The obligatory boundary tone hypothesis and prosodic typology

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Abstract

Two observations about the relationship between sound patterns in the phonological grammar of a language were foundational in motivating the proposal of a prosodic hierarchy with trees defined over phonological constituents in the 1980s: (i) sets of multiple, disparate patterns—suprasegmental and segmental, the application of phonotactic restrictions and processes—cluster together over domains; (ii) the patterns are in containment relationships, whereby the distribution of (non)application of one process invariably implies the (non)application of others. However, work on prosodic and intonational phonology in the past decades has raised doubts about the universality of clustering and containment. At the same time, we argue that Autosegmental-Metrical analyses of intonational phonology have slipped into narrowing the scope of sound patterns used to motivate phonological constituents to the distribution of prosodic boundary tones. We explore the consequences of the strong hypothesis that a span of segmental material is a phonological constituent if and only if it is delimited by at least one boundary tone. We show that clustering and containment can be understood to be at least partially respected under this hypothesis. But adopting it might also lead us to miss diversity in the organization of phonological patterns of natural language.

Index Terms: prosodic hierarchy, prosodic constituents, tone, allophony, intonation, sandhi rules, boundary tones

1. Introduction

The observation that sets of disparate phonological patterns converge on common domains originally motivated the concept of prosodic constituents in Prosodic Hierarchy Theory developed in the late 70s and 80s e.g., Selkirk (1978, 1984); Nespor and Vogel (1986) [1, p. 135], [2, p. 26-27], [3, § 2.4]. These patterns were segmental and suprasegmental—-phonotactics, stress patterns, tonal patterns, and whether or not certain phonological processes applied. Moreover, the unifying domains did not appear to necessarily correspond to syntactic constituents. This empirical observation of convergence of phonological patterns on a single domain has been called *clustering* [4, p. 9].

For instance, in one of the earliest Autosegmental Metrical (AM)-theoretic intonational analyses, Hayes and Lahiri (1991) [5, p. 53] identify phonological chunks in Kolkata Bengali that are delineated by rising pitch contours. Figure 1 shows an example of these repeating rises in another variety of Bengali [6, p. 101]. These melodic chunks are also exactly the same chunks that control whether two segmental assimilation processes can occur: (i) total assimilation of /r/ to an immediately following coronal consonant, and (ii) voicing assimilation of a stop to an immediately following stop. As shown in (1), a speaker may choose to utter the same sentence with different chunkings at different speech rates. Phonological chunks delineated by melodic rises are enclosed in square brackets. However, regardless of the chunking chosen, the two assimilation processes can only occur

when both the segment that gets changed (the target) as well as its conditioning environment (the trigger) occur within the same chunk, as exemplified for the final [r]s in [ɔmor] and [t͡ʃador] in (1), which are underlined when they assimilate to [t͡ʃ] and [t], respectively [5, §§9.1, 9.2]. Hayes and Lahiri (1991) [5] use the convergence of these patterns to motivate identifying this kind of chunk as a "phonological phrase". As put by Selkirk (1978), "By postulating [it] as a structural unit, as a category of prosodic structure which defines a particular type of domain, one expects this sort of correspondence of seemingly disparate phenomena. The convergence is, in this sense, explained" [1, p. 135].
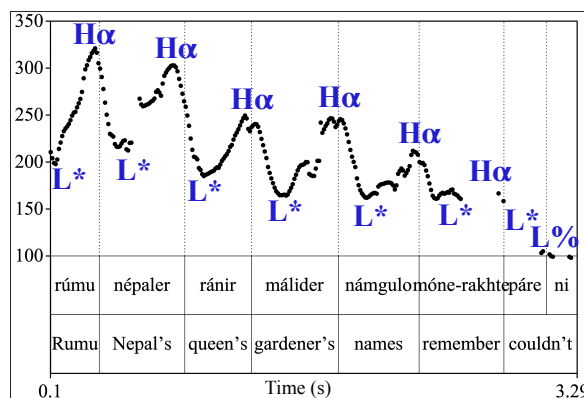

Figure 1: *Phonological chunks delineated by LH melodic rises in Standard Bangladeshi Bengali [6, p. 101]. Fundamental frequency (Hz) on y-axis, time (s) on x-axis. 'Rumu couldn't remember the names of the gardeners of the queen of Nepal.'*

(1) Clustering of tonal and segmental patterns within a single prosodic domain in Kolkata Bengali [5, (54)]

   a. [ɔmor] [t͡ʃador] [tara-ke] [diet͡ʃʰe]
      Amor   scarf   Tara-obj gave
     'Amor *gave* a scarf to Tara'

   b. [ɔmot͡ʃ t͡ʃador] [tara-ke] [diet͡ʃʰe]

   c. [ɔmor] [t͡ʃadot̪ tara-ke] [diet͡ʃʰe]

   d. [ɔmot͡ʃ t͡ʃadot̪ tara-ke] [diet͡ʃʰe]

Another fundamental observation about phononological patterns is that they are in *containment relationships* [7]: "rules that apply before a juncture of a certain strength apply before all junctures of greater strength; and rules that apply across a given juncture strength apply across all junctures of weaker strength" [8, p. 104]. Suppose final devoicing is used to define the right edge of one kind of chunk, and multiple final devoicing chunks occur within a larger kind of chunk identified as having a following pause. Then, the observation is that final devoicing also invariably occurs at the right edge of a pause-defined chunk.

The observation of these kinds of containment relationships between phonological processes was a key motivation for introducing the concept of prosodic trees constrained by the Strict Layer Hypothesis in Prosodic Hierarchy Theory [2]. This hypothesis has been restated, decomposed, and weakened over the years, e.g., see [9, 10] for discussion. The core part of the hypothesis relevant for this paper is that prosodic categories are strictly ordered, e.g., if one assumes the prosodic categories: syllables (σ), feet (Ft), prosodic words (ω), phonological phrases (φ), and intonational phrases (ι), then it is hypothesized that they are in a containment relationship $\sigma <$ Ft $< \omega < \varphi < \iota$, and a "higher-order" category such as an ι cannot be dominated by a lower category such as an ω in a prosodic tree defined over these categories. Containment relationships between phonological patterns then fall out of the definition of the tree coupled with the stipulation of a strict ordering of the categories. A tree structure also enforces *proper bracketing*: "a given constituent cannot simultaneously be part of two or more higher prosodic constituents" [11, (10a)]. For instance, given that an intonational phrase is a higher-order category ("bigger") than a phonological phrase, the edge of an intonational phrase can't be inside a phonological phrase.

Debate about universals of prosodic structure has often centered on the assumption of a small set of particular cross-linguistic prosodic categories and what categories should be in this set [10, 12]. For instance, Match Theory assumes that syntactic constituents map on prosodic constituents of just three categories in natural language [13], and work from this perspective already has the starting assumption of this inventory of prosodic categories. However, what Vogel (2009) calls the "phenomenon-based" perspective [10, p. 12] is that prosodic constituents reveal themselves via the observation of clustering and containment relationships of different phonological patterns in a language and can be "constructed as needed" [14, 15]. Unfortunately, counterexamples to both clustering and containment relations from the "phenomenon-based" perspective have been attested. A survey of word-level (between foot- and phrase-level) phonological patterns in 63 diverse languages found that only 9 of the languages exhibited phonological patterns clustered on a single domain [14, p. 56]. About two-thirds of the languages exhibited 3 or more distinct domains, up to 7.

Two well-known cases where containment relations (and proper bracketing) are not respected come from French and Luganda. French has repeating prosodic chunks that exhibit a rising tonal melody. French also famously exhibits liaison: a segmental process whereby word-final consonants can be resyllabified as the onset of following vowel-initial words in certain syntactic environments. Production experiments found that accentual domains were sometimes bigger than liaison domains, but other times smaller [16, 17]. That is, sometimes liaison did apply across accentual domain junctures, but other times it did not. Similarly, in Luganda, Hyman et al. (1987) [18] found that a chunk in which a low tone deletion process occurs can coincide with a chunk in which a (word-)final vowel shortening process, but multiple vowel shortening chunks can occur inside a low tone deletion chunk, and vice versa.

The failure of containment relations is dire for the hypothesis that the right data structure for relating phonological chunks is a tree. Hyman et al. (1987)'s proposal to rescue trees as data structures for phonology was to partition prosodic categories into different classes, e.g., one for tone and another for quantity [18]. Separate kinds of prosodic trees are built from each class, i.e., one kind out of tonally-defined constituents; another out of quantity-defined constituents.

While cyclicity/multiple spell-out domains have also been proposed to account for failures of clustering and containment [7], here, we focus on the idea of a separate prosodic hierarchy for tonal domains. We being by arguing in §2 that AM Theory, in practice, has slid into tacitly assuming the idea of a separate prosodic hierarchy for tonally-defined constituents, effectively singling out (certain kinds of) tonal phenomena as "special" or "different". To make this assumption explicit, we propose the following strong hypothesis as a starting point:

(2) **The obligatory boundary tone hypothesis**: *A span of segmental material is a phonological constituent if and only if it is delimited by at least one boundary tone.*

In the rest of the paper, we examine if the hypothesis is too strong, and if so, how it must be weakened to fit with the observed data, in the context of exploring how clustering and containment relations can be assessed over tonal patterns alone.

2. Are prosodically-conditioned tonal phenomena different?

Even though Hayes and Lahiri (1991)'s Bengali analysis uncovers clustering of tonal and segmental patterns, it still adopts a "tone-first" approach: given a tonally defined chunk, do other phonological patterns (including segmental allophonic variation) also share the same domain? Similarly, in another classic example of clustering, Jun (1993, 1998) first identifies a "tonally defined" chunk of Seoul Korean with a rise-rise melodic pattern as an "accentual phrase" [19, 20].[1] Within the span of such tonally-defined chunks, it is found that Post-obstruent Tensing (a lenis obstruent becomes tense after another lenis obstruent) and Lenis Stop Voicing (a lenis stop becomes voiced between voiced segments) apply. Jun (1998) calls the tone-first approach the "intonational approach", which "defines the prosodic units larger than a word based on the surface phonetic form of an utterance by looking at suprasegmental features such as intonation and final lengthening" [20, p. 189].

In the decades since then, it seems that segmental processes have not only taken a backseat to tonal patterns for motivating phonological constituents, but that tonal patterns alone have been taken to be necessary and sufficient for motivating constituents. In short, the approach seems to have drifted from "tone-first" to "tone-only". Thus, while Gussenhoven (1990) is sometimes pointed to as a singular proposal about separating out tonal domains [21], intonational analyses based on AM theory, in practice, largely seem to do exactly that.

Jun (2022)'s recent overview of ToBI transcription notes that, in practice, the junctural analysis "BI" (break index) part of ToBI is often left out in developing AM analyses of intonational phonology—-only the tones are analyzed [22, p. 169]. Moreover, the neglected BI tier seems to be where information about segmental sandhi phenomena has been noted, if at all, as can be observed in Jun (2005)'s first prosodic typology volume [23], which compiles descriptions of intonational phonology for thirteen different languages based on AM theory. Segmental sandhi diagnostics are briefly mentioned for the smallest break index, '0', for Mainstream American English and Serbo-Croatian, and Chickasaw and Greek transcription proposals include BI annotations about segmental sandhi application and/or mismatches with tonal correlates for prosodic constituency.

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[1] We are simplifying here; the chunk-initial tone depends on the initial segment, and there are many allophonic realizations of the characteristic tonal melody.

In Jun (2014)'s second volume of prosodic typology on fourteen languages, segmental allophony correlates of prosodic constituency are mentioned with any detail only for European Portuguese and Catalan (and very briefly in a footnote for Lebanese Arabic) [24]. In Frota and Prieto (2015)'s volume on the intonation of Romance languages, segmental sandhi rules are only mentioned briefly for the intonational phrase in Catalan [25, p. 13]. Is it generally the case that tonal correlates of prosodic constituency are more reliable or salient than segmental correlates, as a property of natural language? Or is it just that the research community has paid more attention to tonal correlates, while neglecting segmental ones? If prosodic constituents are defined on the basis of tonal correlates, then those tonal correlates will vacuously be invariably reliable.

It doesn't seem to only be that researchers are neglecting to look for prosodically-conditioned segmental allophony. When segmental sandhi rules are discussed in the three prosodic typology volumes mentioned above [23, 24, 25], they are described as being unreliable. Gordon (2005) cautions that segmental diagnostics for phonological constituents in Chickasaw are "not foolproof" [26, p. 322-23]. Arvaniti and Baltazani (2005) find in their corpus of spoken Greek that that segmental processes that had previously described as phonological rules may be restricted to certain lexical items, optional, and/or gradient, suggesting "the necessity of empirically re-examining the phonological descriptions of Greek sandhi in particular, and of the reliability of sandhi as a phrasing marker in general" [27, p. 104].

And although we introduced Bengali in §1 as exemplifying clustering of segmental and tonal patterns over a prosodic domain, the full picture is more nuanced. The assimilation processes described for Kolkata Bengali (West Bengal) "are not regularly applied" in the speech of Standard Bangladeshi Bengali (Northern and Eastern Bengal) [6, p. 58]. However, Khan (2008, 2014) [6, 28] report the same kind of prosodic chunks delineated by rising melodic patterns in Bangladeshi Bengali as in Kolkata Bengali. In fact, "repetitive rising contours" are reported as occurring across diverse languages of South Asia. No such uniformity is mentioned for segmental processes [29].

As another example, the Lenis Stop Voicing rule within a tonally-defined accentual phrase (AP) in Korean has been described as both optional and gradient [30]. AP-medially, a lenis stop can sometimes surface as only partially voiced or voiceless; it can also be realized as a fricative or approximant. Represented in terms of a symbolic voicing rule, allophonic variation in lenis stop realization thus seems to be an unreliable correlate of the accentual phrase. However, Lee (2024) finds that using intensity and duration measures to characterize lenis stop realization more generally in terms of reduction rather than voicing tells a different story [31]. In a large spontaneous speech corpus of Seoul Korean, lenis stops are uniformly reduced in AP-medial relative to AP-initial position, even voiceless ones. A characterization including fine-grained phonetic detail can also potentially unify (at least some) domain-medial processes with domain-initial strengthening as a continuous signal providing information about constituency [32]. If characterizing other instances of segmental allophonic variation in terms of phonetic trajectories also reveals increased reliability of prosodic chunking, then that is still evidence that prosodically-conditioned tonal patterns are different, if they are so salient that they are easily perceptible to the ear and well-characterized in terms of symbolic representations while segmental patterns may not be.

Direct mapping to phonetic trajectories is in fact also what Pierrehumbert (1980) proposed for English intonation [33, p. 11]. And processes involving pitch range manipulation, such

as downstep, are well-described directly via operations on f0 trajectories. In the next two sections, though, we focus on exploring how symbolic representations of tonal patterns can also be fruitful for helping us understand prosodic typology.

3. Clustering over tonal patterns

In the preceding section, we discussed how AM theory in practice seems to assume that each prosodic constituent above the word level must exhibit distinct, characteristic tonal patterns. In §1 we proposed an even stricter restriction of tonal patterns to just boundary tones in the *obligatory boundary tone hypothesis* (2) to make this assumption explicit. This tighter restriction is again motivated by what seems to happen in intonational analyses in practice. The assumption of a special status for boundary tones is reflected in Beckman and Pierrehumbert (1986): "One reason that the existence of the accentual phrase is less firmly supported in English than in Japanese is that it is not delimited by any boundary tones. The only tones which are properties of the accentual phrase occur at the location of the accent, whereas in Japanese there are tones both at the accent location and at the edge of the accentual phrase" [34, p. 269]. When we restrict phonological chunks to being motivated by tonal patterns, we can still define and assess a version of the clustering hypothesis because there can be multiple tonal patterns that are dependent on the same chunk. Defining a chunk as the domain over which those tonal patterns cluster then recognizes a generalization. The chunks partition the linear "output tonal pattern of an utterance" [19, p. 67].
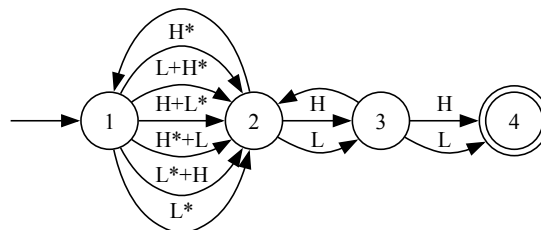
Figure 2: *Clustering over tonal patterns in the finite state acceptor in Pierrehumbert (2000) [35, Fig. 6], which generates licit English intonation patterns based on Beckman and Pierrehumbert (1986) [34].*

Figure 2 shows how chunks defined based on clusters of tonal patterns can be identified. It's Pierrehumbert (2000)'s [35, Fig. 6] finite state acceptor that generates licit English intonation patterns based on Beckman and Pierrehumbert (1986), with numeric labels added for the states (indicated by circles). Any tonal sequence that can be generated by traversing a path from the start state (labeled '1') to the final state (labeled '4', with double circle) is licit. Each state is a prosodic category defined by a cluster of tonal patterns. State 2 identifies a domain defined by the cluster of 6 licit melodies. State 3 identifies a domain defined by a cluster of 2 possible tones, as does State 4.

Marginal annotations in Pierrehumbert (2000)'s original figure label the first part of a tonal sequence generated up to State 3 as the "intermediate phrase" (ip) and the entire sequence generated upon reaching State 4 as the "intonational phrase". We have excluded those annotations in Figure 2 because they are not part of the tonotactic grammar. The prosodic chunks are defined based on stopping points (states) in the course of generating the tonal sequence, and changing the state label doesn't impact that definition. We could switch to an "ip" label for State

3 as a mnemonic: "let's refer to the sequence of steps to reach State 3 prior to transitioning to State 4 as building an ip."

Other marginal notes in Pierrehumbert (2000)'s original figure label the first six-member tonal cluster as "pitch accents" and the other two tones both as "boundary tones". By the obligatory boundary tone hypothesis, we would miss the State 2 cluster over pitch accent melodies, which is in fact what Beckman and Pierrehumbert (1986) choose to do. But identifying states based on tonal melody clusters underscores that generalizations over tonal patterns can cross-cut whether tones are pitch accents or boundary tones. Along these lines, Khan (2020) [29] finds that there is inter-language variation in whether the L and H tones of the "repetitive rising contours" of South Asian languages arise as (part of) pitch accents or boundary tones. How the tones associate may vary, but the output is still the familiar rising tonal melody that defines a phonological domain. And even if the initial L of the rising contour associates to a stressed syllable (like in Bengali, see Figure 1), i.e., is a pitch accent, it is also a prosodic boundary tone in the sense that it has a dependency on the accentual phrase constituent since only the first and no other stressed syllable in an AP bears a L tone. This kind of multiple dependency/association of tones can be formalized using tree transducers [36] and underscores the need for flexibility in AM theory rather than a strict dichotomy between pitch accents and boundary tones [37]. It also highlights that careful consideration about how a boundary tone is even defined is required to interpret the obligatory boundary tone hypothesis.

Perhaps the most striking feature of the English tonotactic grammar in Figure 2 is how few states there are, which is not an anomaly of the English tonotactic grammar, but typical in intonational analyses. Compare this to the proliferation of domains found when constituents are constructed as needed as domains of segmental allophony [14, 15]. This could be another way in which tonal patterns are different: even when constituents are constructed as needed based on the clustering of tonal melodies, only 2-3 constituent types emerge. However, it isn't clear how much analyses may have been biased towards assuming just 2-3 kinds of chunks due to the influence of the classic analyses of English, Japanese, Bengali, and Korean we've been discussing.

Defining clusters over tonal melodies while adopting the obligatory edge tone hypothesis also introduces the risk of hallucinating nonexistent phonological chunks because phonological chunks are not the only grammatical source of tones in natural language. What if the source of a tone is not due to a prosodic constituent, but some other grammatical source, e.g., as a reflex of morphosyntactic features? In initial work on the intonational phonology of Samoan (Orfitelli and Yu 2009), we immediately jumped to assuming the existence of the level of an intermediate phrase when we observed consistent sentence-medial high tones [38]. It was only in later analyses that we even considered that some of the sentence-medial high tones might have an alternative grammatical source—-the spellout of absolute case [39]. Gussenhoven and others also have an alternative analysis of American English intonation to Beckman and Pierrehumbert (1986)'s, where the intermediate phrase tone is instead parsed as a trailing tone of a pitch accent and there is no intermediate phrase level [40]. Ladd (2022) raises a similar issue in accounting how the idea that "boundary tones need not be part of a well-formed tonal string" got drowned out over the past few decade of the practice of AM theory [41, p. 251]. If the absence of boundary tones is tolerated in a tonotactic grammar, then adopting the obligatory boundary tone hypothesis would result in potentially missing the identification of phonological chunks.

4. Containment in tonal patterns

In the previous section, we began to take a derivational perspective by defining clusters in terms of the steps taken to generate tonal sequences. Further extending this perspective to considering phonological processes operating on tones is helpful to understand the typology of containment relationships. There are no processes defined in tonotactic grammars like Figure 2; such grammars express restrictions on the surface output tonal sequences. Instead, discussion of containment relations in the literature has centered on the ordering of different kinds of boundary tones. In output tonal sequences, a boundary tone delimiting a smaller domain should always precede the a boundary tone delimiting a bigger domain. For instance, Beckman and Pierrehumbert (1986) argue that English exhibits stacking of the intermediate phrase tone immediately followed by the intonational phrase tone at the end of each intonational phrase [34, p. 288]. Similarly, Hyman (1990) finds stacking of phonological phrase tones and intonational phrase tones in Kinande [42].

Complications for boundary tone containment relations arise with *concurrent boundary tone overriding*: a process that "triggers the deletion of boundary tones of smaller prosodic units when coinciding with the boundary tones of larger prosodic units" [6, p. 118-120]. The standard way to conceptualize boundary tones via a process is as a phrasal tone insertion rule [42]. If containment relations between phrasal tone insertion rules are respected, then we would expect, say, an accentual phrase boundary tone to be inserted when an intonational phrase boundary tone is, resulting in boundary tone stacking. If overriding occurs, then containment relations appear to be violated, at least on the surface. Overriding does seem to be reported fairly frequently, e.g., in Korean [19], French [43] (overriding of final accent), Bengali and other South Asian languages [6, 29], as well as Georgian [24]. To try to uncover a pattern for which languages exhibit overriding, it would be helpful to consider overriding together with other interactions of boundary tonal processes with processes involving lexical and/or grammatical tone, as well as segmental patterns [42, 44, 45].

5. Conclusions

Tonal patterns—especially the distribution of boundary tones—seem to enjoy a privileged, or even exclusive status for motivating prosodic constituents in the practice of AM-theoretic intonational phonology. We have stated this analytic bias as strongly as possible: that a span of segmental material is a phonological constituent if and only if it is delimited by at least one boundary tone. Discovering phonological constituents by noticing when tonal patterns cluster together in tonotactic grammars has been fruitful in work on intonational phonology. Assuming the obligatory boundary tone hypothesis and examining the consequences underscores the need for careful consideration in even how a boundary tone is defined, and the risks of missing domains marked by tonal patterns that are not boundary tones, or of hallucinating tonally-defined chunks if other grammatical sources of tones other than prosodic constituent boundaries are not considered. The continued growth of work representing segmental allophonic variation directly in terms of fine-grained, phonetic trajectories appears to be promising in understanding how segmental allophonic variation may yet be a reliable signal for prosodic constituency. But characterizing tonal patterns and processes symbolically in addition to via phonetic trajectories still promises to offer rich insights into prosodic typology.

6. References

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