Interval Theory predicts that $[VT^h][\underline{V}]$ should pattern like $[VT][\underline{V}]$, since both following syllables comprise only the vowel (assuming that T^h *vs.* T does not significantly effect the length of the following vowel). Under subsegmental syllabification, on the other hand, a long interlude, even if only a long singleton segment such as T^h, is expected not only to contribute more weight to the preceding syllable, but also to the following syllable. Given the effect of complex onsets described in section 3, we might hypothesize that if onset complexity contributes to weight, so should onset length, independently of complexity. This prediction is borne out: T^h is significantly avoided (relative to T) as an onset in breves (1.38 *vs.* 1.02 mean anceps::breve ratio, $p = 4.0 \times 10^{-29}$). It follows that intervocalic T^h appears to contribute more weight than T to both the preceding and following syllable.

To summarize this section, consider three competing parses of the sequence VT^hV. First, the traditional parse predicts that a long singleton onset such as T^h could, if anything, make its own syllable heavier (represented by the arrow in table 5), but not, without lengthening the preceding vowel, the previous one. This model fails to capture the significant and consistent effects that voiceless aspirated stops have on the weight of preceding open syllables.

$$\mathrm{V} \quad [\ \mathrm{T^h} \ \ \mathrm{V}$$

Table 5: Traditional parse.

Second, Interval Theory (e.g. Steriade 2009) predicts that a long intervocalic singleton could make the preceding interval heavier, but not, without lengthening the following vowel, the following vowel. This model can capture the apparent gradient effect that singleton T^h has on the weight of the preceding open syllable, but fails to capture the apparent gradient effect it has on the weight of its own syllable. (Ryan 2010 considers the implications of onset weight for syllables vs. intervals in more detail.)

$$\mathrm{V}\quad \mathrm{T^h}\ ]\quad \mathrm{V}$$

Table 6: Interval theory.

Finally, if syllabification is subsegmental, such that boundaries are not necessarily crisply aligned to segments, we predict that a long intervocalic singleton could contribute to the weight of both the preceding and following syllables, being divided between them. This model can explain both the progressive and regressive weight effects of longer interludes, even if the interludes are merely long singletons.

$$\mathrm{V}\quad \mathrm{T^h}\quad \mathrm{V}$$

Table 7: Subsegmental syllabification.

5. The possible onsethood effect

In the previous section I demonstrated that an intervocalic voiceless aspirated stop (T^h) makes both the preceding and following syllables pattern as heavier than an intervocalic plain stop does. These effects, I argued, are difficult to explain if the aspirated stop is contained wholly within either the preceding or following syllable. I now offer a second, independent case study whose findings are likewise difficult to explain under categorical syllabification. This case involves what I shall call the POSSIBLE ONSETHOOD EFFECT, which concerns whether an intervocalic CC cluster is licit as an onset.

The facts are as follows. First, a short vowel followed by a CC interlude is virtually always treated as categorically heavy in Epic Sanskrit, i.e., VCCV is parsed VC.CV. This is true, as mentioned above, even if CC is a possible word-initial onset in Sanskrit. For instance, *tatra* is parsed *tat.ra* (heavy–light), even though *tr* can be parsed as an onset (cf. *tra.yaḥ*, light–heavy). Thus, we distinguish between VC.CV where C.C is a possible onset in Sanskrit *vs*. VC.CV where C.C is not a possible onset in Sanskrit, even though in all cases the cluster must be divided VC.CV to account for the fact that the preceding syllable cannot be treated as light. (NB. Sanskrit does not generally permit *muta cum liquida* compression as Greek and Latin often do.)

The possible onsethood effect can then be summarized thus: If C.C is a possible (word) onset, the preceding syllable is treated as gradiently lighter than if it is not a possible onset (ratio difference of 1.06 to 0.93, $p < 1.4 \times 10^{-4}$). At the same time, if C.C is a possible onset, the following syllable is treated as gradiently heavier than if it is not a possible onset (1.22 *vs*. 1.07, $p < 4.6 \times 10^{-36}$). In other words, in just the case that C.C is a possible onset, some weight appears to shift away from the preceding syllable onto the following syllable.[3]

Once again, this suite of facts is difficult to explain under both traditional categorical syllabification and interval theory, while gradient subsegmental syllabification offers a possible solution. For concreteness, take *atra* as the possible-onset interlude and *atna* as the impossible-onset interlude — *tr* can initiate a word in Sanskrit, while *tn* cannot. In both cases, the initial patterns as categorically heavy. It cannot be placed in a crucially light position in the meter. Nevertheless, the initial of *atra* patterns as gradiently lighter than the initial of *atna*. Under the traditional parse, the initial is the same, namely, *at*, in both cases. Moreover, the ultima of *atra* patterns as heavier than the ultima of *atna*. But

[3]More specific data for TR vs. RT (T = obstruent, R = approximant): First, VTRV is lighter than VRTV ($p = 6 \times 10^{-5}$, average ictus::anceps = 0.88 for TR, 0.98 for RT; $n = 207,413$ heavy pairs). Second, VTRV is heavier than VRTV ($p = .001$, average anceps::breve = 1.09 for TR, 1.01 for RT; $n = 177,048$ light pairs).

traditional syllabification fails to capture the dependence of this weight differential on whether the coda plus onset sequence is a licit onset or not. Interval theory, for its part, can explain the regressive weight reduction (at least assuming possible-onset CCs tend to be shorter than impossible-onset CCs), but not the progressive weight increase.

If syllabification is a gradient perceptual process, a ready explanation for the possible onsethood effect presents itself. Once again, take *atra* and *atna* for concreteness. In the former, some of the *t* closure could be perceptually reaffiliated with the following syllable, since *tr* is a possible onset. In the latter, none of the the *t* closure could be reaffiliated with the ultima, since *tn* is not a possible onset. In sum, the coda consonant is gradiently parsed between the syllables in just the case that the the coda and onset are both legal margins in the language.

6. Conclusion

I have shown that analyzing how the bards place different syllable types in meter reveals that their sensitivity to syllable weight goes far beyond the categorical distinction of heavy and light. For example, even though onset complexity plays no role in any categorical heavy/light contrast in Sanskrit, its effects exert themselves as statistically significant preferences on the part of the poets. In many cases, the statistical contrasts are exactly what we would expect from the crosslinguistic typology of categorical contrasts. For instance, C_0VC patterning as statistically lighter than C_0VV in Sanskrit and Finnish aligns with the typological generalization that if the weight of C_0VC and C_0VV is distinguished, the former is almost always the lighter (Gordon 2006).

But my weight preference methodology also reveals additional significant factors in syllable placement which are harder to explain under traditional theories. I presented two case studies from Sanskrit metrics. First, intervocalic singleton voiceless aspirated stops (T^h) make the both the preceding and following syllables pattern as heavier than their unaspirated counterparts (T) do. Second, an intervocalic CC cluster following a short vowel always closes the preceding syllable for the purposes of assessing categorical weight; therefore VCCV must always be parsed as VC.CV. Nevertheless, in just the case that CC is a possible (word-initial) onset, some weight appears to shift away from the preceding syllable (VCCV becomes lighter) to the following one (VCCV becomes heavier).

I argued that neither of these effects can be explained by a model of categorical syllabification of segments, whether it be the traditional syllabic parse or the vowel-to-vowel interval parse advocated by Steriade (2008b, 2009). Rather, these case studies support a model of syllabification as a gradient perceptual process, in which weight is assessed over constituents that are not necessarily crisply delimited by segments. This view is an extension of the treatment of geminates as (usually) heterosyllabic and is also related to the notion of ambisyllabicity. In contrast to some ambisyllabicity proposals (e.g. Kahn 1976), however, intervocalic consonants cannot be taken to be shared in their entirety between adjacent syllables, since, e.g., VT^hV in the first case study would be wrongly predicted to render the preceding syllable as fully closed and hence categorically heavy. Rather, I maintain, these patterns are best explained by a model of syllabification in which segments are gradiently divided between syllables.

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