On the locality of vowel harmony over multi-tiered autosegmental representations

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1 Introduction

This qualifying paper aims to investigate the locality of vowel harmony patterns over autosegmental representations (ARs) using Jardine (2017)'s forbidden substructure constraints (FSCs) over ARs. The investigation will provide a well-defined, computationally motivated theory of well-formedness in vowel harmony. Jardine (2017) developed a theory of tonal well-formedness and determined that tone patterns are fundamentally local over two-tiered ARs. Investigating the locality of vowel harmony patterns will determine the expressive power of multi-tiered ARs and allows for a theory of well-formedness that makes accurate typological predictions.

A goal shared by all of generative phonology is to distinguish attested patterns from logically possible, but unattested ones. A theory of well-formedness in vowel harmony that accomplishes this goal must be both expressive enough to explain the attested typology of vowel harmony patterns and restrictive enough to exclude the logically possible unattested vowel harmony patterns. This qualifying paper will adopt a formal language theory approach that provides explicit ways of determining the expressivity and restrictiveness of phonological patterns.

1.1 The formal language theory approach

The goal of distinguishing attested phonological patterns from possible unattested patterns is currently being investigated using formal language theory to determine the expressive power required to compute phonological patterns in general. The Chomsky hierarchy, in (1), classifies stringsets in terms of the relative expressivity of the grammars needed to generate them. Each class that is lower on the hierarchy is also a proper subset of the class above it.

(1) The Chomsky Hierarchy:
Finite $\subsetneq$ Regular $\subsetneq$ Context-Free $\subsetneq$ Context-Sensitive $\subsetneq$ Computably Enumerable

A significant body of work in computational phonology shows that phonological generalizations are properly contained within the regular class of stringsets (Heinz & Idsardi, 2013). Recent work has further established a subregular hierarchy of stringset classes, i.e. star-free (SF) and weaker classes (Heinz, Rawal, & Tanner, 2011; Rogers & Pullum, 2011; Rogers et al., 2013). A generative phonlogical theory must be expressive enough to predict the regular patterns and restrictive enough to rule out patterns that fall into a larger class, such as context-free. The classifications of stringsets and ARs in this manner are not directly comparable, but Jardine (2018; following Jardine and Heinz, 2015) provides a method for comparing the expressivity of the grammars that generate them. Jardine (2018) establishes a sub-SF class of "forbidden k-factor grammars" over ARs, ASL^{g}, that is expressive enough to capture a range of attested tone patterns (ASL^{g_T}). The ASL^{g_T} class includes patterns that would also fall within three different subregular stringset classes: strictly local (SL), tier-based strictly local (TSL), and strictly piecewise (SP). The goal of this qualifying paper is to determine whether or not the typology of vowel harmony patterns must be captured by a class of grammars, using ARs with more than two tiers, that is more expressive than the $\mathrm{ASL}^{\mathrm{gT}}$ class.

Patterns represented with multi-tiered ARs demonstrate whether or not enriching the representation necessarily increases the expressivity of a grammar. Representations of vowel harmony refer to subsegmental features, which will be represented using multiple featural tiers, such that each feature occupies a separate tier that is associated to a vowel on the segmental tier (following Clements, 1976; McCarthy, 1988). Such ARs include at least one additional tier compared with the ARs of tone patterns, which utilize only two tiers (Jardine, 2016, 2017, 2018). This qualifying paper will determine whether or not enriching ARs in this way increases the expressivity of a grammar such that it falls outside of the previously established $\mathrm{ASL}^{\mathrm{gT}}$ class. Four aspects of multi-tiered ARs of vowel harmony are investigated: the complexity of vowel harmony patterns with neutral vowels in Akan and Finnish, and generalizations that include domain information like in Turkish, the locality of an asymmetry between harmony triggers and undergoers in Baiyina Oroquen (Walker, 2014a), and whether or not multi-tiered ARs predict the generation of an unattested pattern: “sour grapes” (McCarthy, 2011; Padgett, 1995; Walker, 2010). Each of these investigations will provide additional evidence of the expressive power needed for a grammar to generate vowel harmony patterns.

Vowel harmony can be viewed either as an input-output map or as a phonotactic “cooccurrence restriction upon the vowels that may occur in a word” (Clements, 1976). A hierarchy that classifies sets of ARs, based on the Chomsky and related subregular hierarchies, differs significantly from a parallel hierarchy for sets of pairs of ARs, such as in a transformation (or map) from underlying to surface form. Previous analyses use ARs to describe vowel harmony patterns as the spreading of a vowel feature from one vowel throughout the word until it is blocked (Clements, 1976; Goldsmith, 1976; McCarthy, 1988; Padgett, 2002; Sagey, 1986; vanderHulst, 2017; Walker, 2010, 2014b). Clements (1976)’s well-formedness condition motivates feature spreading in order to ensure that all elements on one tier of an AR are connected via an association relation to some element on another tier of the same AR. The result is an AR in which all elements on one tier are associated to some element on another tier. A majority of scholars have thus viewed vowel harmony as mapping an input with a vowel feature associated to one vowel onto an output where that same feature is associated to multiple vowels.

This qualifying paper constitutes the first in-depth formal language theoretic study of vowel harmony as a phonotactic restriction rather than an input-output map. ARs within the Chomsky-based hierarchy cannot be compared with sets of pairs of ARs within a separate hierarchy. In order to compare vowel harmony with other patterns classified within the subregular hierarchy of ARs this qualifying paper will be taking a slightly different approach than has been taken before by evaluating only the restrictions on output substructures. While vowel harmony has been considered a derivational process, this paper will aim to determine the locality of only the surface restrictions on vowel harmony patterns over ARs. The harmonizing ARs that will be examined contain at least one feature that is associated to more than one vowel, as it would be on the surface. Ignoring input structures in this way allows for the classification of vowel harmony within the sub-SF hierarchy of patterns, which allows for the comparison of vowel harmony with other phonological patterns that have been classified on the same hierarchy, such as tone in Jardine (2018).

1.2 Motivating Autosegmental Representations (ARs)

This qualifying paper will determine the locality of surface restrictions on vowel harmony patterns over multi-tiered ARs by investigating whether they can be captured using Jardine (2017)'s "forbidden substructure constraints"(FSCs). FSCs are defined as surface markedness constraints (OT; Prince & Smolensky, 1993, 2004), "which ban pieces of autosegmental representations" (Jardine, 2017, p. 1). FSCs serve as a type of phonotactic restriction such that "well-formedness is based on contiguous structures of a specific size" (Jardine, 2017, p. 3). One can use FSCs as a definition of locality because they refer to elements within a structure that are connected by either an ordering or association relation. A phonological pattern is thus local if it can be described with FSCs because it can be captured by referring to a subset of the elements within structures and their connections. Jardine (2017) uses FSCs to show that attested tone patterns are local in this way.

1.2.1 Multi-tiered ARs. Autosegmental representations (ARs) of tonal patterns generally consist of two tiers: the TBU and segmental tiers (Goldsmith, 1976; Jardine, 2016, 2017), but an open question that remains is: From a formal perspective, what is the range of patterns that can be represented using more than two autosegmental tiers? This paper investigates the expressive power needed to represent one such set of patterns. Vowel harmony patterns refer to subsegmental features, which will be represented using multiple featural tiers; each feature occupies a separate tier that is associated to a vowel on the segmental tier (following Clements, 1976; McCarthy, 1988). For example, assuming binary features, vowel features like [± back], [± high], etc. are represented on separate tiers and associated to a vowel on the segmental tier, as in (2). Association relations are represented by straight lines that connect elements (segments and features) on different tiers. Where a tier consists of multiple elements, the successor ordering relation between elements on that tier is represented by arrows.

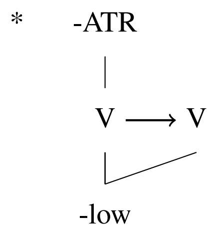
(2)

$$\begin{array}{c} \pm\ \text{high} \\ | \\ \text{V} \\ | \\ \pm\ \text{back} \end{array}$$

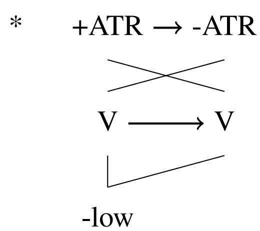
The goal for this project is to extend the work of Jardine (2017) to determine whether vowel harmony patterns are local over ARs with more than two tiers, as in (2). This qualifying paper evaluates whether or not the restrictions on attested vowel harmony patterns can be captured using FSCs that contain elements of more than one feature tier.

1.2.2 Representational assumptions. Use of ARs requires discussion of at least some of the basic representational assumptions held throughout this paper. The basic assumptions are taken from Clements (1976)'s Well-Formedness Condition, which includes stipulations of *Full Specification* (FS), the *No Crossing Constraint* (NCC) (Goldsmith, 1976; Sagey, 1986), and the *Obligatory Contour Principle* (OCP) (Leben, 1973). Examples of structures that violate each of these assumptions are shown in (3)-(5) below.

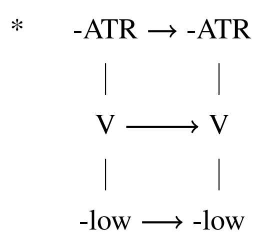
(3) Violates FS



(4) Violates NCC



(5) Violates OCP



First, FS means that each featural element must be associated to at least one vowel on the segmental tier and each vowel on the segmental tier must be associated to at least one element on a featural tier. FS crucially allows vowels to be associated to multiple featural tiers as is necessary for each vowel feature to occupy its own tier. The hypothetical representation in (3) straighforwardly violates FS because there is a vowel that is not associated to any feature on the ATR tier. While both vowels are associated to a single -low feature, the second vowel is not associated to any feature on the ATR tier. Since vowel harmony patterns will be analyzed, it will be assumed that consonants cannot be associated to vowel features and that FS and vowel harmony in general ignore consonantal elements on the segmental tier.

Second, the NCC states that association lines between the segmental tier and a feature tier never cross. Odden (1994) adds that the NCC can only evaluate the association between the segmental and one featural tier at a time. The representation in (4) violates the NCC because +ATR precedes -ATR, but is associated to a vowel that is preceded by a vowel associated to -ATR; this configuration creates visually crossed association lines.

A notable effect of FS along with the NCC is that they prevent what have been called gapped structures (Archangeli & Pulleyblank, 1994; Ringen & Vago, 1998). A gapped structure is one in which a feature appears to have skipped over a vowel that it could potentially be associated to. FS would prevent gapped structures in which the "skipped" vowel is not associated to anything on that particular feature's tier. The NCC would prevent gapped structures in which the surrounding two vowels are associated to the same feature and the "skipped" vowel is associated to a different feature on the same tier.

Lastly, the OCP stipulates that adjacent featural elements must be distinct. The representation in (5) violates the OCP because on both the ATR and low feature tiers there are two identical adjacent features, -ATR and -low respectively. The OCP in conjunction with FS results in representations where multiple adjacent vowels are associated to a single feature rather than having multiple adjacent iterations of the same feature each associated to a single vowel. An example representation of an Akan word that satisfies all of the AR properties discussed here is shown in (7).

Both the NCC and the OCP have also been derived via a concatenation operation (○) that merges autosegmental "graph primitives"(Jardine & Heinz, 2015, p. 1). An autosegmental graph primitive consists of an element on the segmental tier, the elements on each feature tier and the associations between the featural and segmental tiers. The concatenation operation combines a finite set of adjacent graph primitives to generate a fully specified AR. For example, the AR in (7) is derived from the set of graph primitives in (6). Each primitive in (6) is concatenated with a single adjacent primitive. If two adjacent primitives share an identical feature those two features are merged into one feature with two associations, as in (7). The merging of identical adjacent features essentially prevents surface ARs from having multiple iterations of a feature and crossed associations, thus satisfying both the OCP and the NCC. However, if two segmental elements are associated to the exact same feature and a different element intervenes then both iterations of that feature will occur in the surface AR because only adjacent primitive elements are concatenated and can thus be merged. This qualifying paper will show that an intervening element can be a vowel associated to the same feature with a different value or a domain boundary. It will further show that a domain boundary primitive may include that boundary on both segmental and feature tiers.

(6) Concatenation of adjacent autosegmental graph primitives

$$\begin{array}{ccccc} & & \text{-ATR} & & \text{-ATR} \\ & & | & & | \\ \text{t} & \circ & \text{i} & \circ & \text{e} \\ & & | & & | \\ & & \text{-low} & & \text{-low} \end{array}$$

(7) Satisfies FS, NCC, and OCP

-ATR

$$t \longrightarrow i \longrightarrow e$$

-low

Again, the initial consonant in (7) cannot be associated to a vowel feature so, while it is ordered with respect to the vowels, FS does not require the consonant to be associated to any element on either feature tier. The AR of *tie* satisfies FS because each vowel is associated to a feature on each of the featural tiers and all features are associated to at least one vowel. The AR of *tie* also satisfies both the NCC and the OCP because there is only one of each feature. The features are represented on separate tiers so association lines cannot cross and there is nothing else on those tiers that could violate the OCP. In addition, (3)-(7) illustrate that, unlike the usual notation, this paper will be adding a representation of the successor ordering relation on each tier using arrows.

1.3 Assimilation Mechanisms

Vowel harmony has previously been analyzed as an assimilatory process that results in multiple vowels being associated to the same feature on the surface. Such assimilation can result from the spreading of vowel features throughout a word or agreement between non-adjacent vowels. This qualifying paper will show that both spreading and agreement generate vowel harmony patterns on the surface, and all such patterns are captured by a uniform theory of markedness constraints. In the vowel harmony literature, the term “spreading” has generally referred to an assimilatory process that transforms underlying ARs with underspecified vowels into surface ARs in which at least some vowels are associated to a single feature. On the surface, the result of a spreading process over ARs is a structure in which a single feature is associated to multiple vowels on the segmental tier, as in (7) above. The surface result of an agreement process over ARs is a structure in which two non-adjacent vowel features on the same tier have identical binary values, as in the simplified AR of a Finnish word in (8a). In this paper, the term “spreading” will refer to the resulting multiple association of features rather than the process that derives such structures. Similarly, “agreement” is used here to refer to surface ARs with non-adjacent identical features, as in (8a).

(8) Agreement

(a)
```
     +back ──────→ -back ─────→ +back
       |             |            |
r ───→ u ───→ v ───→ e ───→ t ───→ a
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(b)
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        +back           -back        +back
          |               |            |
r   ○     u    ○    v   ○  e   ○  t  ○  a
```

On the surface, both spreading and agreement are derived via the concatenation operation, as shown in (6) and (8b), respectively. In (6), adjacent identical features are merged to generate multiple association. In (8b), multiple iterations of a +back feature are possible when a primitive with a -back feature intervenes between two primitives with +back features. The AR in (8b) is possible because each primitive is only concatenated to a single primitive that is directly adjacent to it. Both the spreading and agreement ARs satisfy FS, the NCC, and the OCP.

It will be shown that vowel feature assimilation patterns that result from both spreading and agreement are local because they are generated by FSCs. FSCs are markedness constraints that represent the phonotactic restrictions of a language and can further demonstrate the expressive power of a particular representation. This paper will use FSCs to capture both spreading and agreement surface patterns. Thus vowel harmony can be considered a single set of patterns despite being derived by different assimilatory processes because all surface vowel harmony patterns are generated by a single theory of markedness.

2 Neutral vowels

In languages that exhibit vowel harmony patterns, vowels are described as either undergoing harmony or remaining neutral. Traditional accounts of vowel harmony have identified two categories of neutral vowels: blocking and transparent vowels (vanderHulst & Smith, 1986). A vowel is said to block harmony when the vowels on either side do not have to share the same feature. A vowel is said to be transparent when the vowels around it have the same feature, but the transparent vowel does not share that feature. In other words, harmony appears to skip over transparent vowels.

2.1 Blocking vowels

An example of vowels that block harmony is found with ATR harmony in Akan (Clements, 1976). The Akan vowel inventory, in Table 1, consists of ten vowels with two main featural distinctions: ± ATR and ± low. There are two +low vowels, [ɜ] and [a], +ATR and -ATR, respectively. All other vowels are considered -low and distinguished by ATR such that the +ATR vowels are [i, e, u, o] and the -ATR vowels are [ɪ, ɛ, ʊ, ɔ].

Table 1
Akan Vowels

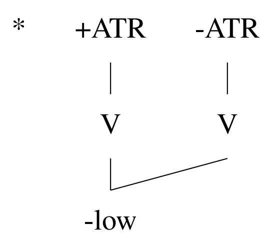
	+ATR	-ATR
-low	i	ɪ
	u	ʊ
	e	ɛ
	o	ɔ
+low	ɜ	a

The harmony generalization is that if a word contains a sequence of -low vowels, then those vowels will also share the same ATR feature (Clements, 1976). For example, the words in (9) contain only -low vowels, which are also all either +ATR or -ATR.

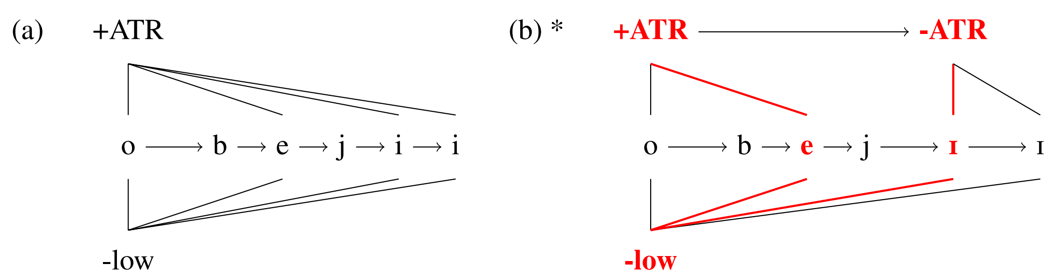
(9) -low vowels share an ATR feature value
  a. tie 'listen'
  b. obejii 'he came and removed it'
  c. ɔbɛjɛɪ 'he came and did it'
  d. wubenumˀ'you will suck it'
  e. wʊbɛnʊmˀ'you will drink it'

The surface requirement that adjacent -low vowels share the same ATR feature can also be written as a FSC, which forbids two adjacent vowels associated to the same -low feature from being associated to different ATR features, as in (10). The ordering relation on the ATR tier in (10) is omitted because the + or - values of the two ATR features are irrelevant for this constraint, as long as they differ. The ordering relation on the segmental tier of this FSC is also omitted and the reason will be made clear by the example in (11).

(10)



(11) [obejii] ‘he came and removed it’

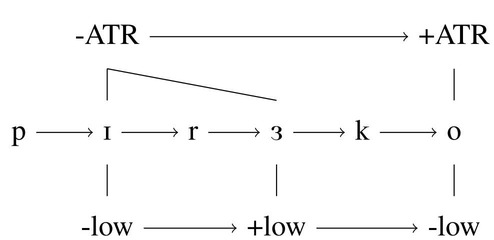


The AR for the grammatical Akan word [obeijii] “he came and removed it” is shown in (11a). Here a single +ATR and a single -low feature are each associated to each vowel within the word, demonstrating full ATR and low harmony. On the other hand, the hypothetical Akan word, [obejɪɪ], represented in (11b) is ungrammatical because it demonstrates full -low harmony, but does not demonstrate full ATR harmony; so, the AR in (11b) contains the forbidden structure of (10), shown in bold and red.

However, in traditional vowel harmony terms the presence of a +low vowel blocks the rightward spread of ATR, some examples are shown in (12). Translating this to the static surface representations assumed here, two -low vowels must be associated to the same ATR feature, but if a +low vowel intervenes they can be associated to different ATR features. The representation of (12a) exemplifies this pattern and is shown in (13).

(12) Vowels on either side of +low can have different ATR features
  a. pɪrɜko ‘pig’
  b. obisaɪ ‘he asked’
  c. mɪkɔkɜri ‘I go and weight it’
  d. okog^{w}arɪ^{ʔ}‘he goes and washes’

(13) [pɪrɜko] ‘pig’



Crucially, the AR in (13) does not contain the FSC from (10). While the AR for [pɪrɜko] “pig” does contain two vowels associated to a -low feature and two different ATR features, they are each separately concatenated to the intervening [ɜ] vowel, which is associated to a +low feature. So, the surrounding vowels are associated to two separate -low features on the surface and thus the AR satisfies FS and the NCC. Because the forbidden structure is not present [pɪɾʒko] “pig” is grammatical.

In summary, the vowel harmony pattern with blocking vowels in Akan can be captured using the FSC in (10), which does not refer to adjacency on any tier. Akan vowel harmony could thus be considered local because the FSC that captures the pattern need only refer to the associations between vowels and features. The next section outlines a vowel harmony pattern with the other type of neutral vowel, called transparent.

2.2 Transparent vowels

Finnish provides an example of backness harmony with four transparent vowels. The Finnish vowel inventory in Table 2 consists of 16 vowels with contrastive length and three main featural distinctions: ± back, ± low, and ± round (Ringen & Heinamaki, 1999; Välimaa-Blum, 1986). The four vowels transparent to backness harmony, [i, iː, e, eː], are all [-back, -round, -low]. Of the harmonizing vowels [y, yː, u, uː, ø, øː, o, oː] are all +round and -low while [æ, æː, ɑ, ɑː] are all +low and -round. The +back vowels are [u, uː, o, oː, ɑ, ɑː] and the -back vowels are [i, iː, e, eː, y, yː, ø, øː, æ, æː]. The difference between harmonizing and transparent Finnish vowels is characterized by low and round feature values. Transparent vowels are all [-low, -round] and thus harmonizing vowels have a positive value for the low and/or round feature.

Table 2

Finnish Vowels

	-round	+round		
-low	i, iː	y, yː	u, uː	
	e, eː	ø, øː	o, oː	
+low		æ, æː	ɑ, ɑː	-round
	-back		+back	

The Finnish harmony generalization is that all of the harmonizing vowels in a root will share the same back feature with each other and harmonizing suffix vowels will share the same back feature with the harmonizing root-final vowel (Nevins, 2010; Ringen & Heinamaki, 1999; vanderHulst, 2017; Välimaa-Blum, 1986). Since the same harmony generalization holds for both root and suffix vowels the Finnish generalization can also be stated as two harmonizing vowels must share the same back feature. For example, the words in (14) contain only +round or +low vowels, which are also either all +back or all -back.

(14) harmonizing vowels share a back feature value

a. pøytæ ‘table’
b. kæntæː ‘turn’
c. tykætæ ‘like’
d. poutɑ ‘fine weather’
e. murtɑː ‘break’
f. kokɑtɑ ‘cook’

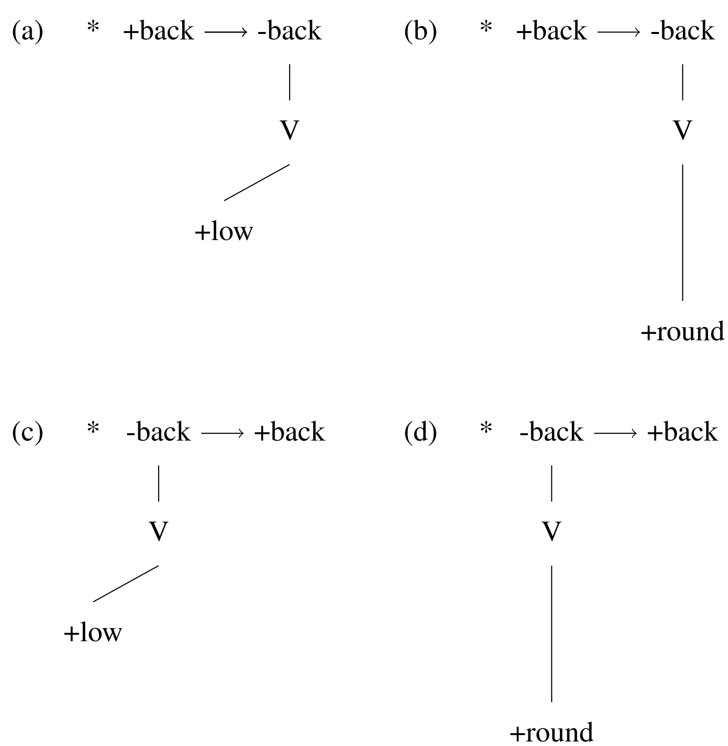
Transparent vowels, however, do not block or undergo harmony so in the Finnish words in (15) +back harmony appears to skip over the [-back, -round, -low] vowels [i, iː, e, eː]. The novel contribution of the current analysis is to treat transparent vowels in the same way as harmonizing vowels; the FSCs posited in this section are able to generate the Finnish pattern without underspecification of back features.

(15) back harmony skips over transparent vowels

a. ruvetɑ ‘start’
b. tuoliɑ ‘chair’
c. lukeɑ ‘read (inf.)’
d. kɑuneus ‘beauty’
e. nɑivius ‘naiveness’
f. kotikɑs ‘cozy’

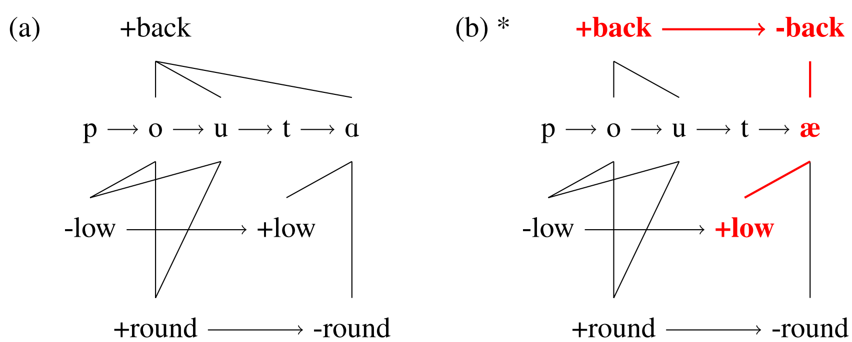
The surface requirement that +round and +low vowels share the same back feature can also be stated negatively as a constraint that forbids either a +round or a +low vowel from being associated to a different preceeding back feature. Together, the four FSCs in (16) generate this negative constraint and the Finnish vowel harmony pattern. The ordering relation on the segmental tier of the FSCs is omitted because the vowels can have consonants between them, as in (17). The ordering relation on the back tier, however, is crucial in order to allow transparency of certain -back vowels.

(16)



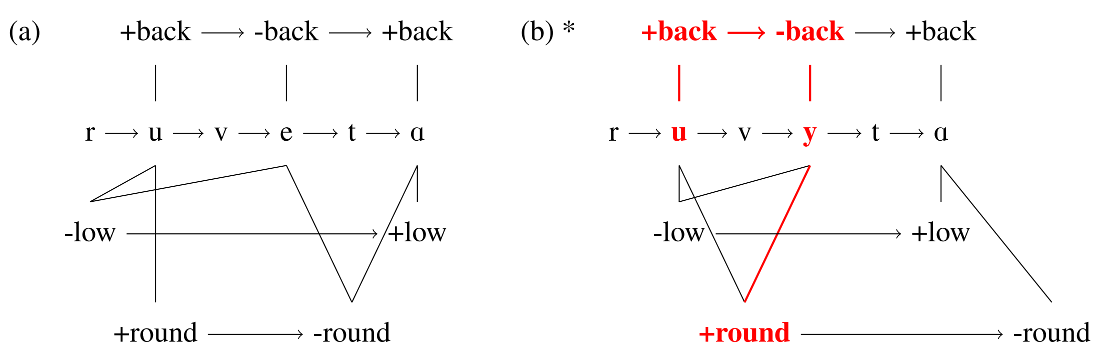
The ARs in (17) illustrate how the Finnish FSCs rule out ungrammatical disharmonic words. The AR for the grammatical Finnish word [poutɑ] ‘fine weather’, shown in (17a), contains both a +round and a +low non-initial vowel as well as a single +back feature, which demonstrates full back harmony. The hypothetical Finnish word, [poutæ] in (17b), however, contains the forbidden structure of (16a) in bold and red. In (17b) the final vowel does not harmonize with the penultimate vowel because they are associated to different back features.

(17) [poutɑ] ‘fine weather’



Crucially, the behavior of the transparent vowels with respect to vowel harmony in Finnish is captured by the four FSCs in (16) without reference to underspecification of back features. For example, the words in (15) all contain vowels with -back features that follow +back vowels, but because the -back vowels are also [-low, -round] the words are grammatical. The transparent vowels are associated to all the same features as the harmonizing vowels and their so-called transparency results from the interaction of the -back features with -low and -round features, as shown in (18). Because the Finnish FSCs only forbid associations to certain back features when vowels are also either +low or +round, the [-back, -low, -round] vowels are able to occur anywhere within a word and do not affect the back feature values of other vowels.

(18) [ruvetɑ] ‘start’



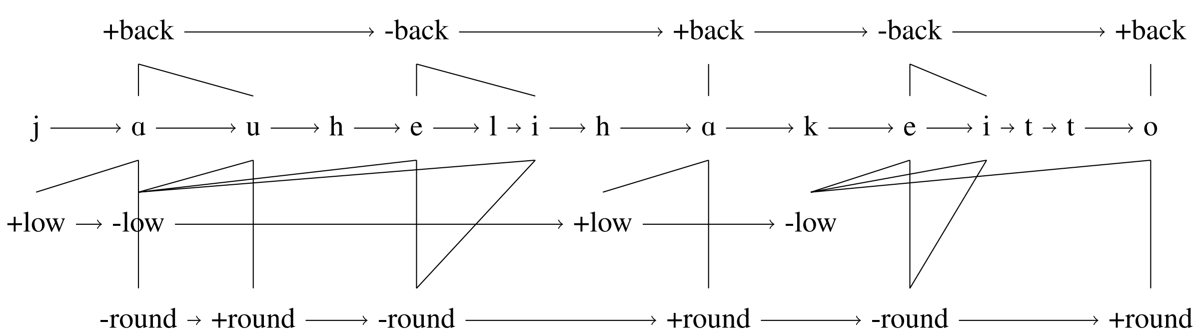
In (18a) the [u] and [ɑ] vowels are each associated to a +back feature, but not the same one. The [e] vowel occurs between them and is associated to a -back feature. Despite the occurence of two

+back features, these were not merged during concatenation because they are both adjacent to the same -back feature, but not to each other. The AR in (18a) is grammatical because it satisfies FS, the NCC, and the OCP and the -back vowel is not associated to a +low or a +round feature, so the AR does not violate any of the FSCs in (16). The AR in (18b), on the other hand, contains a [-back, +round] vowel between the two +back vowels, and so (16b) is violated, as shown in bold and red.

In summary, the vowel harmony pattern with transparent vowels in Finnish can be captured using the four FSCs in (16). These FSCs refer to adjacency on the back tier, which also interacts with both the round and low feature tiers. Finnish vowel harmony could thus be considered local because the FSCs that capture the pattern refer to the associations between vowels and features and the ordering between features.

2.2.1 Agreement is Local. Finnish exemplifies an assimilation mechanism that differs from previous analyses of vowel harmony. Previous analyses of vowel harmony assumed that all vowel harmony patterns result from a single assimilation process: feature spreading. On the surface, spreading ARs are derived via concatenation with adjadcent identical features merged into a single feature associated to multiple vowels. However, in Finnish there are grammatical words like (18a), which contain two +back harmonizing vowels with a transparent vowel between them. The NCC prevents Finnish from generating such words by spreading a single +back feature across a -back feature and the two +back features are not merged because they are not adjacent to each other. So the assimilation between two non-adjacent vowels of a +back feature in words like (18a) must be derived by some process other than feature spreading because the two +back features are not adjacent, and thus not merged during concatenation. In addition, OCP allows multiple iterations of a +back feature to occur as long as each is adjacent to a -back feature. In this paper, this other type of assimilation is called *agreement*. Agreement is represented on the surface as an AR in which two non-adjacent features on a tier share a value and the intervening feature on that tier has the opposite value, as shown in (18a) and (19).

(19) [jɑuhelihɑkeitto] 'minced meat soup'



The analysis of Finnish provided here demonstrates that agreement generates local structures on the surface. Transparent vowels are associated to -back features on the same tier as the back features to which all other vowels associate. Identical +back features are connected via adjacency to the -back feature between them regardless of the number of vowels associated to the intervening -back feature. In (19) more than one transparent vowel is associated to a -back feature that intervenes between two

+back features. On the segmental tier it would appear that two +back vowels, such as [ɑ] and [o], can be separated by more than one -back vowel, but on the back feature tier, the +back and -back features are adjacent. The grammatical AR in (19) also does not violate the Finnish FSCs in (16) and so the Finnish FSCs are still able to capture the agreement pattern and thus Finnish vowel harmony via agreement can be considered local.

3 Morphologically-conditioned harmony

3.1 Turkish

Native Turkish words demonstrate two separate harmony patterns: back and round harmony. In Turkish, a suffix vowel shares its back feature with the root-final vowel, but it is debated whether or not Turkish also utilizes back harmony within roots. In addition, a +high suffix vowel shares its round feature with the root-final vowel. The vowel inventory of Turkish in Table 3 consists of eight vowels with three main featural distinctions: ± high, ± back, ± round. In Turkish the +high -back vowels are [i, ü], the +high +back vowels are [ɨ, u], the -high -back vowels are [e, ö], and the -high +back vowels are [a, o].

Table 3
Turkish Vowels

	-back		+back	
+high	i	ü	ɨ	u
-high	e	ö	a	o
	-round	+round	-round	+round

The Turkish back harmony generalization is that all suffix vowels share the same back feature as the root-final vowel and the round harmony generalization is that a high suffix vowel shares the same round feature as the root-final vowel (Clements, 1976; Crothers & Shibatani, 1980; Nevins, 2010; Padgett, 2002; vanderHulst, 2017). For example, the words in (20) contain suffix vowels that have the same back feature as the preceding root-final vowel. In addition, the high suffix vowels in (20b-e) have the same round feature as the root-final vowel. Unlike in Finnish, Turkish non-final root vowels and suffix vowels do not necessarily share the same features on the surface, which makes it necessary to distinguish morphemes in ARs. Throughout this section, root and suffix morphemes will be distinguished by their position relative to a morpheme boundary, i.e. roots are on the left and suffixes on the right. In words with multiple suffixes, the first or leftmost morpheme is the root and any morphemes to the right of it are considered to be suffixes. In (20), for example, a morpheme boundary is represented by a large plus sign ‘+’.

(20) Suffix vowels share a back feature with root-final vowels
a. ip+ler ‘rope (Nom.pl)’
b. köy+ün ‘village (Gen.sg)’
c. el+i ‘hand (Acc.sg)’
d. kɨz+ɨn ‘girl (Gen.sg)’
e. son+u ‘end (Acc.sg)’
f. pul+lar ‘stamp (Nom.pl)’

In addition, Turkish consists of grammatical words with disharmonic roots, as in (21). For example, a lack of back harmony within root words prevents root and suffix back harmony generalizations from being collapsed into a single harmony pattern, as in Finnish. If back harmony holds only between root-final and suffix vowels, but not within roots, the back features associated to those vowels must also be distinguished as either root or suffix features.

(21) Turkish words with disharmonic roots
a. butik ‘boutique’
b. bordür ‘edge ornamentation’
c. kuvvet ‘strength’
d. mezat ‘auction’
e. tatil ‘vacation’

The Turkish back harmony pattern can thus be captured by an FSC that forbids two adjacent back features on either side of a morpheme boundary from having different values, as in (22). In the FSC in (22a), the +back vowel and the -back vowel must also be identifiable as the root and suffix vowels, respectively. The successor ordering relation on the back tier ensures that the +back vowel is to the left and the -back vowel is to the right. In addition, the morpheme boundary must be represented on the back tier in order to distinguish the root feature from the suffix feature. The same reasoning holds for the FSC in (22b), but the root-final vowel is associated to a -back and the suffix vowel is associated to a +back feature.

(22)

(a) * +back → + → -back   (b) * -back → + → +back

(23) [ip+ler] ‘rope (Nom.pl)’

(a)

$$\begin{array}{ccccccccccc} \text{-back} & & \longrightarrow & & + & & \longrightarrow & & \text{-back} & & \\ | & & & & & & & & | & & \\ \text{i} & \longrightarrow & \text{p} & \longrightarrow & + & \longrightarrow & \text{l} & \longrightarrow & \text{e} & \longrightarrow & \text{r} \end{array}$$

(b) *

$$\begin{array}{ccccccccccc} \textbf{-back} & & \longrightarrow & & \textbf{+} & & \longrightarrow & & \textbf{+back} & & \\ | & & & & & & & & | & & \\ \text{i} & \longrightarrow & \text{p} & \longrightarrow & + & \longrightarrow & \text{l} & \longrightarrow & \text{a} & \longrightarrow & \text{r} \end{array}$$

The Turkish word [ip+ler] ‘rope (Nom.pl)’ illustrates full back harmony, as shown in (23a): both the root and suffix features are -back. The hypothetical word [ip+lar], on the other hand, is ungrammatical because the root and suffix vowels are associated to different back features and so the AR in (23b) contains the forbidden substructure of (22b) in bold and red.

Turkish round harmony can also be written as an FSC, which forbids a suffix vowel that is associated to a +high feature from also being associated to a different round feature from the root-final vowel, as in (24).

(24)

(a) *
$$\begin{tikzcd}
 & & \text{+high} \arrow[d, no head] \\
 & & \text{V} \arrow[d, no head] \\
\text{+round} \arrow[r] & \textbf{+} \arrow[r] & \text{-round}
\end{tikzcd}$$

(b) *
$$\begin{tikzcd}
 & & \text{+high} \arrow[d, no head] \\
 & & \text{V} \arrow[d, no head] \\
\text{-round} \arrow[r] & \textbf{+} \arrow[r] & \text{+round}
\end{tikzcd}$$

(25) [köy+ün] 'village (Gen.sg)'

(a)
$$\begin{tikzcd}
 & \text{-high} \arrow[rr] \arrow[d, no head] & & \textbf{+} \arrow[r] & \text{+high} \arrow[d, no head] & \\
\text{k} \arrow[r] & \text{ö} \arrow[r] \arrow[d, no head] & \text{y} \arrow[r] & \textbf{+} \arrow[r] & \text{ü} \arrow[r] \arrow[d, no head] & \text{n} \\
 & \text{+round} \arrow[rr] & & \textbf{+} \arrow[r] & \text{+round} &
\end{tikzcd}$$

(b) *
$$\begin{tikzcd}
 & \text{-high} \arrow[rr] \arrow[d, no head] & & \textbf{+} \arrow[r] & \textbf{+high} \arrow[d, no head] & \\
\text{k} \arrow[r] & \text{ö} \arrow[r] \arrow[d, no head] & \text{y} \arrow[r] & \textbf{+} \arrow[r] & \textbf{i} \arrow[r] \arrow[d, no head] & \text{n} \\
 & \textbf{+round} \arrow[rr] & & \textbf{+} \arrow[r] & \textbf{-round} &
\end{tikzcd}$$

The AR for the grammatical Turkish word [köy+ün] 'village (Gen.sg)' shown in (25a) contains a -high root-final vowel and a +high suffix vowel. Both vowels are associated to a +round feature, which demonstrates full round harmony. The hypothetical Turkish word [köy-in] in (25b), on the other hand, contains the forbidden structure of (24a) in bold and red because it does not demonstrate full round harmony; the +high suffix vowel is associated to a different round feature than the root-final vowel.

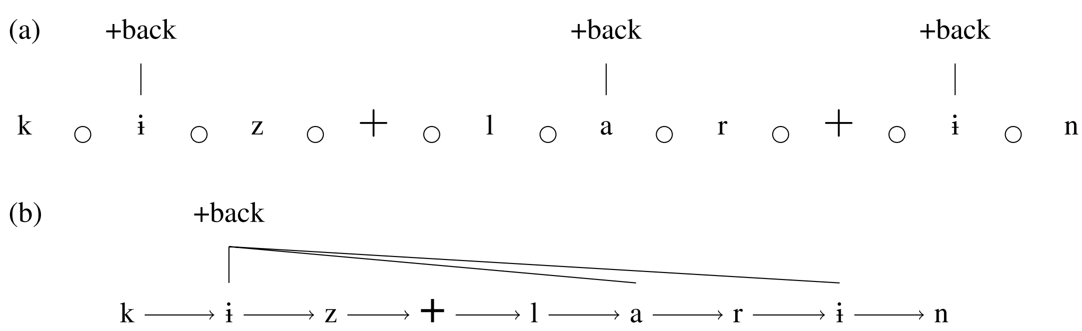
The analysis presented above captures both the Turkish back and round harmony patterns with FSCs in which morpheme boundaries are represented on all feature tiers. One critique of such an analsysis could be that morpheme boundaries can only be represented on the segmental tier and not on feature tiers. Such an analysis would correctly rule out disharmonic suffixes, but not disharmonic roots in Turkish. For example, if the morpheme boundary is removed from the feature tiers, then the FSCs in (22) would look like those in (26).

(26)

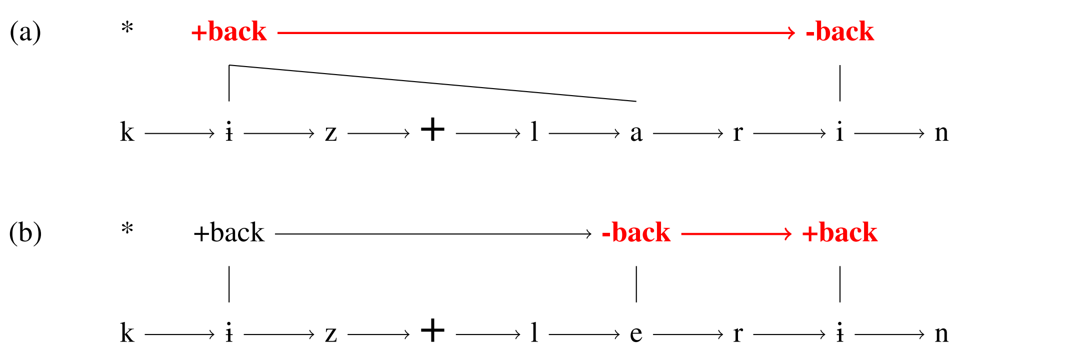
(a) * +back → -back   (b) * -back → +back

On the surface, all Turkish suffix vowels are associated to the same back feature as root-final vowels and the FSCs in (26) forbid any two adjacent back features from having different values. In a grammatical Turkish word with two suffix vowels, like [kɨz+lar+ɨn] 'girls (gen.)', both suffix vowels are associated to the same back feature on the surface, as shown in the AR (27b). The word [kɨz+lar+ɨn] contains the root [kɨz] followed by two suffixes: [lar] and [ɨn]. The representation of these three morphemes is derived via concatenation of autosegmental graph primitives that include consonants, vowels associated to back features, or morpheme boundaries on the segmental tier, as shown in (27a). The grammatical AR in (27b) thus demonstrates that all suffix vowels are associated to the same back feature even when multiple suffixes are present.

(27) Concatenation of Turkish graph primitives



(28)



The ARs in (28a) and (28b), on the other hand, violate the FSCs in (26a) and (26b), respectively. In (28a) the suffix vowel closest to the morpheme boundary is associated to a +back feature that is adjacent to a -back feature, shown in bold and red. Similarly, in (28b) the suffix vowel closest to the morpheme boundary is associated to a -back vowel that is adjacent to a +back vowel, shown in bold and red. The second morpheme is to the left of a boundary and the third morpheme is to the right of the same boundary, but both are considered suffixes because they follow an initial morpheme. Because the two suffixes do not share the same back feature, (28b) violates (26b) despite both morphemes being suffixes; so the back harmony holds between suffixes as well as between root-final and suffix vowels. Thus the FSCs in (26)—without morpheme boundaries on feature tiers—do capture the suffix harmony pattern in Turkish.

However, Turkish also has grammatical words with disharmonic roots. The FSCs in (26) do not discriminate between root and suffix vowel features because there is no morpheme boundary on the feature tier. A grammatical Turkish root like [tatil] ‘vacation’ would violate (26a) when its AR is derived using the graph primitive that includes morpheme boundaries only on the segmental tier because the AR contains the forbidden structure shown in bold and red in (29a).

(29) [tatil] ‘vacation’

(a)

$$\begin{tikzcd} & \textbf{+back} \arrow[rr] \arrow[d, dash] & & \textbf{-back} \arrow[d, dash] & & \\ t \arrow[r] & a \arrow[r] & t \arrow[r] & i \arrow[r] & l \arrow[r] & + \end{tikzcd}$$

(b)

$$\begin{tikzcd} & \text{+back} \arrow[rr] \arrow[d, dash] & & \text{-back} \arrow[r] \arrow[d, dash] & + & \\ t \arrow[r] & a \arrow[r] & t \arrow[r] & i \arrow[r] & l \arrow[r] & + \end{tikzcd}$$

The AR in (29b) introduces a new graph primitive that includes the morpheme boundary on both the segmental and back tiers and it violates (26a), which thus forbids a grammatical Turkish root. So the FSCs in (26) are able to capture the Turkish suffix harmony pattern with morpheme boundaries represented only on the segmental tier, but they are not able to capture disharmonic roots in Turkish. Enriching the representation to include a morpheme boundary in the set of representations that can occur on the feature tier increases the expressive power of the AR such that the two back features are distinguished as root features in (29b). Including the morpheme boundary on the back tier thus prevents (29b) from violating the FSCs posited for Turkish in (22).

In summary, Turkish demonstrates the necessity of adding a morpheme boundary ‘+’ to the set of representations that can occur on a feature tier. Because all root and suffix vowels do not necessarily have to share the same features on the surface it is necessary to distinguish them from one another. Identifying whether a vowel is part of a root or a suffix is accomplished by ordering the vowels relative to a morpheme boundary. However, since vowels are also ordered with respect to consonants, it is necessary to include an ordering relation on feature tiers so that the FSCs are connected. The morpheme boundaries are projected onto each feature tier so that vowel features are ordered relative to the boundary and can be distinguished as belonging to a root or a suffix and grammatical disharmonic roots are generated. In this way, the vowels are indirectly ordered relataive to each other via the ordering between their features in addition to their association to those features. Turkish vowel harmony can be considered local because both its back and round harmony patterns are captured by the connected FSCs in (22) and (24), respectively, which refer to the associations between vowels and features as well as the ordering relation between features and a morpheme boundary.

3.1.1 Locality of Agreement. Unlike Finnish, Turkish has both suffix vowel harmony and disharmonic roots so the morphological domain of harmony must be restricted. The analysis above adds a morpheme boundary to the set of representations that occur on both the feature and segmental tiers. Including a primitive with morpheme boundaries on all tiers increases the expressive power of ARs such that the possible domain of feature spreading is restricted to a single morpheme by adjacency; however, feature assimilation between morphemes still occurs.

(30) [ip+ler] ‘rope (Nom.pl)’

(a) -back ⟶ + ⟶ -back

i ⟶ p → + → l ⟶ e ⟶ r

(b) -back + -back

i ○ + ○ l ○ e ○ r

The intervention of a morpheme boundary between identical features in (23a), repeated here for example, is derived via concatenation so that the two iterations of the -back feature are not merged and remain on the surface. The assimilation of -back must thus be due to agreement rather than spreading, like in Finnish, because the surface AR in (30a) contains two identical non-adjacent -back features. The NCC is satisfied in (30) because morpheme boundaries are not associated to anything. The OCP is also technically satisfied because adjacent elements on the feature tier are distinct.

So far, vowel harmony has been shown to result from two different local assimilation mechanisms. Spreading in Akan is local because it associates multiple vocalic elements to a single feature, thus connecting distant elements, and utilizes adjacency on feature tiers. Agreement in both Finnish and Turkish also demonstrates the local nature of vowel harmony assimilation. Computation over agreement ARs is local because assimilation occurs over a finite distance, constrained by adjacency on the feature tiers. While assimilation is possible over any distance on the segmental tier, the adjacency of features to a morpheme boundary restricts the expressive power of multi-tiered vowel harmony ARs. The next section outlines a specific example of how enriching the representation with boundaries on feature tiers affects the expressive power of multi-tiered ARs.

4 Sour Grapes

A phenomenon often discussed in autosegmental spreading literature is the unattested, but logically possible pattern called sour grapes (Lamont, 2018; McCarthy, 2011; Padgett, 1995). Sour grapes spreading is a pattern in which a feature, such as nasality in Lamont (2018), spreads throughout a word; but, if the word contains a blocking segment, like low vowels in Akan, no spreading occurs at all. Sour grapes blockers could thus be considered to block spreading from any distance. Lamont (2018) illustrates what a sour grapes pattern would look like with nasal spreading below.

(31) Long distance blocking of local spreading, e.g. with nasal harmony (copied from Lamont (2018))

a. /wawa/ ↦ [wawa]

b. /mawa/ ↦ [mãw̃ã]

c. /awamawa/ ↦ [awamãw̃ã]
d. /mawasa/ ↦ [mawasa]
e. /mawamawasa/ ↦ [mãw̃ãmawasa]

In (31a-c) nasality spreads from an [m] onto each segment to the right of it. In (31 d-f) an [s] is introduced, which prevents nasality from spreading at all. In (31e) it is clear that [s] only blocks nasal spreading from the closest [m] to its left.

By representing nasality as two primitive autosegments (N for nasal and O for oral) on a single autosegmental tier that is connected only to a segmental tier, Lamont (2018) further shows that the nasal sour grapes pattern over two-tiered ARs must be generated by a grammar that is more expressive than ASL^{gT}. The nasal sour grapes pattern does not meet the requirements for any of the subregular classes of grammars that ASL^{gT} cuts across and so Lamont (2018) posits that sour grapes must be generated by a more expressive Regular grammar.

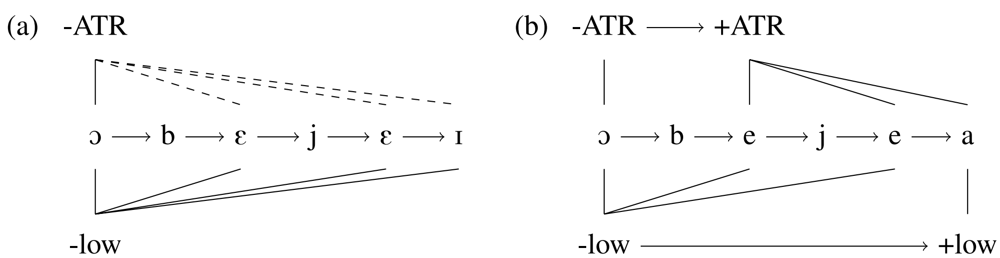
Following Lamont (2018), this section will evaluate the expressive power needed to generate an unattested sour grapes pattern over multi-tiered ARs. It will be shown that the expressive power of multi-tiered ARs is significantly increased by enriching the representation because a sour grapes vowel harmony pattern can be described by FSCs over multi-tiered ARs if word boundaries are added to the set of representations allowed on feature tiers.

4.1 Sour grapes in vowel harmony

A parallel to the nasal sour grapes pattern can be drawn using the Akan vowel harmony pattern discussed in section 2.1. In traditional descriptions of Akan, an ATR feature is said to spread from an underlyingly associated vowel onto all -low vowels to the right. For example, the word ɔbɛjɛɪ 'he came and did it', shown in (32a) and (33a), is grammatical in Akan. However, +low vowels block Akan vowel harmony, so an Akan-like sour grapes word would have a +low vowel and the ATR feature would not spread, as in (32b) and (33b). In (33) dashed lines represent an association via spreading and solid lines represent an underlying association that is also present on the surface.

(32) ATR harmony with sour grapes
a. /ɔbejei/ ↦ [ɔbɛjɛɪ] 'he came and did it'
b. /ɔbejea/ ↦ [ɔbejea]

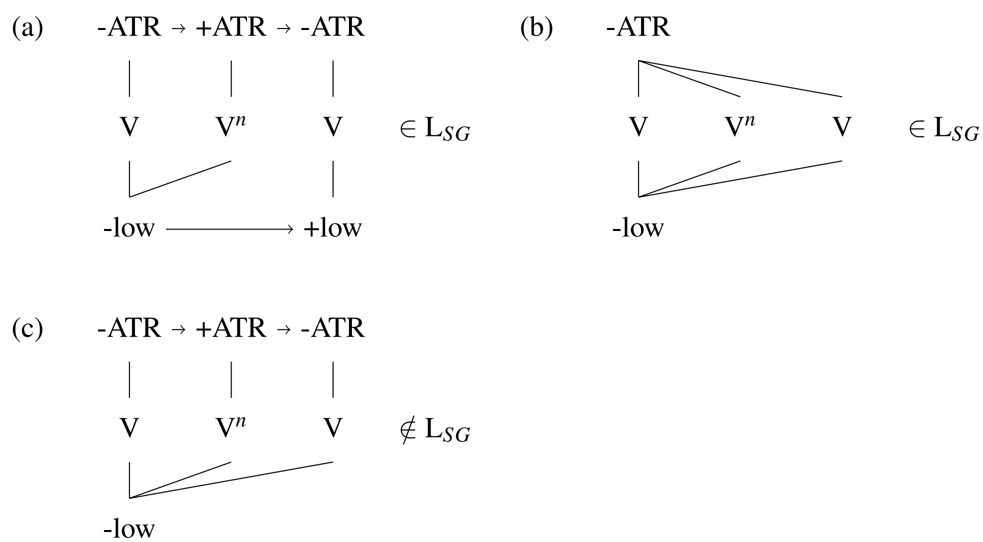
(33) ATR harmony with sour grapes ARs



In (33a) the -ATR feature spreads from the initial -low vowel onto every -low vowel to the right. However, in (33b) the final +low vowel prevents the initial -ATR feature from spreading. So each vowel maintains its underlying associations on the surface and the -low vowels are each associated to one of two different adjacent ATR features.

On the surface, a word in an Akan-like language with sour grapes (L_{SG}) can be distinguished from Akan (L_A) based on the grammaticality of certain ARs. Both L_A and L_{SG} have words with full ATR and low harmony, as in (34b). The difference between L_A and L_{SG} is that L_{SG} allows words with different ATR features and a +low vowel, shown in (34a). Neither L_A nor L_{SG} allow words with different ATR features and full low harmony, as in (34c). A grammar that generates L_{SG} would thus need to distinguish (34a) and (34b) from (34c). In (34), the superscript 'n' represents any possible number of vowels that can occur in a given position with the same featural associations.

(34) Sour Grapes



So far, vowel harmony patterns with neutral vowels have been captured using FSCs over multi-tiered ARs in which a feature on one tier can affect what features are possible on another tier as long as they are associated to the same vowel or connected by adjacency. L_{SG}, on the other hand, introduces the possibility that any number of vowels between a -ATR and a +low vowel can be +ATR. An FSC that forbids the presence of +ATR vowels without a +low vowel somewhere in the word would also have to forbid a certain number of +ATR vowels, which requires counting vowels for its evaluation. Alternatively, existential quantification would allow a constraint to require the presence of +G. Whether counting vowels in a word or using existential quantification, such a constraint would make sour grapes more expressive than the ASL^g class.

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