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

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Revisions (sec = section, p. = page, l. = line):
sec1, p.1, l.11 reword first sentence
sec1, p.1, l.19-26 clarify analysis of vh as phonotactic restriction, only surface ARs
sec1.1, p.4, l.132 fix spelling of "analysis"
sec2.2, p.6, l.170 change "one element on a feature" to "one element on each feature tier"
sec2.3, p.8, l.238-240 add "used to define r_1-r_n" to clarify what the constraint definition language is
sec2.3, p.8, l.244-245 change "is thus a conjunction of surface markedness constraints" to "thus consists of the set of surface markedness constraints"
sec3.1.1, p.12, l.360 fix spelling of "adjacent"
sec3.1.1, p.12, l.365-366 reword second sentence to define locality

1 Introduction

This qualifying paper aims to investigate the locality of vowel harmony patterns using forbidden substructure constraints (FSCs) over multi-tiered autosegmental representations (ARs). The investigation provides 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 allows for a theory of well-formedness that makes accurate typological predictions.

This qualifying paper analyzes vowel harmony as a phonotactic restriction using only surface ARs rather than an input-output map. Previous work has analyzed vowel harmony patterns as resulting from a single assimilation process, whether it be feature spreading or agreement (Bakovic, 2000; Clements, 1976; McCarthy, 2011; Nevins, 2010; Rose & Walker, 2011; van der Hulst & Smith, 1986; Walker, 2010). However, this paper shows that given a uniform theory of surface markedness constraints, vowel harmony patterns utilize surface ARs that can reflect either type of assimilation. The paper further argues that vowel harmony is strictly local on the surface because all such patterns can be captured by FSCs, which refer to the adjacency between features and/or their associations to the vowels in a word.

First, the locality of a traditional spreading pattern will be demonstrated for Akan. The basic spreading pattern with blocking vowels in Akan is captured by a single FSC, which forbids an AR with two different features on one tier and only a single feature on another tier. In this way, Akan demonstrates how different feature tiers can interact to restrict the possible ARs of vowel harmony.

In addition, the underspecification of features has been used to account for vowel harmony patterns with transparent vowels. Feature underspecification means that a language does not associate some vowels to any feature on a particular tier. In such cases, the spread of a feature on that tier is able to skip over the unassociated vowels. This qualifying paper, however, shows that transparent vowels are associated to features on all the same tiers as features that harmonizing vowels are associated to. Rather than being underspecified, a vowel is transparent based on the specific features it associates to. Thus, transparent vowels in Finnish are captured by FSCs without relying on language-specific underspecification.

While underspecification is shown to be unnecessary for vowels, this paper will show that some languages do underspecify boundaries such that they are represented on the segmental tier, but not on feature tiers. For example, this paper will show that morpheme boundaries must be represented on both the segmental and feature tiers in order for FSCs to capture Turkish suffix harmony with disharmonic roots. On the other hand, the Finnish root and suffix harmony patterns do not require morpheme boundaries to be represented on feature tiers. The distinction between the representations in these two languages will be argued to result from the type of graph primitives the language utilizes for the derivation of its ARs.

Lastly, this qualifying paper will show that FSCs over multi-tiered ARs can also capture an unattested sour grapes vowel harmony pattern. Regardless of whether word boundaries are specified on feature tiers or not, their presence in an AR allows the theory outlined here to represent an unattested pattern. Sour grapes is a vowel harmony pattern in which a single blocking vowel prevents the spread of a feature regardless of how many vowels intervene. Despite being unattested in the literature, the current theory predicts such a pattern is possible. So, further work remains to determine whether or not the multi-tiered ARs posited here are too powerful to represent only attested vowel harmony patterns.

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. While this qualifying paper does not accomplish the goal of distinguishing attested from unattested vowel harmony patterns, it adopts a formal language theory approach that provides explicit ways of determining the locality of vowel harmony patterns. This approach can then be used in the future to investigate whether the current surface well-formedness theory can be restricted further such that unattested vowel harmony patterns are not captured by FSCs.

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, 2015a) provides a method for comparing the expressivity of the grammars that generate them. Rogers et al. (2013) provides a cognitive interpretation of string well-formedness whereby the well-formedness of a string can be checked by scanning that string with a window of size k to ensure that it does not contain the forbidden substructure of size k. Jardine (2018) thus 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 goal of this qualifying paper is to determine the suitability of multi-tiered ARs for capturing vowel harmony patterns using forbidden k-factor grammars. Future work will then be able to compare sets of multi-tiered ARs to existing subregular grammars in order to classify vowel harmony patterns with respect to the subregular hierarchy.

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 multi-tiered ARs adequately capture vowel harmony patterns so that their expressivity can eventually be compared to two-tiered ARs of tone. Three aspects of multi-tiered ARs of vowel harmony are investigated: the complexity of vowel harmony patterns with neutral vowels in Akan and Finnish, generalizations that include domain information in Turkish, 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 for the suitability of forbidden k-factor grammars over multi-tiered ARs for generating 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). Some 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; van der Hulst, 2017; Walker, 2010, 2014). 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. Many 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. However, 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. Some influential work has been dedicated to classifying input-output maps in phonology (i.e. from underlying to surface form) as stricly local within a Chomsky-based hierarchy of sets of pairs of strings and demonstrating their learnability (Chandlee &

Heinz, 2018; Chandlee & Jardine, 2013; Chandlee, Eyraud, & Heinz, 2014).

However, this qualifying paper constitutes the first formal language theoretic study of vowel harmony as a phonotactic restriction rather than an input-output map. It 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 aims to determine the locality of only the surface restrictions on vowel harmony patterns over multi-tiered 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 eventual classification of vowel harmony within the sub-SF hierarchy of patterns, which in turn 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).

The structure of the remainder of this paper is as follows: Section 2 is devoted to the representations with discussion of the motivations in 2.1 and assumptions in 2.2 that are adopted throughout the paper as well as a definition of FSCs in 2.3 and an explanation of different assimilation processes 2.4. Section 3 includes the analysis of two languages that exemplify vowel harmony patterns with neutral— i.e. blocking and transparent — vowels. Section 4 analyzes a domain restricted vowel harmony pattern in Turkish. Section 5 discusses how the system laid out so far captures the unattested sour grapes pattern. And section 6 concludes.

2 Defining 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). This section outlines the motivations for adopting the representations used throughout this paper and the basic assumptions and definitions needed to use them for analysis.

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 [$\pm$ back], [$\pm$ 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)

$$\begin{tikzcd}[row sep=small] \pm\text{ high} \arrow[d, dash] \\ \text{V} \arrow[d, dash] \\ \pm\text{ back} \end{tikzcd}$$

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.

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

$$* \quad \begin{tikzcd}[row sep=small] \text{-ATR} \arrow[d, dash] & \\ \text{V} \arrow[r] & \text{V} \\ \text{-low} \arrow[u, dash] \arrow[ur, dash] & \end{tikzcd}$$

(4) Violates NCC

$$* \quad \begin{tikzcd}[row sep=small] \text{+ATR} \arrow[r] \arrow[dr, dash] & \text{-ATR} \arrow[dl, dash] \\ \text{V} \arrow[r] & \text{V} \\ \text{-low} \arrow[u, dash] \arrow[ur, dash] & \end{tikzcd}$$

(5) Violates OCP

$$
\begin{array}{cccc}
* & \text{-ATR} & \rightarrow & \text{-ATR} \\
 & | & & | \\
 & \text{V} & \longrightarrow & \text{V} \\
 & | & & | \\
 & \text{-low} & \longrightarrow & \text{-low}
\end{array}
$$

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 each 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.

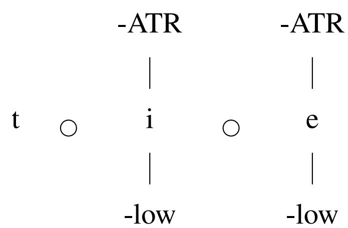
Second, the NCC states that association lines between the segmental tier and a feature tier never cross. Odden (1994) adds that the NCC can only evaluate the association between the segmental and one featural tier at a time. The representation in (4) violates the NCC because +ATR precedes -ATR, but is 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.

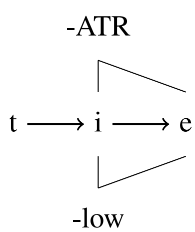
Lastly, the OCP stipulates that adjacent featural elements must be distinct. The representation in (5) violates the OCP because on both the ATR and low feature tiers there are two identical adjacent features, -ATR and -low respectively. The OCP in conjunction with FS results in representations where 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, 2015a, 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



(7) Satisfies FS, NCC, and OCP



Again, the initial consonant in (7) cannot be associated to a vowel feature. 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.

2.3 Definition of Constraints

As mentioned above, this qualifying paper will use Jardine (2017)'s "forbidden substructure constraints" to determine the locality of surface restrictions on vowel harmony patterns over multi-tiered ARs. Previous work on the logical descriptions of formal languages and their applications to phonological well-formedness constraints (Heinz et al., 2011; Rogers et al., 2013) led to the development of the theory of a forbidden substructure grammar (following Jardine, 2017). A forbidden substructure grammar is a logical statement of the form in (8) below. Such a grammar will generate a set of well-formed structures that does not contain any of r_1 through r_n.

(8) Forbidden substructure grammar (Jardine, 2017)
$\neg r_1 \wedge \neg r_2 \wedge \neg r_3 \wedge ... \wedge \neg r_n$

Negative well-formedness constraints are not new to phonological theory, however. Optimality Theory (OT; Prince & Smolensky, 1993, 2004) introduced surface markedness constraints, which evaluate the well-formedness of potential output structures (Jardine & Heinz, 2015b). deLacy (2011) then called for "constraint definition languages" in order to explicitly define the possible range of such constraints and their interpretations. Jardine (2016) and Jardine (2017) introduced the forbidden substructure grammars, which refer to phonological structures and are both restrictive and computationally local. The logical language used to define r_1-r_n in (8) thus constitutes a constraint definition language because it explicitly defines the possible surface well-formedness constraints as being those which forbid an ill-formed piece of a structure (a substructure).

A FSC combines the OT representation of surface markedness (using *) with the logical language for forbidding a substructure, like r_1 in (8). A forbidden substructure grammar thus consists of the set of surface markedness constraints that rule out ill-formed substructures, i.e. FSCs. 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. This qualifying paper will utilize FSCs over multi-tiered ARs to show that vowel harmony patterns are local in the same way.

In addition, this qualifying paper will show that it is necessary to restrict the expressivity of FSCs by excluding word boundaries from the set of representations that can occur in multi-tiered ARs. Such a restriction prevents FSCs over multi-tiered ARs from explicitly restricting forbidden substructures to word edges, which distinguishes the FSCs for attested vowel harmony patterns in Akan, Finnish, and Turkish from the logically possible but unattested sour grapes pattern.

2.4 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 both kinds of assimilation are captured by a theory of markedness based in FSCs. 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. On the other hand, 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 (9a). 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 (9a).

(9) Agreement

(a)

$$\begin{array}{ccccccccccc} & & \text{+back} & \longrightarrow & & & \text{-back} & \longrightarrow & & & \text{+back} \\ & & | & & & & | & & & & | \\ \text{r} & \longrightarrow & \text{u} & \longrightarrow & \text{v} & \longrightarrow & \text{e} & \longrightarrow & \text{t} & \longrightarrow & \text{a} \end{array}$$

(b)

$$\begin{array}{ccccccccccc} & & \text{+back} & & & & \text{-back} & & & & \text{+back} \\ & & | & & & & | & & & & | \\ \text{r} & \circ & \text{u} & \circ & \text{v} & \circ & \text{e} & \circ & \text{t} & \circ & \text{a} \end{array}$$

On the surface, both spreading and agreement are derived via the concatenation operation, as shown in (6) and (9b), respectively. In (6), adjacent identical features are merged to generate multiple association. In (9b), multiple iterations of a +back feature are possible when a primitive with a -back feature intervenes between two primitives with +back features. The non-adjacent +back features in (9b) are still local in the FSC sense because only a single -back feature intervenes regardless of the number of vowels associated to it; so agreement harmony patterns can still be captured by FSCs. Both 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 captured 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.

3 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 (van der Hulst & 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.

3.1 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: $\pm$ ATR and $\pm$ 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

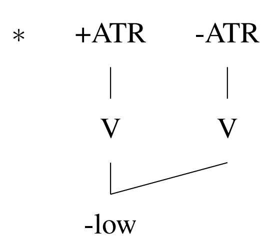
The harmony generalization is that if a word contains a sequence of -low vowels, then those vowels will also share the same ATR feature (Clements, 1976). For example, the words in (10) contain only -low vowels, which are also all either +ATR or -ATR.

(10) -low vowels share an ATR feature value

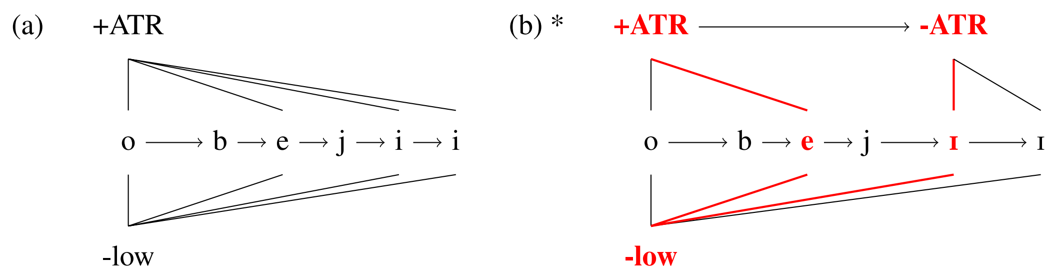
a. tie ‘listen’
b. obejii ‘he came and removed it’
c. ɔbɛjɛɪ ‘he came and did it’
d. wubenumʔ‘you will suck it’
e. wʊbɛnʊmʔ‘you will drink it’

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 (11). The ordering relation on the ATR tier in (11) 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 (12).

(11)



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



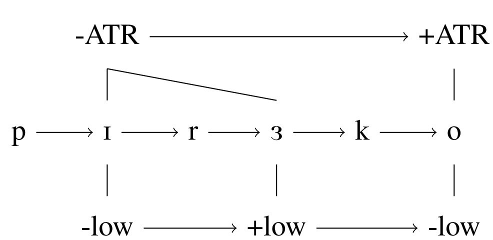
The AR for the grammatical Akan word [obeijii] “he came and removed it” is shown in (12a). Here a single +ATR and a single -low feature are each associated to each vowel within the word, demonstrating full ATR and low harmony. On the other hand, the hypothetical Akan word, [obejɪɪ], represented in (12b) is ungrammatical because it demonstrates full -low harmony, but does not demonstrate full ATR harmony; so, the AR in (12b) contains the forbidden structure of (11), 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 (13). 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 (13a) exemplifies this pattern and is shown in (14).

(13) 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. okogʷarɪˀ‘he goes and washes’

(14) [pɪrɜko] ‘pig’

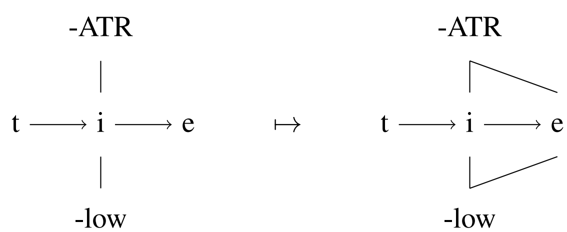


Crucially, the AR in (14) does not contain the FSC from (11). While the AR for [pɪrɜko] “pig” does contain two vowels associated to a -low feature and two different ATR features, they are each separately concatenated to the intervening [ɜ] vowel, which is associated to a +low feature. So, the surrounding 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 [pɪrɜko] “pig” is grammatical.

In summary, the vowel harmony pattern with blocking vowels in Akan can be captured using the FSC in (11), 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 transparent vowels.

3.1.1 Surface spreading is local. Some previous analyses of vowel harmony assume that all harmony patterns result from a single assimilation process: feature spreading. Feature spreading is generally considered to be a transformation from an underlying representation in which a single feature is associated to a single vowel into a surface representation with multiple vowels associated to the same feature, as in (15). In other words, feature spreading maps an underspecified underlying AR onto a fully specified surface AR with multiple association.

(15) Feature spreading



This paper focuses on surface representations and Akan provides an example of a pattern in which vowel harmony assimilation is due to spreading. The surface spreading ARs used throughout this paper are derived via concatenation with adjacent identical features merged into a single feature that is associated to multiple vowels, as shown in (6) and (7). Akan provides an example of a classic spreading pattern, in which an initial vowel feature (ATR) is associated to all the vowels in a word to the left of a +low blocking vowel, as shown in (12a).

The analysis of Akan provided here demonstrates that spreading ARs are local on the surface. Here locality means that spreading ARs consist of a domain defined by a single ATR feature node, they must include a contiguous span of vowels, but they are not bounded in length, as in (12a); or when two different ATR features are present they are adjacent to each other regardless of how many vowels are associated to each. In addition, the FSC posited for Akan is able to capture the Akan ATR harmony pattern for words with and without blocking vowels.

3.2 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; van der Hulst, 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 (16) contain only +round or +low vowels, which are also either all +back or all -back.

(16) 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 (17) +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.

(17) back harmony skips over transparent vowels

a. ruvetɑ ‘start’

b. tuoliɑ ‘chair’

c. lukeɑ ‘read (inf.)’

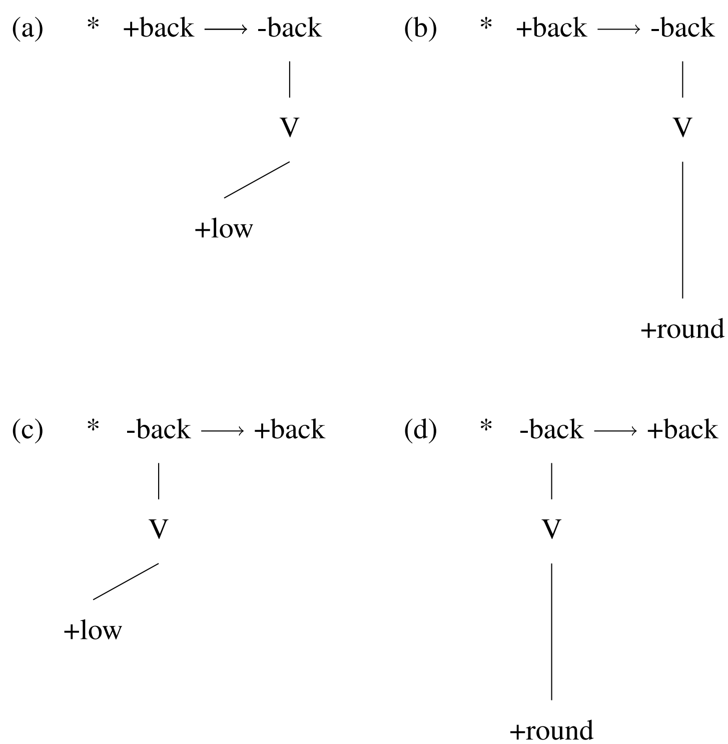
d. kɑuneus ‘beauty’

e. nɑivius ‘naiveness’

f. kotikɑs ‘cozy’

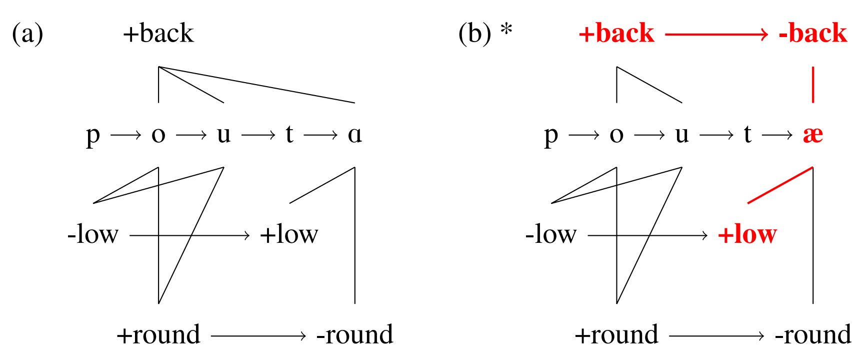
The surface requirement that +round and +low vowels share the same back feature can also be stated negatively as a constraint that forbids either a +round or a +low vowel from being associated to a different preceeding back feature. Together, the four FSCs in (18) generate this negative constraint and 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 (19). The ordering relation on the back tier, however, is crucial in order to allow transparency of certain -back vowels.

(18)



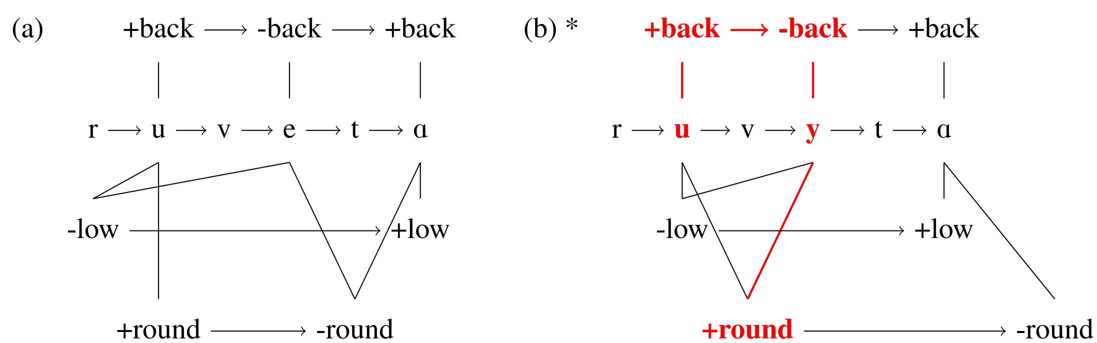
The ARs in (19) illustrate how the Finnish FSCs rule out ungrammatical disharmonic words. The AR for the grammatical Finnish word [poutɑ] 'fine weather', shown in (19a), contains both a +round and a +low non-initial vowel as well as a single +back feature, which demonstrates full back harmony. The hypothetical Finnish word, [poutæ] in (19b), however, contains the forbidden structure of (18a) in bold and red. In (19b) the final vowel does not harmonize with the penultimate vowel because they are associated to different back features.

(19) [poutɑ] 'fine weather'



Crucially, the behavior of the transparent vowels with respect to vowel harmony in Finnish is captured by the four FSCs in (18) without reference to underspecification of back features. For example, the words in (17) 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 (20). 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.

(20) [ruvetɑ] ‘start’

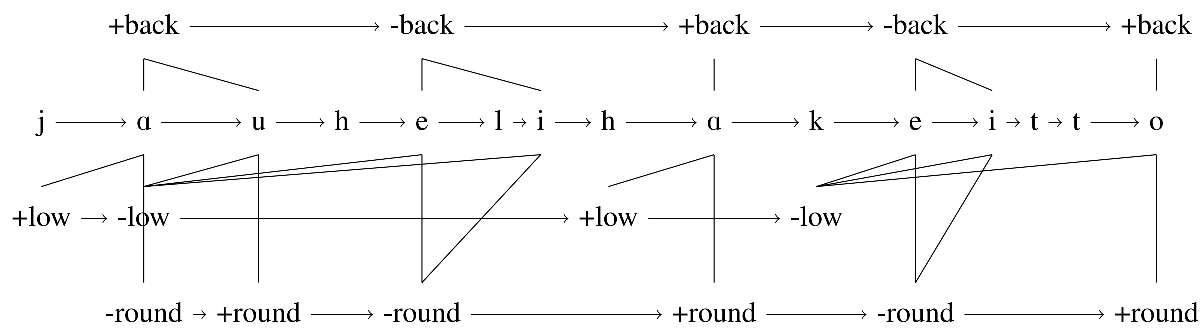


In (20a) the [u] and [ɑ] vowels are each associated to a +back feature, but not the same one. The [e] vowel occurs between them and is associated to a -back feature. Despite the occurence of two +back features, these were not merged during concatenation because they are both adjacent to the same -back feature, but not to each other. The AR in (20a) 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 (18). The AR in (20b), on the other hand, contains a [-back, +round] vowel between the two +back vowels, and so (18b) 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 (18). 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.

3.2.1 Surface agreement is local. Finnish exemplifies an assimilation mechanism that differs from spreading. In Finnish there are grammatical words like (20a), 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 (20a) must be due to a mechanism that differs from 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 (20) and (21).

(21) [jɑuhelihɑkeitto] ‘minced meat soup’



The analysis of Finnish provided here demonstrates that agreement ARs are local on the surface. Transparent vowels are associated to -back features on the same tier as the back features to which all other vowels associate, which eliminates the need for underspecification. 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 (21) 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 +back agreement appears to skip over any number of transparent vowels because they are all associated to a single -back feature, which is adjacent to the agreeing +back features. This adjacency on the back tier allows transparent vowels to be associated to a feature on the same tier as harmonizing vowels, rather than being underspecified. The grammatical AR in (21) also does not violate the Finnish FSCs in (18) and so the Finnish FSCs are still able to capture the agreement pattern and thus Finnish vowel harmony via agreement can be considered local.

4 Morphologically-conditioned harmony

4.1 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: $\pm$ high, $\pm$ back, $\pm$ 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].

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; van der Hulst, 2017). For example, the words in (22) contain suffix vowels that have the same back feature as the preceding root-final vowel. In addition, the high suffix vowels in

Table 3

Turkish Vowels

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

(22b-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 (22), for example, a morpheme boundary is represented by a large plus sign '+'.

(22) 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 (23). 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.

(23) 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 (24). In the FSC in (24a), 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 (24b), but the root-final vowel is associated to a -back and the suffix vowel is associated to a +back feature.

(24)

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

(25) [ip+ler] 'rope (Nom.pl)'

$$\begin{array}{ccccccc} & \text{(a)} & \text{-back} & \longrightarrow & + & \longrightarrow & \text{-back} \\ & & | & & & & | \\ & & \text{i} \rightarrow \text{p} & \rightarrow & + & \rightarrow & \text{l} \rightarrow \text{e} \rightarrow \text{r} \end{array} \qquad \begin{array}{cccccc} \text{(b) *} & \textbf{-back} & \longrightarrow & \textbf{+} & \longrightarrow & \textbf{+back} \\ & | & & & & | \\ & \text{i} \rightarrow \text{p} & \rightarrow & + & \rightarrow & \text{l} \rightarrow \text{a} \rightarrow \text{r} \end{array}$$

The Turkish word [ip+ler] 'rope (Nom.pl)' illustrates full back harmony, as shown in (25a): both the root and suffix features are -back. The two vowels in (25a) are not separated by any other vowels, but are associated to different -back features. Including the morpheme boundary on the feature tier prevents the two -back features from merging during concatenation because they are not adjacent; and so both -back features are represented in order to satisfy the NCC. 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 (25b) contains the forbidden substructure of (24b) 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 (26).

(26)

$$\begin{array}{cccc} \text{(a) *} & & & \text{+high} \\ & & & | \\ & & & \text{V} \\ & & & | \\ & \text{+round} & \rightarrow + \rightarrow & \text{-round} \end{array} \qquad \begin{array}{cccc} \text{(b) *} & & & \text{+high} \\ & & & | \\ & & & \text{V} \\ & & & | \\ & \text{-round} & \rightarrow + \rightarrow & \text{+round} \end{array}$$

(27) [köy+ün] 'village (Gen.sg)'

$$\begin{array}{ccccc} \text{(a)} & \text{-high} & \longrightarrow + \rightarrow & \text{+high} & \\ & | & & | & \\ \text{k} \longrightarrow & \text{ö} & \longrightarrow \text{y} \longrightarrow + \longrightarrow & \text{ü} & \longrightarrow \text{n} \\ & | & & | & \\ & \text{+round} & \longrightarrow + \rightarrow & \text{+round} & \end{array} \qquad \begin{array}{ccccc} \text{(b) *} & \text{-high} & \longrightarrow + \rightarrow & \textbf{+high} & \\ & | & & | & \\ \text{k} \longrightarrow & \text{ö} & \longrightarrow \text{y} \longrightarrow + \longrightarrow & \textbf{i} & \longrightarrow \text{n} \\ & | & & | & \\ & \textbf{+round} & \longrightarrow \textbf{+} \rightarrow & \textbf{-round} & \end{array}$$

The AR for the grammatical Turkish word [köy+ün] 'village (Gen.sg)' shown in (27a) 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 (27b), on the other hand, contains the forbidden structure of (26a) 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.

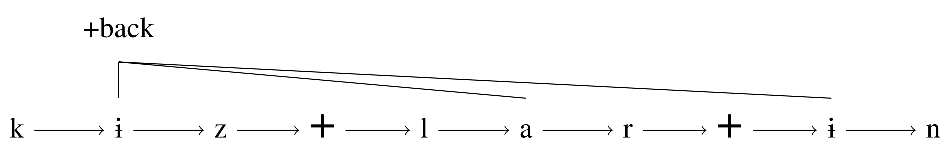
The analysis presented above captures both the Turkish back and round harmony patterns with FSCs in which morpheme boundaries are represented on all feature tiers. One critique of such an analsysis could be that morpheme boundaries can only be represented on the segmental tier and not on feature tiers. Such an analysis would correctly rule out disharmonic suffixes, and would also incorrectly rule out disharmonic roots in Turkish. For example, if the morpheme boundary is removed from the feature tiers, then the FSCs in (24) would look like those in (28). The FSCs in (28) forbid any two adjacent back features from having different values without regards to morpheme boundaries.

(28)

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

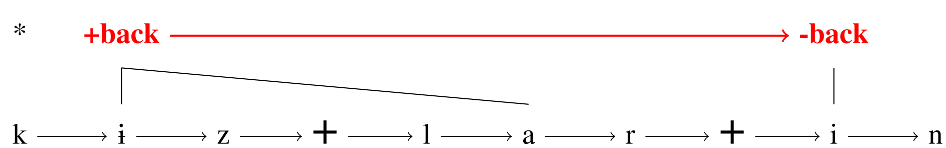
On the surface, all Turkish suffix vowels are associated to the same back feature as root-final vowels. While most Turkish suffixes are monosyllabic, in a grammatical Turkish word with two suffixes the same descriptive generalization holds. For example, in [kɨz+lar+ɨn] 'girls (gen.)' both suffix vowels are associated to the same back feature on the surface, as shown in the AR (29). The word [kɨz+lar+ɨn] contains the root [kɨz] followed by two suffixes: [lar] and [ɨn]. The grammatical AR in (29) thus demonstrates that all suffix vowels are associated to the same back feature even when multiple suffixes are present.

(29) Turkish root-final and suffix vowels all associated to a single back feature

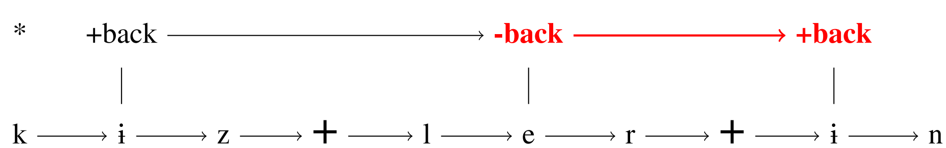


(30)

(a)



(b)



The ARs in (30a) and (30b), on the other hand, violate the FSCs in (28a) and (28b), respectively. In (30a) the first and second vowels are associated to a +back feature that is adjacent to a -back feature, shown in bold and red. Similarly, in (30b) the second vowel 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, (30b) violates (28b) despite both morphemes being suffixes; so back harmony holds between two vowels in different suffixes as well as between a root-final and a suffix vowel. Thus the FSCs in (28)—without morpheme boundaries on feature tiers—do capture the suffix harmony pattern in Turkish words with two suffixes.

However, Turkish also has grammatical words with disharmonic roots. The FSCs in (28) 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 (28a) because the AR contains the forbidden structure shown in bold and red in (31).

(31) [tatil] 'vacation'

$$\begin{tikzcd} & \textbf{+back} \arrow[rr] \arrow[d, no head] & & \textbf{-back} \arrow[d, no head] & \\ t \arrow[r] & a \arrow[r] & t \arrow[r] & i \arrow[r] & l \end{tikzcd}$$

While the AR in (31) does violate the hypothetical FSC in (28a), [tatil] is an attested grammatical Turkish word. Because the FSC in (28a) incorrectly marks an attested disharmonic root as ungrammtical, (28) cannot be said to capture the Turkish back harmony pattern. Alternatively, the FSC in (24a) contains a morpheme boundary on the back feature tier that intervenes between the two back features. Since a disharmonic root like (31) contains two different back features in the same morpheme, it does not violate (24a). For the same reason, the FSCs in (24) predict that a disharmonic polysllabic suffix would also be grammatical, but an initial search was unable to find any such suffixes in Turkish. The FSCs in (24) must be adopted to capture the Turkish back harmony pattern because they do not mark attested disharmonic roots as ungrammatical. Adopting (24) requires that morpheme boundaries are also represented on feature tiers.

Adding a morpheme boundary to the feature tier allows the FSCs in (24), repeated below in (32), to rule out words with a disharmonic suffix while still allowing words with disharmonic roots. As shown below in (32)-(34), both [tatil] and [kɨz+lar+ɨn] are captured by the same set of FSCs.

(32) Turkish FSCs

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

(33) [tatil] 'vacation'

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

(34) [kɨz+lar+ɨn] ‘girls (gen.)’

$$\begin{tikzcd}
 & +\text{back} \arrow[rr] \arrow[d, dash] & & + \arrow[rr] & & +\text{back} \arrow[rr] \arrow[d, dash] & & + \arrow[r] & +\text{back} \arrow[d, dash] & \\
k \arrow[r] & \text{ɨ} \arrow[r] & z \arrow[r] & + \arrow[r] & l \arrow[r] & a \arrow[r] & r \arrow[r] & + \arrow[r] & \text{ɨ} \arrow[r] & n
\end{tikzcd}$$

Again, the Turkish FSCs posited in this section are repeated in (32) above. Including morpheme boundaries on both segmental and feature tiers allows these two FSCs to capture all of the Turkish vowel harmony patterns discussed so far including words with disharmonic roots, shown in (33), and words with multiple suffixes, shown in (34).

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. In this way, the vowels are indirectly ordered relative 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 (24) and (26), respectively, which refer to the associations between vowels and features as well as the ordering relation between features and a morpheme boundary.

The present account of Turkish back harmony predicts the possibility of disharmonic polysyllabic suffixes, but the initial survey did not reveal any such suffixes in the language. A more in-depth review of attested Turkish suffixes will be required to verify whether or not this prediction is attested.

4.1.1 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.

(35) [ip+ler] 'rope (Nom.pl)'

(a) -back $\longrightarrow$ + $\longrightarrow$ -back

i $\longrightarrow$ p $\rightarrow$ + $\rightarrow$ l $\longrightarrow$ e $\longrightarrow$ r

(b) -back + -back

i ○ p ○ + ○ l ○ e ○ r

The intervention of a morpheme boundary between identical features in (25a), 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 because the surface AR in (35a) contains two identical non-adjacent -back features. The NCC is satisfied in (35) 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 vowels —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 the adjacency of concatenated primitives.

While the concatenation of primitives is a universal process for deriving the surface ARs used in this paper, the set of possible primitives is language-specific. For example, Finnish utilizes the same harmony pattern in roots and suffixes so a single set of FSCs can capture the harmony pattern without referencing a morphological boundary on feature tiers. Turkish, on the other hand, has disharmonic roots and suffixes harmonize with the root-final vowel so Turkish FSCs must reference a morphological boundary on feature tiers in order to distinguish suffix features from root features. The difference between Finnish and Turkish ARs with respect to the specification of morphological boundaries results from the graph primitives that each language uses; Finnish utilizes primitives with the morpheme boundary only on the segmental tier, but Turkish utilizes primitives with morpheme boundaries on both the segmental and feature tiers. The next section shows how enriching the representation with boundaries allows FSCs to also capture an unattested vowel harmony pattern.

5 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 described as a pattern in which a feature spreads throughout a word; but, if the word contains a blocking segment 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, shown below in (36).

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

a. /wawa/ ↦ [wawa]

b. /mawa/ ↦ [mãw̃ã]

c. /mawasa/ ↦ [mawasa]

In (36b) nasality spreads from an [m] onto each segment to the right of it. In (36c) an [s] is introduced, which prevents nasality from spreading at all. 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 $\mathrm{ASL}^{\mathrm{gT}}$. The nasal sour grapes pattern does not meet the requirements for any of the subregular classes of grammars that $\mathrm{ASL}^{\mathrm{gT}}$ 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 whether or not FSCs can be used to capture an unattested sour grapes pattern over multi-tiered ARs of vowel harmony. It will be shown that a sour grapes vowel harmony pattern can be described by FSCs over multi-tiered ARs whether word boundaries are included in the set of representations allowed on either the segmental or feature tiers.

5.1 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, the association of an ATR feature is said to spread from an initial -low vowel onto all -low vowels to its right; for example, the word *obisaɪ* ‘he asked’, shown in (37a) and (38a), is grammatical in Akan. However, +low vowels block Akan vowel harmony to their left; so an Akan-like sour grapes word would have a +low vowel and the +ATR feature would not spread to any vowel on the left of that +low vowel, as in (37b) and (38b). The surface ARs in (38) show the difference between the full spreading harmony in a word of Akan and the so-called long-distance blocking effect in a related hypothetical word of the sour grapes pattern.

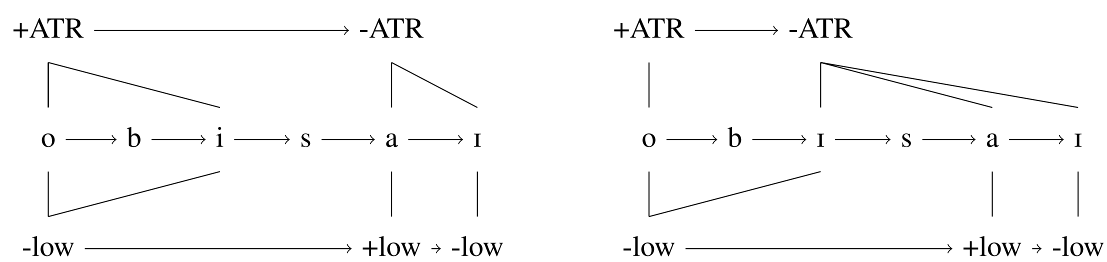
(37) ATR harmony

a. Akan: /obisai/ ↦ [obisaɪ] ‘he asked’

b. sour grapes: /obɪsaɪ/ ↦ [obɪsaɪ]

(38) ATR harmony in Akan vs sour grapes

(a) Akan (b) Sour Grapes

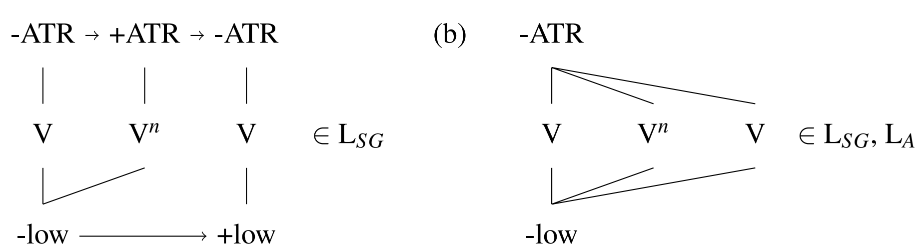


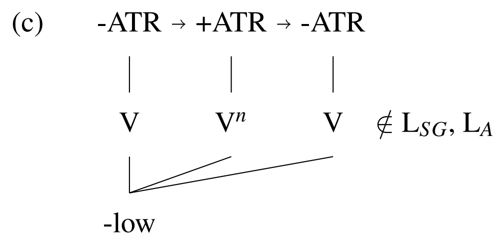
In (38a) the +ATR feature has spread from the initial -low vowel onto the -low vowel to its right and the +low vowel is associated to a different ATR feature. However, in (38b) the penultimate +low vowel prevents the initial +ATR feature from spreading, so the second vowel is associated to a -ATR feature.

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} include grammatical ARs with full -ATR and -low harmony, as in (39b). The difference between L_A and L_{SG} is that L_{SG} allows words with -ATR agreement and a final +low vowel, shown in (39a), but L_A does not. Neither L_A nor L_{SG} allow words with ATR agreement and full -low harmony, as in (39c). While Akan only includes surface ARs with spreading, L_{SG} contains a much larger repertoire of assimilation patterns utilizing both spreading and agreement, much like vowel harmony in general. A grammar that generates L_{SG} would thus need to distinguish (39a-b) from (39c). In (39), the superscript ‘n’ represents any possible number of vowels that can occur in a given position with the same featural associations. Using V^n suggests that an AR will be (un)grammatical regardless of the word’s length as long as the given substructure is present.

(39) Sour Grapes

(a)

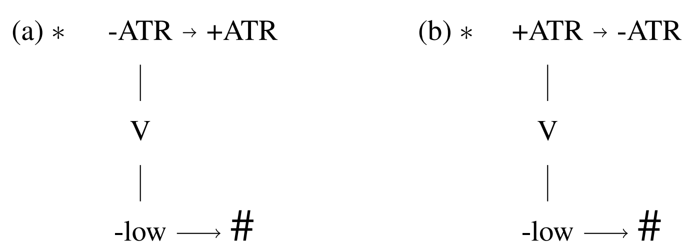




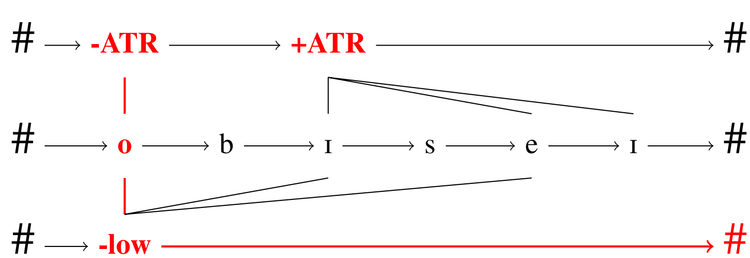
In other words, the L$_{SG}$ vowel harmony pattern allows ATR agreement only when a +low vowel is present; otherwise only full ATR and -low spreading harmony are grammatical. In order to rule out a possible AR like (39c), a FSC would have to forbid a substructure with more than one ATR feature, but no +low feature to the right of -low, as in (42). Restricting the features to the right of -low requires that FSCs make reference to final word boundaries, which will be represented using the # symbol.

5.1.1 Boundaries on feature tiers. Section 4.1 demonstrated, for Turkish, that morpheme boundaries must be represented on feature tiers, and this same requirement can be extended to word boundaries in a sour grapes pattern. As mentioned above, L$_{SG}$ allows surface spreading ARs with full ATR and low harmony in addition to surface agreement ARs only when a final +low vowel is present. In order to restrict the occurrence of ATR agreement, the FSCs in (40) forbid a structure with two different adjacent ATR features when the -low feature is adjacent to a final word boundary.

(40) Sour Grapes FSC



(41) Ungrammatical L$_{SG}$ AR

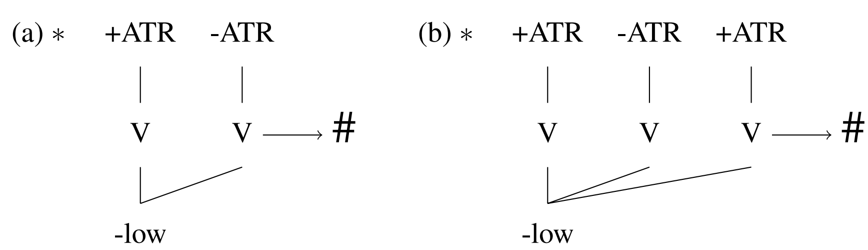


L$_{SG}$ can be captured by FSCs when word boundaries are represented on feature tiers. The FSC in (40) is able to capture the constraint against a word-final -low feature. The AR of the hypothetical

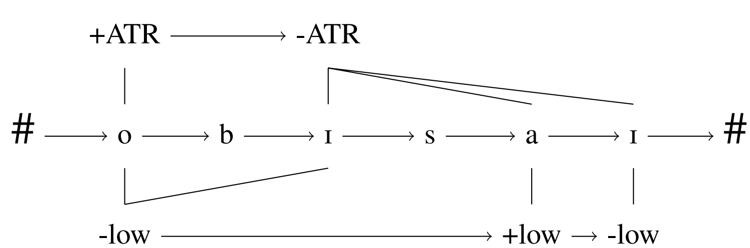
L_{SG} word [obɪseɪ] in (41), for example, is marked ungrammatical because it contains the forbidden structure of (40) with a -low feature adjacent to a final word boundary in bold and red.

5.1.2 Boundaries only on segmental tier. In addition, the argument could be made that word boundaries are represented only on the segmental tier. In that case, the number of features on a tier can be calculated by making reference to the adjacency of vowels to a word boundary and their associations to features. The FSCs in (42) forbid a strutcure with different ATR features in which the -low feature is associated to the word-final vowel regardless of the number of vowels in the word. As in Akan, the ordering relation on the ATR tier is excluded because the same constraint holds regardless of whether -ATR precedes or succeeds +ATR. The ordering relation is omitted between vowels because word-medial consonants would make vowels non-adjacent. Excluding the successor relation between vowels also makes it possible for any number of vowels to occur between those specified in the FSC without changing the grammaticality of the word, as illustrated in (44). The ARs in (43) and (44) illustrate the difference between a grammatical and an ungrammatical L_{SG} word, captured by the FSCs in (42).

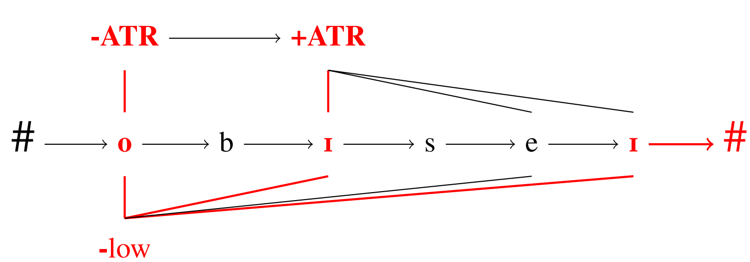
(42) Sour grapes FSCs with boundaries on segmental tier



(43) Grammatical L_{SG} AR



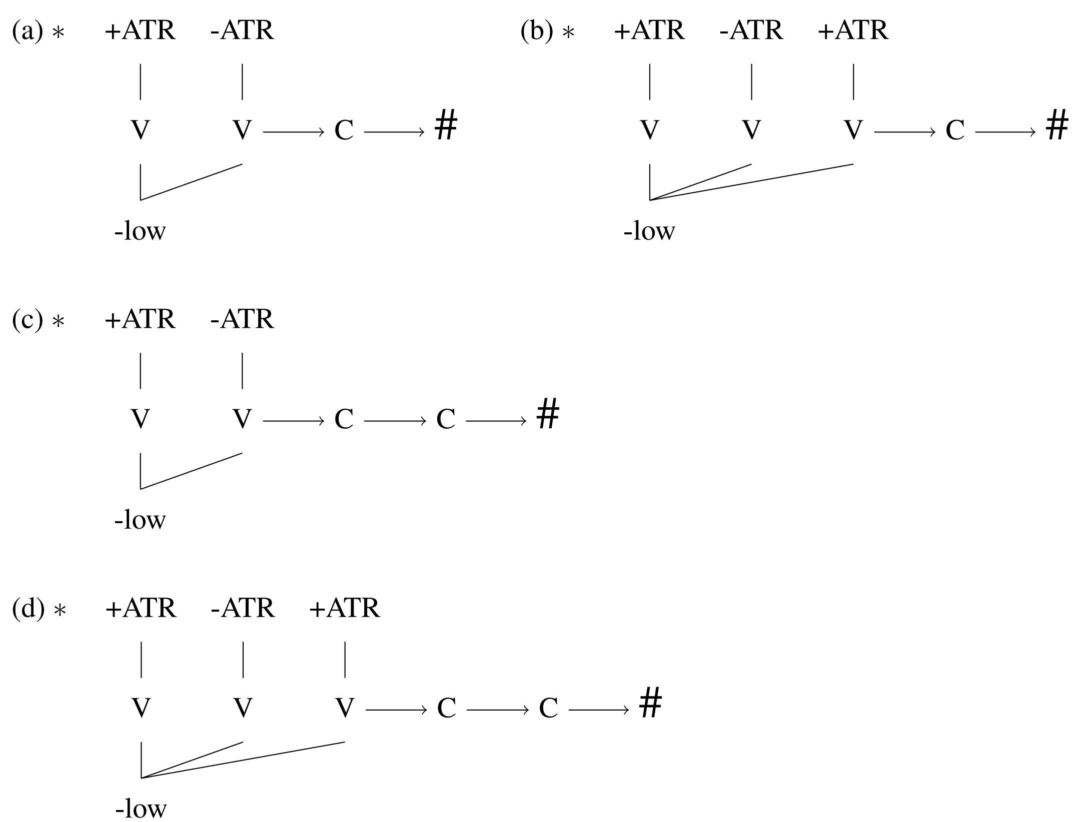
(44) Ungrammatical L_{SG} AR



The FSCs in (42) allow the grammatical AR in (43) and mark (44) ungrammatical because it contains the forbidden substructure of (42b) in bold and red. The difference between these two ARs is that (43) contains a +low feature, but (44) contains only a single -low feature associated to the final vowel.

The FSCs in (42) necessarily include the successor relation between a word-final vowel and the final word boundary, but Akan— on which L_{SG} is based —also includes words with final consonants. Because consonants are not assoicated to vowel features, the present theory has thusfar ignored them as irrelevant to vowel harmony except to make vowels on the segmental tier non-adjacent. However, the FSCs in (42) make reference to the adjacency of a vowel to a final word boundary. If a word contains a consonant between a vowel and the final word boundary (42) would not mark that word as ungrammatical in L_{SG}. A word with one or more final consonants could still contain the substructure of (39c), which has been argued to be ungrammatical in L_{SG}. In order to rule out such ARs with final consonants, one could posit an additional series of FSCs in which the possible word-final consonants are represented with 'C' and enumerated adjacent to the final word boundary, as in (45).

(45) Sour grapes FSCs with consonants and boundaries on segmental tier



The FSCs in (45) above all contain one or more consonants adjacent to a vowel, a word boundary, or both. Including the FSCs in (45) means that a sour grapes vowel harmony pattern with word boundaries only on the segmental tier can still be captured by FSCs, but it requires more FSCs than any other pattern discussed in this paper.

6 Discussion

A goal of generative phonology repeated throughout this paper is to distinguish attested phonological patterns from unattested, but logically possible patterns. This distiction is clearly made if we posit a theory in which attested patterns are local and unattested patterns are nonlocal. We can make this distinction based on locality by positing that attested patterns must be describable by FSCs. 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 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 (2016) and Jardine (2017) found that FSCs over two-tiered ARs are expressive enough to capture a variety of attested tone patterns, which are thus local. Similarly, this qualifying paper has demonstrated the suitability of FSCs over multi-tiered ARs for capturing the attested vowel harmony patterns in Akan, Finnish, and Turkish. The FSCs for these patterns minimally consist of features on a tier connected to each other or a morpheme boundary by the successor relation. Maximally, the FSCs for the attested vowel harmony patterns examined here consist of vowels on a segmental tier associated to two different feature tiers with the successor relation connecting elements on one of the feature tiers. Based on these results and the definition of locality provided above, attested vowel harmony patterns are local.

However, FSCs over multi-tier ARs can also describe the unattested sour grapes pattern. Lamont (2018) showed that FSCs over two-tiered ARs are not expressive enough to capture an unattested sour grapes nasal harmony pattern. However, the interaction between multiple feature tiers allows FSCs over multi-tiered ARs to capture the so-called long distance blocking effect of a sour grapes vowel harmony pattern. When word boundaries are explicitly represented on the segmental or feature tiers, the sour grapes FSCs follow the same conventions as the FSCs of attested vowel harmony patterns: at least one vowel on the segmental tier is associated to features on two different feature tiers and the successor relation connects elements on only one feature tier. So, based on the above definition sour grapes vowel harmony is also local.

But the problem remains of distinguishing attested vowel harmony patterns from the unattested sour grapes vowel harmony pattern. Section 5 demonstrates that sour grapes vowel harmony can be captured by FSCs over multi-tiered ARs when word boundaries are represented only on the segmental tier or when word boundaries are represented on both the segmental and feature tiers. The fact that the theory outlined in this paper is not restrictive enough to exclude the unattested sour grapes pattern may suggest that the multi-tiered ARs used here are too expressive. Future work will investigate whether it is necessary to use string-based representations rather than ARs or if a more expressive class of grammars can capture attested vowel harmony patterns over multi-tiered ARs while excluding unattested patterns like sour grapes.

7 Conclusion

This qualifying paper adopts a formal language theory approach to determine the locality of vowel harmony patterns, but fails to distinguish attested vowel harmony patterns from a logically possible unattested sour grapes pattern. Using Jardine (2017)'s FSCs, attested surface vowel harmony patterns are shown to be local. However, the theory of well-formedness developed here is expressive enough to capture attested vowel harmony patterns, but not restrictive enough to rule out the unattested sour grapes pattern.

Unlike previous work on vowel harmony, this paper analyzes only surface ARs to show that given a uniform theory of markedness constraints attested vowel harmony patterns include those due to both spreading and agreement. Despite being derived by different assimilation processes, attested vowel harmony patterns can be considered as part of a single set of local patterns because they can be captured by FSCs over multi-tiered ARs.

Future work to be done on this topic will investigate the possibilities of restricting the representation or increasing the expressive power of the grammars that generate vowel harmony. One posibility is that it will be necessary to use string-based representations rather than ARs to represent vowel harmony patterns. Alternatively, a more expressive class of grammars may be able to capture attested vowel harmony patterns over multi-tiered ARs while excluding unattested patterns like sour grapes.

8 References

Archangeli, D., & Pulleyblank, D. (1994). *Grounded phonology* (Vol. 25). MIT Press.

Bakovic, E. (2000, January). *Harmony, dominance, and control* (PhD thesis). Rutgers University, New Brunswick, New Jersey.

Chandlee, J., & Heinz, J. (2018). Strict locality and phonological maps. *Linguistic Inquiry*, *49*(1), 23–60.

Chandlee, J., & Jardine, A. (2013). Learning phonological mappings by learning strictly local functions. In *Proceedings of the 2013 annual meeting on phonology*.

Chandlee, J., Eyraud, R., & Heinz, J. (2014). Learning strictly local subsequential functions. In *Transactions of the association for computational linguistics* (Vol. 2, pp. 491–503).

Clements, G. (1976). Vowel harmony in non-linear generative phonology: An autosegmental model.

Crothers, J., & Shibatani, M. (1980). Issues in the description of turkish vowel harmony. *Issues in the Description of Turkish Vowel Harmony*, 63–68.

deLacy, P. (2011). Markedness and faithfulness constraints. In M. van Oostendorp, C. Ewen, E. Hume, & K. Rice (Eds.), (pp. 1–22). Blackwell.

Goldsmith, J. (1976). *Autosegmental phonology* (PhD thesis). Massachusetts Institute of Technology.

Heinz, J., & Idsardi, W. (2013). What complexity differences reveal about domains in language. *Topics in Cognitive Science*, *5*(1), 111–131.

Heinz, J., Rawal, C., & Tanner, H. G. (2011). Tier-based strictly local constraints for phonology. In *Proceedings of the 49th annual meeting of the association for computational linguistics: Human language technologies: Short papers* (Vol. 2). Association for Computational Linguistics.

Jardine, A. (2016). *Locality and non-linear representations in tonal phonology* (PhD thesis). University of Delaware.

Jardine, A. (2017). The local nature of tone association patterns. *Phonology*, *34*(2), 385–405.

Jardine, A. (2018). The expressivity of autosegmental grammars.

Jardine, A., & Heinz, J. (2015a). A concatenation operation to derive autosegmental graphs. In *Proceedings of the 14th annual meeting on the mathematics of language (mol 2015)* (pp. 139–151). Chicago, USA: Association for Computational Linguistics.

Jardine, A., & Heinz, J. (2015b). Markedess constraints are negative: An autosegmental constraint definition language. In *Proceedings of the 51st annual meeting of the chicago linguistics society*.

Lamont, A. (2018). ms. University of Massachusetts Amherst.

Leben, W. (1973). *Suprasegmental phonology* (PhD thesis). Massachusetts Institute of Technology.

McCarthy, J. (1988). Feature geometry and dependency: A review. *Phonetica*, *38*. Retrieved from http://scholarworks.umass.edu/linguist_faculty_pubs/38

McCarthy, J. (2011). Autosegmental spreading in optimality theory. In *Tones and features* (Clements Memorial Volume., Vol. 27). Retrieved from https://scholarworks.umass.edu/linguist_faculty_pubs/27

Nevins, A. (2010). *Locality in vowel harmony*. *Linguistic Inquiry Monographs* (Vol. 55). MIT Press.

Odden, D. (1994). Adjacency parameters in phonology. *Language*, *70*(2), 289–330.

Padgett, J. (1995). Feature classes. In J. Beckman, S. Urbanczyk, & L. Walsh (Eds.), *Papers in optimality theory* (Vol. 18, pp. 385–420).

Padgett, J. (2002). Feature classes in phonology. *Language*, *78*(1), 81–110. Retrieved from http://www.jstor.org/stable/3086646

Prince, A., & Smolensky, P. (1993). *Optimality theory: Constraint interaction in generative grammar* (No. 2). Rutgers University Center for Cognitive Science.

Prince, A., & Smolensky, P. (2004). *Optimality theory: Constraint interaction in generative grammar*. Blackwell.

Ringen, C., & Heinamaki, O. (1999). Variation in finnish vowel harmony: An ot account. *Natural Languge and Linguistic Theory*, *17*, 303–337.

Ringen, C., & Vago, R. (1998). Hungarian vowel harmony in optimality. *Phonology*, *15*, 393–416.

Rogers, J., & Pullum, G. (2011). Aural pattern recognition experiments and the subregular hierarchy. *Journal of Logic, Language, and Information*, *20*, 329–342.

Rogers, J., Heinz, J., Fero, M., Hurst, J., Lambert, D., & Wibel, S. (2013). Cognitive and sub-regular complexity. *Formal Grammar*, 90–108.

Rose, S., & Walker, R. (2011). Harmony systems. In J. Goldsmith, J. Riggle, & A. Yu (Eds.), *The handbook of phonological theory* (pp. 240–290). Blackwell.

Sagey, E. (1986). *The representation of features and relations in non-linear phonology* (PhD thesis). Massachusetts Institute of Technology.

van der Hulst, H. (2017). A representational account of vowel harmony in terms of variable elements and licensing. In *Approaches to hungarian* (Vol. 15). John Benjamins Publishing Company.

van der Hulst, H., & Smith, N. (1986). On neutral vowels. In *The phonological representation of suprasegmentals* (pp. 233–281).

Välimaa-Blum, R. (1986). Finnish vowel harmony as a prescriptive and descriptive rule: An autosegmental account. In F. Marshall (Ed.), *Proceedings of the third eastern states conference on linguistics*. University of Pittsburgh.

Walker, R. (2010). Nonmyopic harmony and the nature of derivations. *Linguistic Inquiry*, *41*(1), 169–179.

Walker, R. (2014). Surface correspondence and discrete harmony triggers. In *Proceedings of the annual meetings on phonology*.