The local nature of tone association patterns (DRAFT)

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1 Introduction

This paper argues that tone association patterns are fundamentally *local* over autosegmental representations (ARs) in a well-defined, computational sense. This notion of locality provides for an explicit theory of tonal well-formedness that is attractive compared to previous explanations in that it makes clear typological predictions that cover a broader range of attested patterns but does not predict unattested patterns which involve *global* calculations over the entire representation. Also, it provides a clear path for understanding how these patterns can be learned.

To illustrate, (1) gives two example patterns that are attested in tone and pattern that is unattested. The pattern in (1a) restricts multiple association to the right edge of the word (as in Mende; Leben, 1973, 1978; Dwyer, 1978) and (1b) shows multiple association on the left (as in Hausa; Newman, 1986, 2000).[1] Finally, an unattested pattern is given in (1c) in which a single H tone associates closest syllable to the center of the word:

(1)　　a.　HL　　HL　　　HL

　　　　b.　HL　　　HL　　　　HL

　　　　c.　LHL　　　LHL　　　　LHL

A theory of tonal phonology that is fundamentally local explains why (1a) and (1b) are attested but (1c) is not. The attested patterns can be described by *banned substructure constraints* which ban 'pieces' of ARs; for example, (2) identifies and bans a structure in which a nonfinal H has spread to more than one syllable (the exact notation will be discussed in §5).

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[1]The data in these languages will be discussed momentarily in §3.

(2) ¬(H)→(L)
        | \ /
       (σ) (σ)
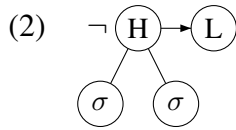
With such a structure banned, the initial H in (1a) cannot spread and so the L does instead. For (1b), in contrast, this structure would not be banned, leaving the initial H free to spread. The analyses in §5 of such *edge-based* patterns show how such patterns can be fully described by listing banned substructures like the one in (2). It is also shown how *positional* patterns, which refer to positions in the word, *quality-specific* patterns, which refer to specific tones, and *culminativity* patterns, which restrict the word to one of a type of tone, are all local in this way. However, banned substructure constraints cannot describe the pattern in (1c)—intuitively, this is because there is no finite set of substructures we can ban in order to ensure that the number of syllables on either side of the H tone are equal. Capturing this pattern instead requires *global* evaluation in that it is necessary to count the number of syllables on either side. Thus, a *computationally local* theory of tone excludes (1c) from the typology.

Some mention should be given to the adoption of ARs for tone, as they have recently been called into question (Cassimjee and Kisseberth, 1998; Leben, 2006; Hyman, 2014; Shih and Inkelas, 2014). There are several reasons for continuing to use ARs. First, as a theory of representation, ARs are the best-studied in terms of their formal properties (Bird and Klein, 1990; Coleman and Local, 1991; Eisner, 1997a; Kornai, 1995; Wiebe, 1992). More importantly, as to be seen throughout this paper, ARs straightforwardly capture relations between tone-bearing units (henceforth TBUs) that result in contours and 'plateaus' of adjacent TBUs that agree in tone. Any theory of representation must capture this, and it is thus extremely likely that the local autosegmental constraints on multiple association 'translate' into local constraints in alternative representational theories. For other arguments for ARs, the reader is referred to the substantial literature on this topic (ex., Goldsmith, 1976; Yip, 2002; Hyman, 2011, 2014).

This paper is structured as follows. §2 first introduces the computational notion of locality in terms of banned substructures in terms of strings. §3 then gives a brief typology of basic tone association generalizations. §4 extends the notion of banned substructures to ARs, and §5 demonstrates how each of the patterns in §3 are local by analyzing them with banned substructure grammars. §6 constrasts this result with previous theories of tone, which miss this local nature of the patterns. §7 then concludes.

2 Banned substructure grammars

The notion of locality central to the current proposal is based on *banning substructures*, and is drawn from work on logical characterizations of formal languages (Büchi, 1960; Rogers, 1998; Rogers et al., 2013; Thomas, 1982) and their application to well-formedness constraints in phonology (Graf, 2010a,b; Heinz, 2007, 2009, 2010a; Heinz

et al., 2011; Rogers et al., 2013).[2] Banned substructure grammars provide a *strong* theory of well-formedness (Heinz, 2007, 2010a) for which there are proven methods for inducing grammars from positive data only (García et al., 1990; Heinz, 2010a,b; Jardine and Heinz, 2016).

A banned substructure grammar is a statement of the following form:

(3) $\neg r_1 \wedge \neg r_2 \wedge \neg r_3 \wedge ... \wedge \neg r_n$

We interpret this notation, taken from logical characterizations of formal languages, to say "don't contain r_1, r_2, r_3, ..., or r_n". That is, given some universal set of structures, this statement specifies a subset of well-formed structures that contain none of r_1 through r_n. For example, let our universal set of structures be all logically possible strings of H- and L-toned TBUs. The following banned substructure grammar specifies exactly the set of strings which *do not* contain HLL as a *substring*, or contiguous 'piece' of a string.

(4) $\neg$HLL

To give an example pattern from tone that can be described with such a constraint, words in Kagoshima Japanese have exactly one high pitched syllable, either on the final or the penultimate syllable (Haraguchi, 1977; Kubozono, 2012). Thus, LLHL and LLLH are well-formed strings of syllables in Kagoshima (respective examples are [kagaríbi] 'watch fire' and [irogamí] 'colored paper' (Haraguchi, 1977)), but *LHLL is not. We can (partially) model this pattern with the banned subgraph grammar $\neg$HLL, which can be interpreted as saying "A H-toned syllable cannot be followed by two low-tone syllables."

Evaluating the well-formedness of a string with respect to this constraint has a straightforward cognitive interpretation (Rogers et al., 2013): for any string of H and L TBUs, whether or not it is well-formed with respect to the Kagoshima Japanese pattern can be checked by scanning the string with a window of size 3 to ensure that it does not contain the HLL substring. This, then, is the *local* nature of banned substructure constraints: well-formedness is based on contiguous structures of a specific size. This also allows for learning model for these constraints, as a learning algorithm only needs to scan through input data in this way in order to discover the pattern (García et al., 1990; Heinz, 2007, 2010a). A detailed description of such learners over strings and their applications to phonotactics can be found in Heinz (2010a).[3]

The remainder of this paper shows how this notion of locality can be extended to a theory of autosegmental well-formedness in tone. First, the following section surveys examples of major association generalizations in tone.

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[2]This is thus a significantly different notion of locality than the adjacency-based notion often proposed in phonology (c.f. Odden, 1994; Gafos, 1996; Chiośain and Padgett, 2001)

[3]The 'window size' for scanning and learning can be seen as coming from constraints on working memory (e.g. Miller's (1956) 'magical number' of 7 ± 2 objects). Thus, that the tonal patterns in this paper are describable by banned subgraphs up to six nodes in size can be explained by positing that the human phonological learning module can only pay attention to subgraphs of that size.

3   The typology

This section illustrates major types of association generalizations, broadly categorized as *edge-based*, *positional*, and *quality-sensitive* generalizations. A *culminativity* constraint on H tones in Hirosaki Japanese (Haraguchi, 1977) is also discussed.

3.1   Edge-based and positional association

Mende, spoken in Sierra Leone, is a classic example of an edge-based association pattern and one of the original arguments for treating tonal units independently of their TBUs. Tonal 'plateaus' of adjacent syllables with the same tone are limited to the right word edge, as are contours. The following are some examples. As throughout this paper, the standard notation is used; [á] (H) transcribes a high toned syllable, [à] (L) a low tone, [â] (F) a falling tone, and [ǎ] (R-F) a rising-falling toned syllable.

(5)   Mende word tone (Leben, 1973, 1978)
	a. mbû	'owl'	b. ngílà	'dog'	c. félàmà	'junction'
	F		HL		HLL	
	d. mbǎ	'companion'	e. nyàhâ	'woman'	f. nìkílì	'groundnut'
	R-F		LF		LHL	

In terms of ARs, plateaus are represented as *multiple association* of a single tone to multiple syllables and contours are represented as multiple association of multiple tones to a single syllable. The generalization then is that multiple association can only occur on the right edge of the word.[4]

(6)   F = HL   HL = HL   HLL = HL
         ↙ | | | ↘
         σ   σ σ   σ σ σ

      R-F = LHL   LF = LHL   LHL = LHL
             ↙ | ↙ | | |
             σ   σ σ   σ σ σ

In contrast to Mende, in the Chadic language Hausa (Newman, 1986, 2000), plateaus and contours occur on the left edge of the word, not the right. (As with Mende, there are exceptions, but this is the basic pattern.)

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[4]It was later noted by Dwyer (1978) that Mende does allow, among other things, multiple association on the left edge to the second syllable:

(i)   a. kónyô HF 'friend'
      b. séwúlò HHL 'rodent'
      c. lèlèmá LLH 'mantis'

Dwyer (1978) states that Leben's original analysis "account[s] for at least 90% of the modern Mende morphemes and probably 98% of Proto Southwestern Mande" (p. 185), and, as to be shown later in Footnote 7, accounting for these exceptions does not change the local nature of the pattern, this paper shall focus on Leben (1973)'s original generalization.

(7) Hausa word tone
    a. fáadì   'fall'   b. hántúnàa   'noses'   c. búhúnhúnàa   'sacks'
       HL   HHL   HHHL
    d. mântá   'forget'   e. káràntá   'read'   f. kákkáràntá   'reread'
       FH   HLH   HHLH

For example, while three-syllable HL words were pronounced HLL in Mende, they are HHL in Hausa. In autosegmental terms, this means that multiple association in Hausa is allowed at the left, and not the right edge:

(8)   FH = HLH   HLH = HLH   HHLH = HLH
             ⃥│   │││   ⟋││
            σσ   σσσ   σσσσ

However, association generalizations are not limited to referring to only the left or right edge. In the Northern Karanga dialect of Shona (henceforth simply 'N. Karanga'; Odden, 1986; Meyers, 1987; Hewitt and Prince, 1989), morphologically-based tone alternations on the verb result in a well-formedness pattern which refers to both edges. The pattern is summarized with the data from the N. Karanga NON-ASSERTIVE tense in (9) below. The pattern in question holds over the domain comprising the verb root and suffixes, ignoring the morphological complex /handáka/ 'I didn't', which comprise a different phonological domain. Maximally, a series of three H toned syllables is followed by an unbounded stretch of L toned syllables and a final H-toned syllable.

(9)   N. Karanga NON-ASSERTIVE tense

       a. hàndákà-p-á   'I didn't give'   H
       b. hàndákà-tór-à   'I didn't take'   HL
       c. hàndákà-tór-ès-á   'I didn't make take'   HLH
       d. hàndákà-tór-és-èr-á   'I didn't make take for'   HHLH
       e. hàndákà-tór-és-ér-àn-á   'I didn't make take for e.o.'   HHHLH
       f. hàndákà-tór-és-ér-ès-àn-á 'I didn't make take a lot for e.o.' HHHLLH
       g. hàndákà-tór-és-ér-ès-ès-àn-á (same as f.)   HHHLLLH

In autosegmental terms, the leftmost H associates maximally to the first three syllables, while the second H of the NON-ASSERTIVE tense associates only to the final syllable. Modulo the restriction that it cannot spread to the penult, the initial H spreads as close as it can to the third syllable. In this way, N. Karanga is also a *positional* generalization, as it refers to a particular syllable in the word.

3.2   Quality-sensitive association

Kukuya (Bantu, Kongo; Archangeli and Pulleyblank, 1994; Hyman, 1987; Zoll, 2003). Kukuya shows a very similar distribution of tone patterns as Mende, with the exception that *LHH forms are not possible, while instead LLH forms are. The following table (from Zoll, 2003, p.229) summarizes the Kukuya patterns.

(10)   Kukuya word tone patterns (Zoll, 2003)
         a. bá 'palms'   b. bágá 'show knives'   c. bálágá   'fence'
            H   HH   HHH
         d. kâ 'to pick' e. sámà 'conversation' f. káràgà   'to be entangled'
            F   HL   HLL
         g. sǎ ' knot'   h. kàrá 'paralytic'   i. mʷàrògí 'younger brother'
            R   LH   LLH   (*LHH)

The generalization here, as pointed out by Zoll, is that there is a *quality-sensitive* restriction on association: L tones may freely multiply associate, but H multiply associates just in the case that the only tone in the word. Thus, (10c) bálágá 'fence' is licit when *HHL is not. This generalization is clearer when looking at the autosegmental diagrams for three-syllable H-, LH- and HL-melody forms:

(11)   HHH = H   HLL = HL   LLH =   LH   * LH
              ⟍   ⎮ ⟍   ⟋ ⎮   ⎮ ⟍
              σσσ   σσσ   σσσ   σσσ

Note that whereas multiple association in contours only occurs on the right edge (e.g., (10k) LF [pàlî] 'goes out'), in terms of multiple association of tones, only L, and not H, can freely multiply associate. Thus, *LHH is illicit, but LLH is allowed. Thus, Kukuya is an example of a quality-sensitive well-formedness condition that refers to specific tonal phonemes (this terminology is due to Zoll (2003)).

3.3   A melody constraint: culminativity

Finally, constraints on the melody can operate independently of the number of TBUs. In Hirosaki Japanese (Haraguchi, 1977), there is a *culminativity* constraint in that there must be *exactly* one H tone on the melody tier.[5] The following data from Haraguchi (1977) exemplify this pattern. The relevant TBU for Hirosaki Japanese is the mora, including the moraic coda nasals, which can carry tone (e.g. in (12i) [tòránkù] 'trunk'). The relevant domain comprises both nouns and certain suffixes.

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[5]Kobayashi (1970) cites a variety called Hirosaki Japanese for which the intonational facts are quite different, involving spreading of the H tone. While the data cited there warrant further study, this paper focuses on the data from Haraguchi (1977).

(12) Hirosaki Japanese (Haraguchi, 1977, pp. 76–7)

Noun		Isolation	+Nom	Noun		Isolation
a.	'handle'	é	è-gá	f.	'chicken'	nìwàtòrí
		H	LH			LLLH
b.	'picture'	ê	é-gà	g.	'lightening'	kàmìnàrî
		F	HL			LLLF
c.	'candy'	àmé	àmè-gá	h.	'fruit'	kùdàmónò
		LH	LLH			LLHL
d.	'rain'	àmê	àmé-gà	i.	'trunk'	tòráṅkù
		LF	LHL			LHLL
e.	'autumn'	ákì	ákì-gà	j.	'bat'	kóòmòrì
		HL	HLL			HLLL

There are two major restrictions here. One is that there is must be exactly one H or F-toned mora in the word—if there is a F-toned mora, then there cannot be an H, and vice-versa. Additionally, F-toned mora can only appear word-finally; e.g., LHLL is attested in (12i) [tòráṅkù] 'trunk' and LLLF is attested in (12g) [kàmìnàrî] 'lightening' but *LFLL is not attested.

These restrictions become much clearer when looked at as ARs. If we view F-toned mora as mora multiply associated to an H and L tone, then the restriction on H- and F-toned mora reduces to the statement that there must be exactly one H tone on the melody tier.

(13)   *HLLF =* H LHL   *LLLL = *   L

          | ⟋⟍   ⟋⟍
         μμμμ   μμμμ

There is also a quality-sensitive restriction on multiple association: H cannot associate to multiple morae. That the falling contour is restricted to the right word edge can also be seen as a edge-based restriction of that only word-final morae can associate to multiple tones.

That in Hirosaki Japanese there *must* be *exactly one* H tone somewhere in the word makes this tone pattern 'long-distance', as the requirement holds over the entire length of the word. It is important to remember that, in terms of the melody tier in the AR, this 'long-distance' generalization can be reduced to a statement about the well-formedness of the melody tier that is independent of the number of TBUs to which it associates.

4   Locality and autosegmental representations

The preceding section illustrated how tone patterns can exhibit edge-based, positional, and quality-specific association patterns, as well as culminativity constraints. The remainder of the paper argues that these patterns are fundamentally local in the sense introduced

in §2, but in order to do this we need to extend the notion of banned substructure grammars to ARs. This section shows how this can be done by banning *subgraphs* of graph representations of ARs.

ARs are a kind of *graph* (Goldsmith, 1976; Coleman and Local, 1991; Jardine and Heinz, 2015), where a graph is a set of elements or *nodes* and a set of binary relations or *edges* over those elements. We can represent an AR as a set of labeled nodes with *undirected edges* representing association and *directed edges* representing precedence on each tier (marked below with arrows, like the representations of Raimy, 2000). This paper also assumes boundary elements, labelled #, denoting the beginning and ending of each tier. An example is given in (14c).

(14)   a. Word: félàmà   b. AR: HL   c. Graph:
               'junction'
               (Mende; =5c)
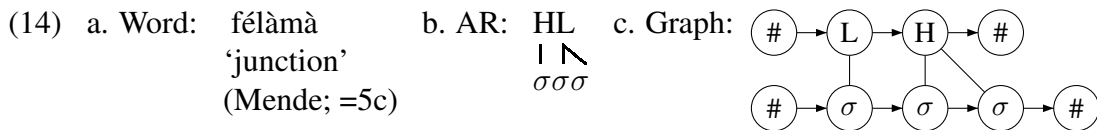
For visual clarity, boundaries will be omitted from most depictions of ARs.

Of course, not every graph is an AR, and this paper will assume a number of generally agreed-upon axioms for ARs. First, the elements are arranged into some number of tiers— for the purposes of this paper, two—and ordered on each tier (Goldsmith, 1976). Second, ARs obey the No-Crossing Constraint, which states that the association relation respects the orders on each tier (Goldsmith, 1976; Hammond, 1988; Coleman and Local, 1991). Third, ARs are *fully specified*; that is, all tones are associated to some TBU, and all TBUs are associated to some tone (Goldsmith, 1976). Finally, the representations here will all assume the Obligatory Contour Principle (OCP; Leben, 1973; Goldsmith, 1976; McCarthy, 1986), which states that adjacent melody tier units must be distinct. Full specification and the OCP have been argued against as a universals (see, e.g., Pulleyblank 1986 for full specification, Odden 1986 for the OCP), but they will suffice for the tone patterns discussed here, and the results of this paper do not depend on whether or not these properties are universal.[6] Formal definitions of all of the above properties can be found in (Goldsmith, 1976; Coleman and Local, 1991; Kornai, 1995; Jardine, 2014; Jardine and Heinz, 2015).

A substructure of an AR is thus a *subgraph*, a 'piece' of a graph. An example subgraph of (14c) is given below in (15a), as highlighted in (15b).

(15)   a.   b.

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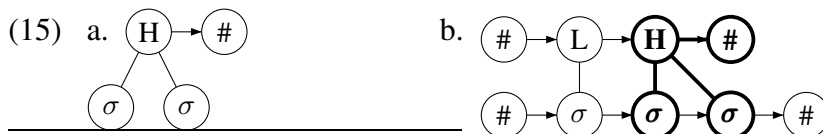
[6]Jardine and Heinz (in press) show that applying banned substructure constraints to structures with underspecification requires explicit marking of underspecified units, but also that this is no different than traditional formulations of phonological rules or constraints. The OCP can be stated as a series of banned substructure constraints; see §5.4.

Let us assume that subgraphs are *connected*, i.e., that one can travel from one node to any other node in the graph by following some path of edges (ignoring directionality of the directed edges). (Formal definitions of these concepts can be found in graph theory texts such as West 2000.)

Given that we have a universal set ARs and a notion of substructures of ARs, we thus can immediately extend the notion of a banned substructure grammar to ARs. The tonal patterns surveyed in this paper will thus be analyzed using statements of the form $\neg r_1 \wedge \neg r_2 \wedge ... \wedge \neg r_n$ where each r_i is a *subgraph*. For example, the following grammar has a single constraint which bans the subgraph in (15a).

(16)   ¬ (H) → (#)
       (σ) (σ)
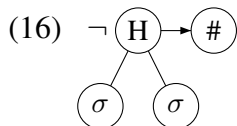
The grammar in (16) specifies the set of ARs which do not have multiple association of a final H tone. The following shows how grammars consisting solely of such constraints can capture the patterns discussed in §3.

5   Banned subgraph analyses of association patterns

This section shows how the the edge-based, quality-sensitive, and positional association well-formedness generalizations of tone mapping patterns in Mende, Hausa, Kukuya, N. Karanga, and Hirosaki Japanese discussed in §3 can all be described by banned graph grammars over ARs as defined in the preceding section. This demonstrates that all of these patterns are fundamentally *local* in the computational sense defined in §§2 and 4.

5.1   Edge-based and positional association

To begin with edge-based generalizations, recall that in Mende, multiple association can only occur on the right edge of the word, while in Hausa, it was restricted to the left edge of the word. The following contrasts well-formed ARs in the two patterns, repeated from (6) and (8) in §3 using the notational conventions introduced in §4.

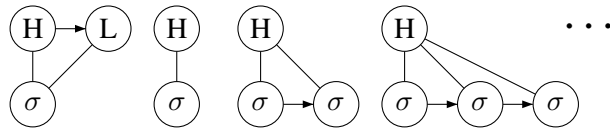(17)   ARs with multiple association on right edge (valid only in Mende)
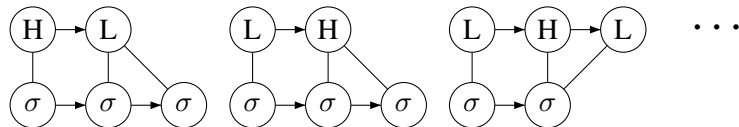
(18)   ARs with multiple association on left edge (valid only in Hausa)
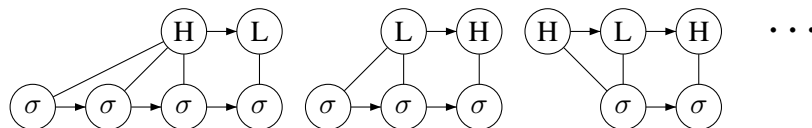
Of course, multiple association when there is a single TBU or a single tone in the melody is the same in both patterns (because it is both at the left and right edge).

(19) ARs valid both in Mende and Hausa

To begin by analyzing (17), we can recast the generalization negatively as the following two generalizations: *non-final tones do not multiply associate* and *non-final syllables cannot multiply associate*, where 'non-final' means not the last unit on its tier. The former can be by the following banned subgraph grammar:

(20) Grammar banning multiple association of non-final tones
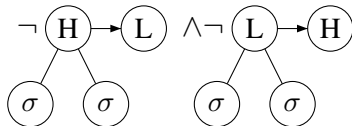
The subgraphs in the above grammar single out a non-final H and a non-final L, respectively, which are associated to multiple syllables.[7] (Again, because we are adhering to the OCP, a non-final H can only be followed by an L tone, and vice-versa.) Note that any AR in which association occurs anywhere besides the right edge will contain one of these subgraphs, as highlighted below in (21). Note that (21a) and (21b) are valid ARs in Hausa.

(21) a. * b. * c.*
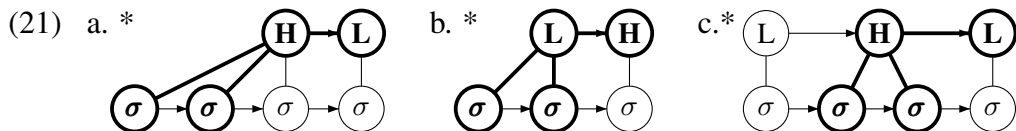
Even though the structures in (20) only refer to two timing tier units, they ban graphs like in (21) with plateaus on the left edge no matter the length of their plateau (as in (21a)). Note that all of the valid Mende ARs in (17) or (19) are well-formed with respect to (20) because they contain neither of these subgraphs.

Next, we also want to ban nonfinal contours. This can be by banning the subgraph in (22), which picks out a multiply-associated syllable followed by some other syllable.

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[7]Footnote 4 discussed data in Mende in which a non-initial tone can, in fact, associate to two syllables. To allow association to one or two syllables, we can replace (20) with the following:

(i) ¬
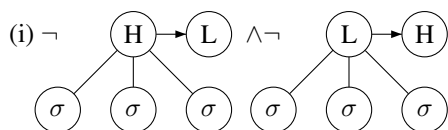
Note the lack of a directed edge between the H and L nodes in (22); this means that both falling and rising contours are matched by this subgraph, as the reader can confirm in the examples in (22a) and (b).

(22)   Grammar banning non-final contours

(23)   a. *   b. *   c. *
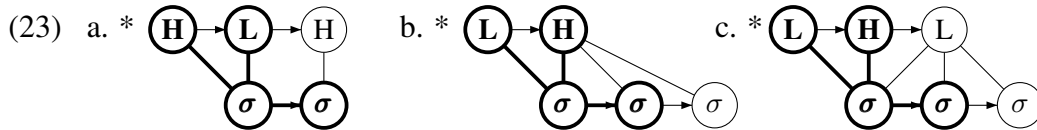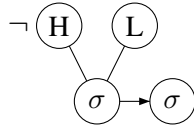
   Note that (22) also bans non-final LHL contours as well, as such a structure is a superstructure of (22). An example is given in (23c). The graph in (23c) contains two instances of (22), but just the first instance is highlighted.
   Thus, to capture the right edge-based generalization of Mende, we take the conjunction of the grammar in (20) banning association of non-final tones with the gramar in (22) banning non-final contours.

(24)   Mende banned subgraph grammar
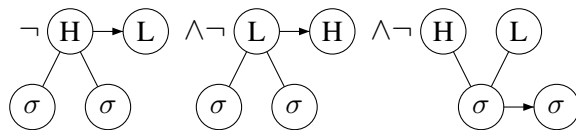
   As explained above, this distinguishes the set of ARs that are well-formed with respect to Mende (such as the examples in (17) and (19)) with those that are not (such as the examples in (18)).
   The Hausa pattern, then, can be captured with subgraphs targeting multiple association on the opposite edge—that is, a banned subgraph grammar forbidding *non-initial* spreading and *non-initial* contours. This statement is given below in (25).

(25)   Hausa banned subgraph grammar
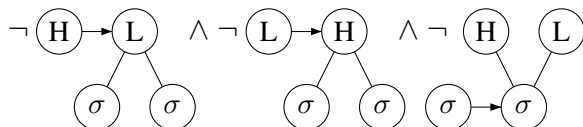
   Note that each of these subgraphs are essentially the mirror images of those for the Mende grammar in (24): the former two subgraphs match non-initial spreading tones, and the final subgraph matches a non-initial contour. As with the three edge-based constraints

in Mende, banning these three subgraphs will be enough to capture the generalization that multiple association can only occur on the left edge. Note that in both the grammars for Hausa and Mende, spreading of H and L tones are treated separately; that is, they are referred to with separate subgraphs. This shall be taken advantage of later in the analysis for the quality-sensitive association pattern in Kukuya, which will use both subgraphs representing multiple association of H from the Mende and Hausa patterns.

Finally, the generalization referring to both edges in N. Karanga can be analyzed in the following way. Recall from §3.1 that H-toned Karanga verbs in the NON-ASSERTIVE tense have a pattern in which H tones associate to the initial and final syllable, with the initial H maximally spreading up until the third syllable.

(26) Valid ARs in N. Karanga NON-ASSERTIVE association pattern
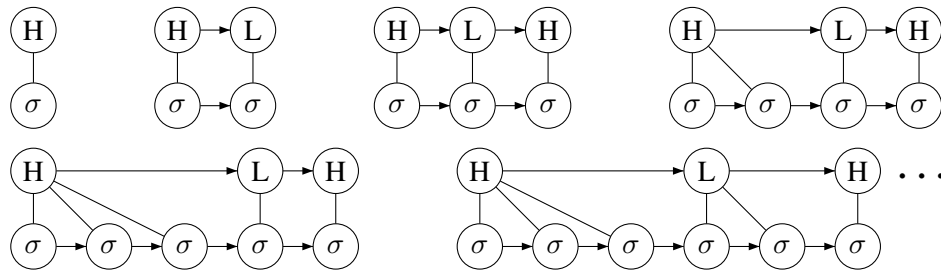
First, there are three possible tone melodies, H, HL, and HLH, depending on the number of syllables in the word. This generalization can be restated in negative terms as follows: there are no initial L tones, and no LHL sequences on the melody tier. These constraints on the melody are captured by the statement in (27).

(27) Banned subgraph grammar for N. Karanga melody
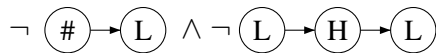
There are also several constraints on association. First, there are no contours. Second, a final H tone never multiply associates. Third, no H tone associates to more than three syllables. These three constraints can be stated, respectively, with the three banned subgraphs in (28).

(28) Banned subgraph grammar for N. Karanga association
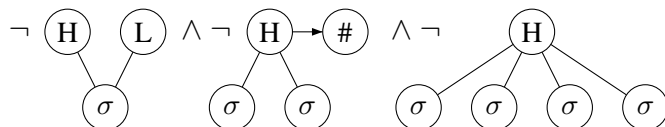
Note that banning the second structure in (28) ensures not only that a final H only associates to one syllable (as demonstrated by (29a) below), but also that bisyllabic or longer forms must include an L. Examples of this are given in (29b) and (c).

(29) a. *

b. *

c. *
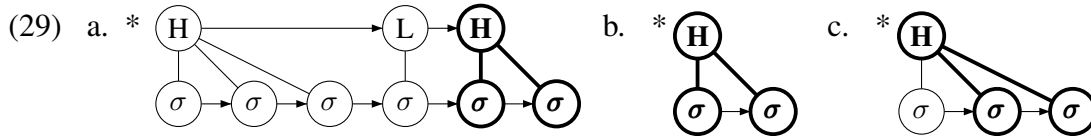
The final banned subgraph in (28) excludes structures in which the *initial* H has associated to four or more syllables, as in (30) below.

(30) *
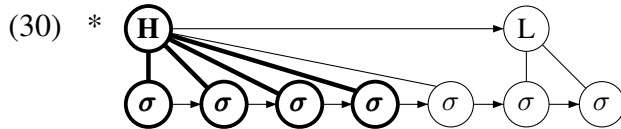
These are the only restrictions on H associations that we need to consider. The remainder of the constraints deal with where the medial L can associate. For associations with L, there are two important generalizations. First, an L does not associate to the final syllable in words of three syllables or more. Second, an L tone associated to the second or third syllable cannot multiply associate. These two generalizations are captured by the series of banned subgraphs in (31).

(31) Banned subgraph grammar for position of L in N. Karanga
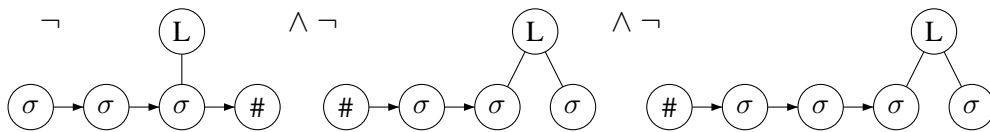
Banning the first subgraph in (31) ensures that an H must associate to the final syllable in trisyllabic or longer words. (An L does not associate to the final syllable in monosyllabic words, but this is subsumed under the generalization, covered by (27), that there is no initial L.) The second and third banned subgraphs in (31) motivate the tertiary spreading of the H in forms of five syllables or more by restricting multiple association of the medial L when it is associated to the second and third syllable. This ensures that the associations to the second and third syllable, respectively, are 'filled in' by the initial H.

Thus, a combination of the melody constraints in (27) and association constraints in (28) capture the edge-based generalization that N. Karanga NON-ASSERTIVE verbs have H tones at the right edges, and the constraints on where L associates in (31) capture the positional generalization that the initial H maximally associates to the third syllable. The N. Karanga association pattern can thus be described with a banned subgraph grammar comprised of the conjunction of (27), (28), and (31).

5.2   Quality-sensitive association

Quality-sensitive association generalizations are local in the same way. Recall that in Kukuya, multiple association of H is disallowed in the presence of an L tone, but is
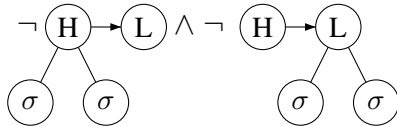
allowed when H is the only tone on the melody tier, as illustrated in (32). We can capture this by banning subgraphs we have already seen used in Mende and in Hausa.

(32) Well-formed ARs in Kukuya
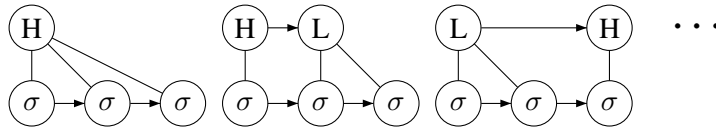
In other words, a H from spreading when it is either nonfinal or noninitial. Thus, we can capture the Kukuya generalization by banning multiple association of a nonfinal H, as in the grammar (24) for Mende, and by banning multiple association of a noninitial H, as in the grammar (25) for Hausa.

(33) Grammar banning multiple association of H in presence of L

This bans any spreading of an H in the presence of L, but allows spreading in case H is the only tone on the melody tier, as is illustrated below in (34).

(34) *
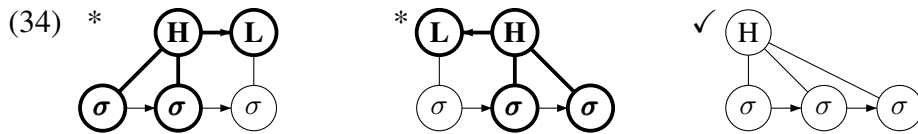
Crucially, the banned subgraphs in (33) capture that H and L behave independently with respect to spreading: H cannot spread if it is noninitial or nonfinal, whereas L can spread in both of these situations. Note, however, that with only these constraints, L is allowed to spread freely. To prevent this spreading from creating unwanted contours (such as in (35b) below), we must also ban the subgraph in (35a). Note that, as the order between the L and H in the subgraph is not specified, (35a) prevents both falling and rising contours produced this way.

(35) a. ¬
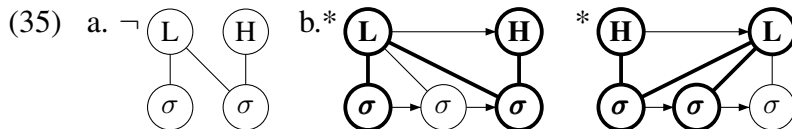
Finally, like Mende, Kukuya allows contours only on the right edge. The full grammar for Kukuya is thus as in (36), with banned subgraphs representing the constraints on H, L, and non-final contours.

(36) Kukuya banned subgraph grammar

$$\neg\ \overset{H}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{L}{\bigcirc}\ \wedge\ \neg\ \overset{H}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{L}{\bigcirc}\ \wedge\ \neg\ \overset{L}{\bigcirc}\ \overset{H}{\bigcirc}\ \wedge\ \neg\ \overset{H}{\bigcirc}\ \overset{L}{\bigcirc}$$
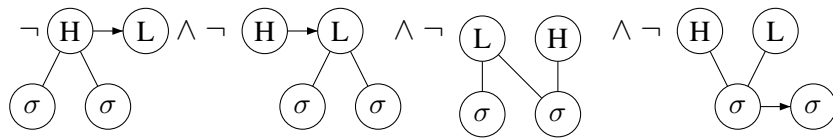
Thus, the quality-sensitive association generalization in Kukuya is also local in that it can be captured by banned substructure grammars.

5.3 Culminativity

Recall from §3.3 that in Hirosaki Japanese (Haraguchi, 1977) words, at most one H or F can appear in a word, and F may only appear word-finally. Each word must contain either a H or F, and cannot contain both. Interpreting these using ARs, these restrictions on H can be handled by banned substructure constraints on the melody tier. Falling contours are restricted to word-final TBUs. Some examples are given below.

(37) Well-formed ARs in Hirosaki Japanese
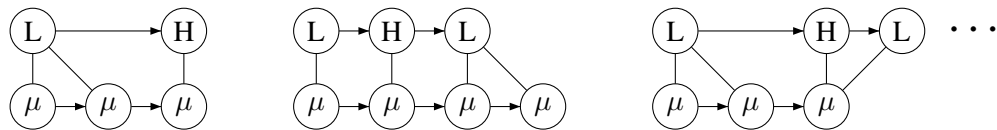
First, the following constraints on the melody ban words with no H tones or more than one H tone.

(38) Grammar specifying exactly one H in the melody

$$\neg\ \overset{\#}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{L}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{\#}{\bigcirc}\ \wedge\ \neg\ \overset{H}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{L}{\bigcirc}\!\!\!\rightarrow\!\!\!\overset{H}{\bigcirc}$$

The former bans words without H tones because, assuming the OCP, any AR equivalent of any string of L tones will have a single L in the melody tier. Some examples are given in (39a). Similarly, for any string with more than one H- or F-toned TBU, such as *HLLLH, or *LHLF, its corresponding graph will contain the latter subgraph in (38). This bans any such graph, no matter how many L-toned TBUs intervene between the two Hs on the melody tier, as illustrated in (39b).

(39)   a. *   b. *
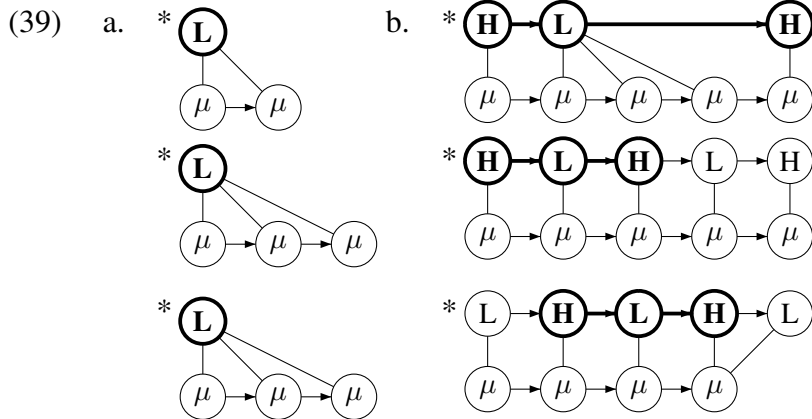
Thus, the melody for the set of APGs in the Hirosaki Japanese pattern can be specified by the banned subgraph grammar in (38).

However, we must also restrict the associations of the melody nodes to TBUs. First, the H tone in Hirosaki Japanese does not spread at all. ARs in which a H tone associates to multiple TBUs can be excluded by the banned subgraph in (40a), as exemplified in (40b).

(40)   Banned subgraph grammar for multiply-associated H

    a. ¬   b. *
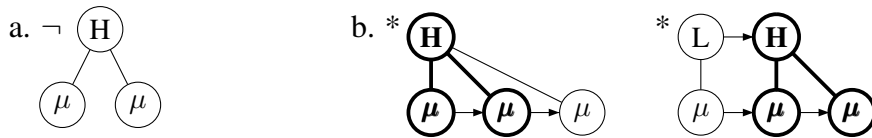
Finally, only falling contours occur in Hirosaki Japanese, and they only occur on the final TBU. These generalizations can be captured, respectively, by a banned subgraph specifying a LH sequence associated to a single TBU (i.e., a rising contour) and the banned subgraph specifying a non-final contour seen above in Mende and Kukuya (modulo the labeling of the TBU).

(41)   Banned subgraph grammar governing contours in Hirosaki Japanese
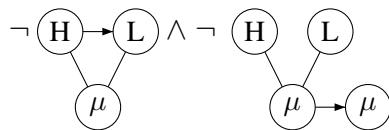
The 'long-distance' pattern of Hirosaki Japanese can thus be fully described by the conjunction of banned subgraph grammars in (38) governing the obligatoriness and culmanitivty of H in the melody and in (40a) and (41) governing association of tones to TBUs.

5.4   Discussion

This section has shown how edge-based, positional, and quality-sensitive association generalizations, as well as generalizations referring to the melody independent of TBUs, are all describable by banned substructure grammars. This means that these patterns are fundamentally *local* in the computational sense defined in §§2 and 4. The largest subgraph for any grammar had 6 nodes, required for (31) in N. Karanga. Most of the other subgraphs were of 4 or 5 nodes.

A particularly interesting result is the locality, when viewed over ARs, of the Hirosaki Japanese pattern, which is *non*-local over strings. Intuitively, this is because there is no finite set of substructures we can ban to remove the set of strings of only L-toned TBUs:

(42)   *L, *LL, *LLL, *LLLL, *LLLLL, ...

As mentioned above, with ARs and the assumption that the OCP holds, these can all be marked as ill-formed by banning a #L# melody, because assuming the OCP means that all adjacent L-toned TBUs are associated to the same L on the melody tier. It is this same assumption allows the constraint against a HLH substructure in the melody to enforce the absence of two H tones in the melody. This is consistent with the notion that ARs can reduce long-distance generalizations to local ones (see, e.g., Odden, 1994), although in a different way.

Of course, as mentioned in §4, the OCP has been argued against as a universal (e.g., by Goldsmith (1976) and Odden (1986)). However, if we make the OCP a language-specific constraint, it is still local, as it can be described (assuming H and L tones) with the following banned substructure grammar.

(43) $\neg$ (H)$\rightarrow$(H) $\wedge\neg$ (L)$\rightarrow$(L)

We would then posit that the above constraints are also active in Hirosaki Japanese.

Finally, these grammars can be efficiently learned using an algorithm similar to those using a 'scanning window' described in §2, with the only difference being that the algorithm needs to scan for connected subgraphs in the input. This is known to be efficient for graphs in general (Ferreira, 2013). Also, such an algorithm can learn autosegmental grammars from string input, as (given the assumption that the OCP holds) strings can be directly related to ARs (Jardine and Heinz, 2015).

6   The non-local nature of previous approaches to tone

Adopting the banned substructure notion of locality as a *theory* of autosegmental well-formedness in tone makes specific typological predictions: a well-formedness pattern should not be attested if it cannot be described in terms of the presence or absence of banned substructures. As shown in the preceding section, this gives a unified explanation

of the attested typology. Furthermore, as discussed in §2, the notion of banned substructures is *restrictive* due to the computationally simple nature of evaluation, and it is also learnable.

These are all significant advantages over previous theories. For example, derivational frameworks require at least a globally-evaluated directionality parameter to capture right- and left-edge-based patterns (one such formalization can be found in Archangeli and Pulleyblank, 1994), but the typology is less clear when other patterns are considered. For the two-edged pattern in N. Karanga, Hewitt and Prince (1989) further define an 'edge-in' association paradigm, which is based on, but distinct from, a paradigm used by Yip (1988). This proliferation of language-specific association paradigms makes it unclear what the typological predictions of a derivational theory is, as there are no clear constraints on what constitutes a possible paradigm.

Furthermore, analyses in derivational frameworks often miss the surface generalizations. Hyman (1987)'s analysis of Kukuya depends on a language-specific rule to 'fix' a multiply-associated H created through left-to-right association:

(44) Kukuya L-Spreading (Hyman, 1987, p. 316, (7))

$$\begin{array}{lll}
\text{L H} & \rightarrow \text{L H} & \rightarrow \text{LLH} \\
| \quad \backslash\!\backslash & \quad\, \backslash\!\!\backslash & \\
\sigma\,\sigma\,\sigma & \quad \sigma\,\sigma\,\sigma &
\end{array}$$

Zoll (2003) rightly criticizes this analysis for missing the surface generalization that H could not spread in the presence of an L tone. However, this insight is directly captured with the banned substructure constraints in (36) which forbid the multiple association of a H that is either followed by, or preceded by, a L tone. In this way, the banned substructure grammar preserves the insight (originally attributable to Zoll) that H and L can behave independently of some general directional association paradigm.

Zoll (2003)'s theory of Optimal Tone Mapping insightfully captures such surface generalizations through using CLASH and LAPSE constraints to capture quality-specific generalizations and ALIGN constraints (McCarthy and Prince, 1993) to capture edge-based generalizations. However, ALIGN constraints are problematic for two reasons. One, as Zoll (2003) admits, they cannot capture the positional N. Karanga pattern. Two, the global evaluation of ALIGN constraints predicts bizarre patterns (Eisner, 1997b; McCarthy, 2003). For example, Eisner (1997b) gives a constraint belonging to the ALIGN family which produces the 'centering' of association of H tone to the middle of a word originally given in (1c). As mentioned following that example, banned substructure grammars disclude such patterns, because it makes the strong claim that evaluation of a structure is based only on the well-formedness of its substructures.

One potential criticism of analyses based on banned subgraph grammars is that they explain patterns exclusively through surface constraints, whereas previous theories have explained the patterns through the mapping of an underlying, unassociated melody to a fully associated one. However, this is not a drastic departure from previous theories as

it may seem. For example, Zoll (2003)'s OTM analyses entirely depend on the ranking orders of MARKEDNESS constraints governing surface well-formedness, with the relative ranking of FAITHFULNESS playing no role in language-specific variation. This highlights that language-specific variation in these tone association patterns is, essentially, variation in surface well-formedness. Furthermore, although the present analysis focuses on the local character of this surface variation, it does not reject this view of association patterns as mappings. Indeed, Chandlee (2014); Chandlee et al. (2014) show how surface locality based on substrings can be extended to string-to-string mappings. How this can be done for AR-to-AR mappings is an important goal for future work.

7 Conclusion

This paper has defined a notion of locality for surface association patterns over autosegmental representations based on the notion of banned subgraphs. It then demonstrated that major edge-based, positional, quality-sensitive, and culminativity-based generalizations in tone are local in this way through banned subgraph analyses of patterns in Mende, Hausa, N. Karanga Shona, Kukuya, and Hirosaki Japanese. This notion of locality not only appears to be sufficient to capture major patterns, but as it is based on the well-formedness of substructures it is also restrictive in its typological predictions in comparison to previous theories of tone, and, as discussed in §§2 and 5.4, it is learnable.

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