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Vowel Harmony in Optimality Theory

Abstract

This article reviews the analysis of vowel harmony in Optimality Theory. Vowel harmony is a phenomenon in which the vowels in a word or another domain show systematic agreement for some property, such as rounding, backness, height, or ATR quality. Optimality Theory is a framework of generative linguistics in which grammars consist of a hierarchy of constraints on outputs. The treatment of various aspects of harmony systems are discussed, including what drives harmony, directionality and trigger control, opaque and transparent segments, dominant-recessive patterns, and variation. Data from Turkish, Igbo, Pulaar, Diola Fogny, Finnish, and Hungarian are discussed.

1. Introduction

In vowel harmony, the vowels in a domain, such as the word, systematically agree, or 'harmonize', in some phonological property. For instance, in a language with harmony for lip rounding, words may contain round vowels or unround vowels, but they are not combined. Some systems have complexities that can give rise to interruptions in the harmony pattern. The treatment of vowel harmony in Optimality Theory (OT) has proved illuminating in some respects and challenging in others. In this article, I concentrate on optimality theoretic approaches to unbounded harmony, where harmony has the potential to operate to the full extent in some domain. This characteristic differs from bounded systems, where harmony necessarily reaches a specific location, such as a stressed syllable, and then halts, as occurs in Romance metaphony and Germanic umlaut. The constraints proposed to drive unbounded harmony generally differ from those used for bounded patterns (Klein 1995, Walker 2005, 2011, Finley 2009).

This paper focuses on some primary approaches to vowel harmony in OT. I assume a basic familiarity with OT and its formalisms (Prince and Smolensky 1993/2004, McCarthy 2007). I introduce the phenomenon of vowel harmony (§2), and then turn to some main themes in its analysis. First I discuss what drives vowels to harmonize (§3), and consider which vowel quality or position controls harmony (§4). Cross-cutting these topics is the issue of directionality. Next, I turn to opacity and transparency, where certain vowels halt harmony or are skipped by it (§5). Open issues and innovations are then discussed (§6), followed by the conclusion.

2. Vowel harmony phenomena

To begin, I illustrate the basic phenomenon of vowel harmony and introduce further characteristics as they become relevant in later sections. For overviews on vowel harmony, see van der Hulst and van de Weijer (1995), Archangeli and Pulleyblank (2007), and Rose and Walker (2011).

Turkish (Altaic) is well known for its vowel harmony. Turkish is a suffixing language, and suffix vowels harmonize with the root for backness (Clements and Sezer 1982). The front vowels in Turkish are [i, y, e, ø] and back vowels are [ɯ, u, a, o]. Vocalic alternations are illustrated in (1). Turkish also exhibits round harmony, discussed in §5.

(1)	<u>Nom. sg.</u>	<u>Gen. pl.</u>	
	ip	ip-l^{j}er-in	‘rope’
	kɯz	kɯz-lar-ɯn	‘girl’
	jyz	jyz-l^{j}er-in	‘face’
	pul	pul-lar-ɯn	‘stamp’
	el^j	el^j-l^{j}er-in	‘hand’
	sap	sap-lar-ɯn	‘stalk’

$k^jøj$	$k^jøj$-l^jer-in	'village'
son	son-lar-ɯn	'end'

Harmony in Turkish usually proceeds rightward. Other harmonies proceed leftward, while yet others are bidirectional. Backness harmony in Turkish native forms is exhaustive,[1] that is, vowels of all qualities can be *triggers* (initiate harmony), and all vowels can be *targets* (undergo harmony). However, not all vowel harmony is exhaustive, as discussed in §5.

3. What drives harmony?

A basic issue is what drives vowels to harmonize. In OT, harmony is driven by constraints. Several kinds of harmony-driving constraints have been proposed. I discuss some primary approaches named for the constraint-type involved: Alignment, Spreading, Agree, and Correspondence, and touch on some other strategies.

Alignment constraints that regulate features are a means of driving harmony that emerged early in OT. Kirchner (1993) extended the alignment constraint formalism of McCarthy and Prince (1993) to require that a feature have an association at a designated edge (left/right) of some morphological or prosodic category, such as the word. The basic strategy involves two constraints, an alignment constraint (2) and a faithfulness constraint (3), formulated for backness harmony below.

(2) ALIGN-Right([back], Word): For any feature [back] associated to a segment in a word, that feature has an association to the rightmost syllable of a word.

(3) IDENT-IO(back): Corresponding segments in the input and output have identical values for the feature [back].

The interaction of these constraints is illustrated in (4). For demonstration purposes, suffix vowels are [-back] in the input. However, their backness value in the output is determined by the vowel in the preceding syllable. The same result would be achieved here if they were [+back] or unspecified for [back] in the input.[2]

(4) Alignment-driven harmony

/sap-ler-in/ [+bk] [-bk] [-bk]	ALIGN-R([back], Word)	IDENT-IO(back)
☞ a. sap-lar-ɯn [+back]		**
b. sap-lar-in [+back] [-back]	*W	*L
c. sap-ler-in [+back] [-back]	**W	L

In candidate (a), [+back] spreads from the first vowel to all following syllables. This satisfies ALIGN-R and incurs two violations of IDENT-IO(back), which punishes a change in a vowel's specification for [back]. In (b), [+back] spreads to the second syllable only. This incurs a violation of ALIGN-R, which assigns a penalty for each syllable that intervenes between the rightmost association of a feature [±back] and the rightmost syllable of the word. In (c), [+back] does not spread at all, earning two violations of ALIGN-R. Here, [-back] has spread from the second syllable to the third, so ALIGN-R is obeyed with respect to [-back]. IDENT-IO(back) is obeyed in (c), because it enforces identity for the value of [back], not identity of associations.

Although alignment constraints designate a left/right edge, this does not always guarantee that the constraint will only promote harmony in the direction of that edge. This issue is taken up for Turkish in §4.

Other analyses of vowel harmony evolving the use of alignment constraints with autosegmental representations include Akinlabi (1994), Pulleyblank (1996) and Archangeli and Pulleyblank (2002). Cole and Kisseberth (1994) depart from autosegmental phonology and use alignment constraints operating over structures that they call feature domains to establish domains for harmony.[3] Within feature domains, harmony is achieved through the requirement that a feature be realized with the same value on its anchors (e.g. segment timing slots or moras).

An issue in the application of alignment constraints to harmony is the gradient nature of their violations. They assign different numbers of violation marks to a single locus of violation (e.g. a misaligned feature) according to a metric such as proportional distance in the segment string. McCarthy (2003) discusses reasons to prefer categorical constraints which assign a single violation mark to each locus of violation. See McCarthy (2003), Jurgec (2011), and Walker (2011) for alternative constraints to drive feature spreading that produce similar effects to traditional ALIGN-L/R(F) but which are formulated so as to assign a single mark to each locus of violation.

SPREAD(F) constraints are broadly similar in effect and evaluation to featural alignment constraints (Walker 1998, Padgett 2002; for related proposals see Kaun 1995, Polgárdi 1998). However, they do not reference a category edge, as exemplified in (5).

(5) SPREAD([back], Word): For all tokens of [back] in a word, if a token is linked to any segment, it is linked to all segments.

This constraint refers to segments, but it could refer to vowels instead. (On whether intervening consonants undergo assimilation for the harmonizing feature, see §5.) A violation is assigned for each segment in the word to which a token of [back] is not associated. This formalization promotes harmony in both directions, and unidirectional effects are attributed to the activity of other constraints (see §4).[4]

Some typological research underscores a functional motivation for harmony according to which perceptually weak features can be singled out to propagate in order to increase the likelihood of their accurate perception. This has led to versions of harmony-driving constraints that express a restriction on the feature that is subject to alignment or spreading. For instance, Kaun (1995) identifies a typological preference for front triggers for round harmony. She argues that rounding is more perceptually difficult in front vowels than in back vowels, and she formulates a harmony-driving constraint that requires [+round] in a [-back] vowel to be associated with all vowels in a word.

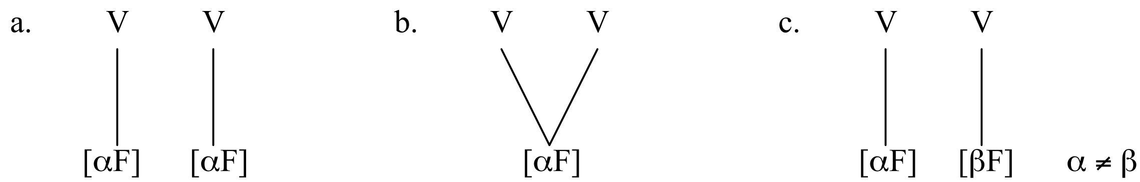
In principle, violations of a harmony-driving constraint could be calculated at the level of the feature rather than the segment. This is pursued in the feature-driven markedness approach (Beckman 1997, 1998), where constraints that encode markedness for a feature or feature combination, e.g. *[αF] or *[αF, βG][5], are also used to promote harmony for those features. In this analysis, a penalty is assigned to every autosegmental feature and spreading serves to minimize those penalties, because it reduces the number of features in the output. This predicts that harmony where triggering is favored by marked feature combinations should spread all features in the marked combination together. However, this is not always the case, as Kaun (1995) has show for perceptually weak triggers.

A different approach to what drives harmony makes use of AGREE(F) (Baković 2000).

(6) AGREE(F): Adjacent segments have the same value for the feature [F].

Like SPREAD(F) in (5), AGREE(F) does not encode a directional asymmetry. It differs from SPREAD in that it does not mandate that a feature be linked across segments, rather, the specified value must be identical. AGREE(F) is satisfied by the structures in (7a-b), but is violated by (7c). In harmonizing vowel sequences, the choice between structures in (7a) and (7b) will fall to other constraints.

(7)



Another property of AGREE that distinguishes it from ALIGN and SPREAD is that it incorporates locality directly, holding over adjacent elements only. As a result, AGREE assigns a penalty only at disharmonic junctures. For instance, AGREE(back) would assign a single violation to [sap-ler-in] in (4c), for the back-front vowel sequence in the first two syllables. ALIGN-R(back) and SPREAD(back) each assign a second violation for the back vowel in the first syllable being followed by a front vowel in the third syllable. This difference has ramifications for typological predictions, taken up in §6.

An approach with some similarities to AGREE employs constraints on feature sequences across segments to drive harmony (Smolensky 1993, Pulleyblank 2002, Mahanta 2007). As formulated by Pulleyblank, such constraints prohibit a sequence of X, Y on a tier, where X ≠ Y, with the constraint family structured so that interactions are stronger between elements that are more similar and closer in proximity. Pulleyblank argues that an advantage of this formalism is that it allows unification with dissimilation and polarity phenomena, which can be driven by constraints of the same type but prohibiting agreement, that is, penalizing sequences in which X = Y. In contrast to AGREE, sequential constraints can distinguish [+F] followed by [-F] from [-F] followed by [+F], so they have the potential to obtain certain kinds of unidirectional effects in harmony (Mahanta 2007).

In other research, harmonizing segments stand in a relation, formalized as *correspondence*, a concept used elsewhere in OT to characterize related structures (e.g. input-output, base-reduplicant; McCarthy and Prince 1995). Krämer (2003) hypothesizes that harmony results from constraints in the same family as those that require corresponding input and output segments to be alike, namely IDENT(F) constraints (see (3)); however, for harmony, the correspondence relation holds between elements within an output. Krämer terms this configuration 'syntagmatic correspondence.' A syntagmatic identity constraint, S-IDENT(F), requires that adjacent elements (e.g. segment, mora, etc.) in an output have identical values for feature [F]. Like AGREE, S-IDENT incorporates adjacency directly into its statement.

A different correspondence-based analysis uses agreement by correspondence (ABC), which is sensitive to the similarity of segments and was first developed for consonant harmony (Hansson 2001, Rose and Walker 2004). The application of ABC to vowel harmony is explored by Hansson (2006a), Rhodes (2008), Sasa (2009), and Walker (2009). In this approach, the correspondence relations formed between segments in an output are optimized through the activity of the constraint hierarchy; correspondence is not restricted to adjacent segments, nor is it guaranteed. The sensitivity to similarity makes ABC potentially well-suited for *parasitic* harmony patterns, where harmony operates only among vowels that agree in another dimension, such as round harmony that targets nonhigh vowels in Kazakh (Altaic) only when the trigger and target are both front (Korn 1969, Cole and Kisseberth 1994). Nevertheless, given typological differences between vowel harmony and consonant harmony, it remains an open question whether it is appropriate for them to be driven by the same type of constraint system.

Summing up, perspectives differ on the type of constraint that drives vowel harmony. Some constraints, like ALIGN and SPREAD, assess violations for all vowels that fail to harmonize within a domain, with ALIGN also being edge-focused and potentially unidirectional in effect. These constraints are most often used in conjunction with autosegmental feature spreading representations. On the other hand, constraints like AGREE and S-IDENT punish disharmony in adjacent sequences only, and they are not committed to representations where the harmonic feature links across harmonizing vowels. Both syntagmatic correspondence and ABC hypothesize a correspondence relation between harmonizing segments; however, in ABC similarity rather than adjacency is emphasized in determining which segments correspond.

4. Trigger control

Trigger control is an area in which the analysis of vowel harmony in OT has sparked progress. Trigger control refers to what determines which vowel serves as the source for harmonic assimilation. In rule-based approaches, properties of the trigger and the procedure by which harmony is carried out are explicitly identified. In contrast, harmony-driving constraints penalize disharmonic configurations, but do not dictate how they are repaired.

Positional faithfulness is a prime strategy for achieving trigger control when the trigger is in a prominent position. Beckman (1998) proposes that faithfulness constraints can single out positions that are phonetically or psycholinguistically prominent. These include (root-)initial syllables (Kaun 1995, Beckman 1997, 1998), stressed syllables (Beckman 1998, Majors 1998), morphological roots (McCarthy & Prince 1994, 1995), and final syllables (Krämer 2003, Petrova et al. 2006, Sasa 2009, Walker 2011). Backness harmony from a root-initial syllable is analyzed with the constraint in (8).

(8) IDENT-σ_1-IO(back): A segment in the root-initial syllable in the output and its corresponding segment in the input have identical values for [back].

Positional faithfulness constraints help to achieve trigger control because they discourage change in the designated prominent position and can resultingly drive other positions to yield. This tactic is illustrated in (9) for a traditional alignment-based approach to rightward harmony in Turkish.

(9) Trigger control: Positional faithfulness

/sap-ler-in/	IDENT-σ_1-IO(back)	ALIGN-R([back], Word)	IDENT-IO(back)
☞ a. sap-lar-ɯn [+back]			**
b. sep-ler-in [-back]	*W		*L

This tableau compares a candidate with rightward spreading of [+back] in (a) with a candidate where [-back] spreads leftward from the final syllable in (b). Despite the difference in direction of spreading, both candidates obey ALIGN-R, because in each the [back] feature is associated with the rightmost syllable, and ALIGN is not sensitive to the position from which the feature originated. Evaluated in relation to the input in (9), (b) fares better than the attested form in (a) with respect to the IDENT-IO(back) constraint that is not position sensitive. This comparison reveals that the right-edge designation in the ALIGN constraint is not sufficient to guarantee rightward spreading. However, position-sensitive IDENT-σ_1-IO(back) favors candidate (a) over (b), which results in rightward harmony.[6] Obtaining spreading in a particular direction using ALIGN(F) can thus require the activity of a constraint that determines trigger control.

Interestingly, positional faithfulness alone is sufficient to obtain unidirectional effects in many harmony patterns. In Turkish, the root-initial syllable is usually also the word-initial syllable, so a constraint enforcing identity for the root-initial syllable can achieve rightward harmony in native forms and it obviates the need for right-edge orientation in the constraint that drives harmony. Furthermore, despite its apparent unidirectionality, Turkish harmony can operate in the opposite direction under certain circumstances: vowels inserted to break up initial clusters in loan words show backness harmony with the following vowel, e.g. [pirens] ‘prince’, [gurup] ‘group’ (Clements and Sezer 1982, Krämer 2003). For reasons such as this, many analyses of harmony in OT use nondirectional harmony-driving constraints and obtain unidirectional effects through interaction with other constraints. Nevertheless, harmony-driving constraints that are edge oriented or otherwise directional could be motivated for directional asymmetries in certain configurations, as I discuss below.

Another trigger control effect is referred to as *stem control*, where the source for harmony in an affix is a vowel in the stem that forms the base for affixation. This phenomenon is demonstrated in the ATR harmony of Igbo (Niger-Congo; Green and Igwe 1963, Ringen 1975, 1979, Emenanjọ 1978, Zsiga 1997). Igbo has the following vowels: [+ATR] [i, u, e, o] and [-ATR] [ɪ, ʊ, a, ɔ]. In noncompound words, all vowels generally harmonize in their ATR value. The ATR quality of vowels in the root determines that of vowels in prefixes, suffixes and adjacent pronouns, shown by the alternations in (10). Roots are underlined.

(10)	e-sò	'following'	à-tʃɔ	'wanting'
	PART-follow		PART-want	
	o sī-ele	'he has cooked'	ɔ pì-ala	'he has squeezed'
	3SG. cook-PFCT		3SG. squeeze-PFCT	
	ò bu-ɣī	'he did not carry'	ɔ̀ zʊ-ɣɪ̄	'he did not train'
	3SG. carry-NEG		3SG. train-NEG	

Because harmony operates in both directions from the root, it cannot be considered unidirectional. Also, the harmony cannot be reduced to root control alone, because some suffixes do not alternate in their ATR quality, e.g. [sɪ] DISTRIBUTIVE, [vù-sì][7] 'carry' DSTR. Suffixes that follow a nonalternating suffix harmonize with the preceding suffix, that is, the closest vowel in the base of affixation determines the quality of an alternating suffix vowel, not necessarily the root, e.g. [(mà ɦ̃a) e-vū-te-sɪ-ɣɪ (abɔ)] '(if they) don't bring (the baskets)'.

Bakovič (2000) proposes that stem control is driven by a requirement that the base stem within an affixed form resemble the base stem in isolation. He postulates that the base stem and its affixed form stand in a correspondence relation and are subject to stem-affixed form (SA) faithfulness. An IDENT-SA(F) constraint requires that a segment in an affixed form and a corresponding segment in the base stem have identical values for [F]. In a form with the nested stem structure $[[[\text{root}]_{\text{stem}}\text{-suffix1}]_{\text{stem}}\text{-suffix2}]_{\text{stem}}$, $[\text{root}]_{\text{stem}}$ will form the base stem for [root-suffix1] and $[\text{root-suffix1}]_{\text{stem}}$ will form the base stem for [root-suffix1-suffix2]. Because the most peripheral affix will not have corresponding segments in the base stem, it will not be subject to segmental identity enforced by IDENT-SA(F), allowing it to undergo harmony controlled by a vowel in its base stem in a manner similar to trigger control achieved by positional faithfulness. Stem-controlled harmony will proceed cyclically due to the nesting of base stems. Note that for Igbo, something in addition to stem control will be needed to obtain nonalternating suffixes.

Returning to directionality, we have seen that positional faithfulness constraints can obtain unidirectional harmony in some situations where harmony is controlled by a vowel in a prominent position. Likewise, stem control can obtain unidirectionality in languages that are exclusively suffixing or prefixing and where harmony operates from stem to affix. However, not all unidirectional harmony patterns conform with what is predicted by these constraints (Mahanta 2007, Sasa 2009, Rose and Walker 2011). For example, Pulaar (Niger-Congo) exhibits a harmony in which mid vowels harmonize for [ATR] with a following vowel (Paradis 1992). Pulaar has seven vowels: [+ATR] [i, e, u, o] and [-ATR] [ɛ, ɔ, a]. High and low vowels are invariant in their ATR quality. Leftward directionality is demonstrated by the forms in (11), where a mid vowel is situated between syllables with opposite ATR values and it harmonizes with the following vowel.

(11) bin^{n}d-ɔː-wɔ ‘writer’

^{m}baroː-di ‘lion’

baro-gel ‘lion’ DIM

Since harmony operates from suffix to stem in these examples, leftward directionality is not derived from stem control or prioritizing the identity of vowels in the morphological root. Furthermore, an IDENT(F) constraint specific to the position that triggers harmony in combination with a nondirectional harmony-driving constraint does not guarantee leftward harmony (Sasa 2009), as shown in (12). IDENT-σ_{final}-IO(ATR) requires that a segment in the final syllable in the output and its correspondent in the input have identical values for [ATR].

(12) Leftward directionality: Final syllable faithfulness is insufficient

/bin^{n}d-oː-wɔ/	IDENT-σ_{final}-IO(ATR)	AGREE(ATR)	IDENT-IO(ATR)
(☞) a. bin^{n}d-ɔː-wɔ [+ATR] [-ATR]		*	*
☜ b. bin^{n}d-oː-wɔ [+ATR] [-ATR]		*	L
c. bin^{n}d-oː-wo [+ATR]	*W	L	*

Candidates with harmony to the medial syllable from the right (12a) or from the left (12b) tie with respect to a nondirectional harmony-driving constraint, given here as AGREE(ATR). Each candidate earns one violation for the disharmonic juncture where a [+ATR] vowel is followed by a [-ATR] vowel. In this input, the medial vowel is [+ATR], which causes IDENT-IO(ATR) to favor (b) over (a), an unwanted result, identified by '☜'. Candidate (c), with harmony to both mid vowels from the high vowel, is ruled out by final-syllable faithfulness. Another fully harmonizing candidate in which /i/ becomes [ɪ] would be ruled out using a constraint that penalizes high [-ATR] vowels.

One means of obtaining leftward harmony in Pulaar is to substitute traditional ALIGN-L([ATR], Word) for AGREE, as shown in (13). Candidate (a) is assigned one violation for misalignment of [-ATR], whereas (b) incurs two violations for the two syllables that separate [-ATR] from the left word edge.

(13) Leftward directionality: ALIGN-L

/bin^{n}d-oː-wɔ/	IDENT-σ_{final}-IO(ATR)	ALIGN-L([ATR], Word)	IDENT-IO(ATR)
☞ a. bin^{n}d-ɔː-wɔ [+ATR] [-ATR]		*	*
b. bin^{n}d-oː-wɔ [+ATR] [-ATR]		**W	L
c. bin^{n}d-oː-wo [+ATR]	*W	L	*

Assigning directionality to the harmony-driving constraint is not the only way to obtain directionality in Pulaar in an account employing faithfulness for the final syllable. In the context of a syntagmatic correspondence analysis, Krämer (2003) proposes that a constraint penalizing harmony from an affix is dominated by its counterpart for harmony from a root in Pulaar. He formulates this using INTEGRITY constraints that prohibit multiple correspondence of features.

Thus far we have considered cases where trigger control has been analyzed at least in part using faithfulness constraints for a prominent position or a stem. Yet in some harmony patterns, trigger status is determined by a vowel's value for the harmonic feature rather than the context in which the vowel occurs. These patterns are termed *dominant-recessive*. ATR harmony in Diola Fogny (Niger-Congo) is a dominant-recessive system (Sapir 1965, Ringen 1975, 1979, Baković 2000). Diola Fogny has [+ATR] vowels [i, u, e, o, ə] and [-ATR] vowels [ɪ, ʊ, ɛ, ɔ, a]. All vowels in a word harmonize for their ATR value. If any vowel in a word is [+ATR] underlyingly, all vowels are realized as [+ATR] (14a-b), otherwise all vowels are [-ATR] (14c). Roots are underlined.

(14) a. /nɪ-<u>jitum</u>-ɛn-ʊ/ [nijitumenu] 'I caused you to be led away'

1SG-lead away-CAUS-2PL

b. /nɪ-<u>baj</u>-ul-ʊ/ [nibəjulu] 'I have for you'

1SG-have-TOWARDSSPKR-2PL

c. /nɪ-baj-ɛn-ʊ/ [nɪbajɛnʊ] 'I caused you to have'

1SG-have-CAUS-2PL

In this system, [+ATR] serves as dominant and [-ATR] as recessive. Roots as well as affixes can undergo harmony and there is no positional affiliation associated with triggers.

One approach to these data employs faithfulness constraints that are sensitive to feature values or that are alternately formulated to distinguish between loss and addition of privative features (McCarthy and Prince 1995, Pater 1999). The constraint in (15) enforces faithfulness for segments with the dominant [+ATR] feature value in the input (Sasa 2006 citing Gressang 2002). It is ranked above its [-ATR] counterpart in (16), which can be violated in words with harmony for [+ATR].

(15) IDENT-IO(+ATR): If a segment is [+ATR] in the input, any corresponding segment in the output is [+ATR].

(16) IDENT-IO(-ATR): If a segment is [-ATR] in the input, any corresponding segment in the output is [-ATR].

The analysis is illustrated in (17) using AGREE(ATR), although this particular choice of harmony-driving constraint is not essential.

(17) Feature value-sensitive faithfulness

/nɪ-baj-ul-ʊ/	AGREE(ATR)	IDENT-IO(+ATR)	IDENT-IO(-ATR)
☞ a. ni-bəj-u-lu			***
b. nɪ-baj-ʊ-lʊ		*W	L
c. nɪ-baj-u-lʊ	**W		L

Candidate (a), with harmony controlled by the [+ATR] vowel in the first suffix, obeys AGREE(ATR) and IDENT-IO(+ATR), and it incurs three violations of IDENT-IO(-ATR). This candidate is favored over (b), in which [-ATR] harmony is triggered by the root, because /u/ → [ʊ] violates IDENT-IO(+ATR). Candidate (c) has two disharmonic syllable sequences, violating AGREE(ATR).

In the circumstance where all vowels are underlyingly [-ATR] (14c), a candidate where all vowels remain [-ATR] will obey each of the constraints in (17). In that case, a switch to [+ATR] vowels will be disfavored by IDENT-IO(-ATR).[8]

Baković (2000) questions the typological predictions of feature value-sensitive faithfulness and proposes instead to analyze control by the dominant value as 'assimilation to the unmarked'. He suggests that the dominant feature value is less marked in comparison to its recessive counterpart. His approach uses a complex constraint, *[-ATR] $\&_l$ IDENT-IO(ATR), which is a local conjunction of *[-ATR] and IDENT-IO(ATR). The complex constraint punishes segments that violate *both* of these constraints, that is, derived [-ATR] vowels: those that are [-ATR] in the output but [+ATR] in the input.[9]

To summarize, four main strategies for obtaining trigger control have been discussed. Positional faithfulness predicts control by prominent positions, and stem-affixed form faithfulness obtains cyclic stem control. For control in dominant-recessive patterns, faithfulness constraints that are sensitive to feature values have been employed, as have complex constraints that penalize derived marked vowels. Although unidirectionality can emerge as epiphenomenal in some systems with the first two types of trigger control, further devices for directionality or control are needed to obtain the range of attested unidirectional patterns.

5. Opaque and transparent segments

Vowels that fail to undergo harmony are called *neutral*. Those that halt harmony are *blocking* or *opaque segments* and those that are skipped (or appear to be so) are *transparent*. In optimality theoretic accounts, feature-based markedness constraints are the most common device used to drive vowels to behave as neutral. Yet what determines whether a neutral vowel is opaque or transparent is a more complex issue intersecting with assumptions about locality in representations.

Turkish round harmony presents a pattern with opaque segments (Clements and Sezer 1982). High vowels harmonize for [round] with a preceding vowel, as illustrated by the genitive suffix in singular forms in (18). However, nonhigh vowels block round harmony, that is, they are realized as unround following a round vowel and harmony for [+round] does not skip over them to reach later syllables, as demonstrated by the genitive plural forms. Backness harmony is also seen in these data, as introduced in §2.

(18)

Gen. sg.	Gen. pl.	
ip-in	ip-l^{j}er-in	‘rope’
kɯz-ɯn	kɯz-lar-ɯn	‘girl’
jyz-yn	jyz-l^{j}er-in	‘face’
pul-un	pul-lar-ɯn	‘stamp’
el^j-in	el^j-l^{j}er-in	‘hand’
sap-ɯn	sap-lar-ɯn	‘stalk’
k^{j}øj-yn	k^{j}øj-l^{j}er-in	‘village’
son-un	son-lar-ɯn	‘end’

Nonhigh round vowels [ø, o] are suggested to be marked, expressed by the constraint *[+round, -high] (Kirchner 1993, Kaun 1995). If *[+round, -high] dominates the constraint that drives round harmony, it can inhibit /e, a/ from undergoing round harmony. Positional faithfulness constraints ranked above *[+round, -high] can preserve [ø, o] in root-initial syllables, seen in (18).

In accounts where the harmony-driving constraint is applicable only to adjacent elements (e.g. AGREE(F), S-IDENT(F)), neutral vowels that are prevented from undergoing harmony are expected to block it, because the harmony constraint would not be better satisfied if a nonadjacent segment underwent harmony. On the other hand, SPREAD(F) lacks an adjacency stipulation: it requires a token of a feature to be associated with every segment in a word. An analysis using SPREAD(F) predicts blocking by vowels that cannot undergo harmony if it is assumed that feature associations cannot skip a segment. *Strict segmental locality* hypothesizes that no outputs are generated in which a single featural autosegment is associated with segments S_1 and S_3 but not an intervening segment S_2 (e.g. Ní Chiosáin and Padgett 1997, 2001, Walker 1998, Jurgec 2011). The same prediction is made with traditional ALIGN(F).

In analyses that assume strict segmental locality, consonants that intervene between harmonizing vowels must undergo harmony. Ní Chiosáin and Padgett (1997, 2001) argue that intervening consonants participate in vowel harmony, but may not be perceived as altered because of the low contrast potential for the harmonizing features in these segments. Under these assumptions, vowel harmony could by driven using constraints that enforce harmony in segments rather than vowels only. Alternatively, harmony-driving constraints or adjacency restrictions could be formulated to apply at a higher prosodic level, such as the mora or syllable head (e.g. Pulleyblank 1996, Krämer 2003).

It is noteworthy that feature-based markedness constraints and/or restrictions on locality play a prominent role in various rule-based accounts of vowel harmony developed prior to OT (e.g. Calabrese 1988, Archangeli and Pulleyblank 1994, Odden 1994). In OT, the constraint-centered grammars serve to naturally integrate these proposals in a unified fashion.

A special case of blocking occurs with segments that undergo harmony but do not transmit it. Such patterning has been identified in Karajá ([ATR] harmony, Macro-Jê; Ribeiro 2002, Rose and Walker 2011) and Icelandic (‘u-umlaut’, Germanic; Anderson 1972, Jurgec 2011). This type of blocking is not predicted by conventional featural markedness constraints, which inhibit the blocking segment from undergoing harmony. Jurgec (2011) terms these segments 'icy targets', and he analyzes them in OT with a theory of feature representations that incorporates heads. Jurgec proposes that segments to which autosegmental features are associated may serve as heads or nonheads for that feature, but only a head can propagate feature spreading. Icy targets are analyzed as nonheads, which causes them to terminate spreading. This proposal is implemented using head-sensitive featural markedness constraints, which prohibit a segment from being a head for [αF] when it is specified [βG].

Turning to vowels that behave as transparent, like opaque segments that do not serve as targets, such vowels are often analyzed as nonparticipants in harmony. An example occurs in the backness harmony of Finnish (Uralic), a suffixing language (Ringen 1975, Kiparsky 1981, van der Hulst and van de Weijer 1995, Ringen and Heinämäki 1999). Finnish has the following vowels: front [i, y, e, ø, æ] and back [u, o, a]. In native noncompound words, vowels are usually drawn either from the front set or the back set, producing alternations in suffix vowels, as shown in (19a). However, [i, e] can occur with vowels from either set (19b), and they are characterized as transparent, because harmony for [+back] can operate across them, as illustrated in (19c).

(19)	a.	pøytæ-næ	'table' ESSIVE
		pouta-na	'fine weather' ESSIVE
	b.	værttinæ	'spinning wheel'
		koti	'home'
		iso	'big'
		kesy	'tame'
		verho	'curtain'
	c.	koti-na	'home' ESSIVE
		lyo-da-kse-ni-ko	'for me to create'

cf. lyø-dæ-kse-ni-kø ‘for me to hit’

Like the tactic for nonparticipant opaque segments, transparency in harmony is suggested to be driven by feature-based markedness constraints, in this case *[+back, -round, -low], which prohibits back vowels that are nonlow and unround, [ɯ, ɤ] (Ringen and Heinämäki 1999). When ranked above the harmony-driving constraint, *[+back, -round, -low] will prevent [i, e] from undergoing harmony for [+back].

Harmony with transparent vowels shows what appears to be a nonlocal interaction. If locality is assumed to be strictly enforced at the segmental or syllabic level, this presents a difficulty, because blocking could be expected by vowels that do not undergo harmony, as discussed above. One solution is to treat whatever obtains locality as a violable constraint (e.g. Smolensky 1993, Cole & Kisseberth 1994, Uffmann 2004). The *SKIP(σ) constraint assigns a penalty when feature spreading skips an intervening syllable (Uffmann 2004, see Levergood 1984 for a precursor). When *SKIP(σ) is ranked below a harmony-driving constraint and a markedness constraint that prevents a vowel from undergoing assimilation, there is the potential for transparency, as illustrated in (20).

(20) Transparency: Violable *SKIP(σ)

/koti-næ/	*[+back, -round, -low]	SPREAD([+back], Word)	*SKIP(σ)
☞ a. koti-na [+back]		*	*
b. kotɯ-na [+back]	*W	L	L
c. koti-næ [+back]		**W	L

The input considered here has a front vowel in the suffix, and the SPREAD(F) constraint regulates [+back] only (Ringen and Heinämäki 1999). In (b), [+back] has spread from the first syllable to all vowels, but this incurs a violation of the prohibition on back vowels that are unround and nonlow. In (a), harmony skips [i] and targets the final vowel, violating *SKIP(σ). This fares better than (c) with respect to the higher-ranked SPREAD constraint. Specifications for [-back] are not shown here. Ringen and Heinämäki (1999:317) suggest that transparent [i] is unspecified for [back] in the output but realized as front.

Other approaches take the position that a feature with associations that skip segments or anchors at another prosodic level is not a well-formed phonological representation. A structure where feature associations skip a syllable, as in (20a), would thus not be generated as a candidate for evaluation. This raises the question of how to drive transparency if locality at the segmental or syllable level is inviolable. A related problem arises for analyses where the harmony-driving constraint refers to adjacent segments or syllables, such as AGREE(F) and S-IDENT(F). These constraints will not drive nonadjacent vowels to harmonize – (20a) will incur two violations with respect to these constraints for [back], one for the sequence [koti] ([+back] followed by [-back]) and one for the sequence [ti-na] ([-back] followed by [+back]), whereas (20c) will incur just one violation. These issues have given rise to several different proposals for the treatment of transparency.

Some analyses propose that something besides the primary harmony-driving constraint alone produces harmony across a transparent vowel. For example, transparency as *balance* characterizes transparent vowels as showing mutual harmony or mutual disharmony with both flanking syllables (Krämer 2003). Krämer implements this concept using local conjunction of constraints in his system. Other work considers the feature-based markedness constraint that prevents a transparent vowel from undergoing harmony to be *targeted* (Baković 2000, Baković and Wilson 2000). Departing from standard OT (Prince and Smolensky 1993/2004), a targeted constraint acts to favor a minimally perceptible repair for a form that violates the markedness constraint. Interacting with AGREE(F), it prefers transparency to opacity for vowels that do not undergo harmony because a candidate with transparency is more similar to the fully harmonic form.

A different perspective centers on the constraint(s) that drive harmony. Departing from traditional assumptions about the assessment of ALIGN(F), Pulleyblank (1996) proposes that it is evaluated locally with respect to potential anchors for a feature. As a result, ALIGN(F) can promote representations where duplicate occurrences of a harmonic feature appear in syllables flanking a transparent vowel. In an ABC analysis, where correspondence is not restricted to adjacent segments, transparency is achieved when intervening vowels do not correspond with those that harmonize. Because harmony is mediated through a correspondence relation which checks featural identity rather than imposing feature sharing, transparency does not violate strict segmental locality.[10]

Yet another slant questions whether transparent vowels do not participate in harmony. If 'transparent' vowels were considered to be phonological participants in harmony, then the problem of locality would be resolved. Finley (2008) proposes an abstract analysis in which transparent vowels undergo spreading for the harmonic feature but it is not pronounced in the segment's phonetic realization. Jurgec (2011) also hypothesizes that transparent vowels become associated to the harmonic feature, but the feature's associations are represented in such a way that it is realized less prominently on transparent segments than on segments characterized as targets. Jurgec's analysis connects to studies that have found evidence for systematic differences in the production of transparent vowels in contexts where they are said to be disharmonic with neighboring vowels versus those in which they harmonize, suggesting at least some degree of assimilatory effect. This issue has been examined in detail for transparent vowels in Hungarian (Uralic; Benus et al. 2004, Gafos and Benus 2006, Benus and Gafos 2007) and Kinande (Bantu;

Gick et al. 2006, Kenstowicz 2009). However, these articulatory differences do not always translate to perceptible distinctions of a magnitude that might be considered phonemic.

Related issues surround vowels that appear to trigger disharmony, termed 'Trojan vowels' by Krämer (2003). For instance, in Hungarian, certain roots described as containing a neutral front vowel take a back vowel suffix, while others take front vowel suffixes (Vago 1973). These vowels appear to have the same quality as front vowels that can be transparent in word-medial contexts, i.e. neutral vowels in Hungarian behave as transparent or in some roots as Trojan vowels. Some OT accounts have analyzed Trojan vowels in Hungarian so that they are featurally identical in outputs to the neutral vowels that take front suffixes (e.g. Ringen and Vago 1998 using floating features and Krämer 2003 using local constraint conjunction). On the other hand, articulatory research on Hungarian by Benus and Gafos (2007) found that neutral vowels in monosyllabic roots that take back vowel suffixes have a significantly less advanced tongue body position than neutral vowels in roots that select front vowel suffixes. Yet despite this difference the neutral vowels share a front perceptual quality. Gafos and Benus (2006) propose that analysis of these phenomena incorporate more nuances of the relation between articulatory and acoustic characteristics of vowels. Open questions remain about the implications of articulatory differences with perceptually subtle effects for the phonological analysis of vowel harmony. For an overview of the issues, see Gafos and Dye (2011).

To conclude, featural markedness constraints are a predominant means of obtaining neutral vowels' lack of participation in harmony. In analyses where adjacency is integral, blocking is a straightforward outcome, but the treatment of transparency is more complex. This has focused new attention on the representations that are involved in harmony and on investigating whether transparent vowels function as participants, and if they do, what the nature of their participation is.

6. Innovations and open issues

The analysis of vowel harmony in OT has contributed to new innovations that depart from aspects of standard OT. These proposals have come from two main research directions: variation in harmony and resolving problematic typological predictions.

Analyses of variation in vowel harmony within OT concentrate on capturing richer subtleties in the data beyond categorical characterizations of the behavior of speakers or speech communities. Patterns of variation have been investigated in Finnish (Ringen and Heinämäki 1999) and Hungarian (Hayes and Londe 2006; see Törkenczy 2011 for an overview). For example, in Hungarian, which shows backness and rounding harmony, [ɛ] is variably transparent, as evidenced by variation in suffix choice in a word like [hotɛl-nɔk] ~ [hotɛl-nɛk] 'hotel' DAT. The statistical tendencies in the data are not predicted by a single fully ordered hierarchy of constraints, which has led to re-examination of how grammars are modeled. One approach models grammars with partially ranked constraints, where the relative frequency of a form is predicted by the frequency with which it is selected out the available rankings (Ringen and Heinämäki 1999). Another strategy uses stochastically ranked constraints, where the relative ranking of constraints is not fixed but probabilistic, predicting a range of possibilities and the relative proportions of their attestation (Hayes and Londe 2006).[11] In work that seeks to address both phonetic and phonological properties of vowel harmony, as well as patterns of variation, constraints have been modeled in a dynamical fashion that integrates discrete and continuous aspects of the system (Gafos and Benus 2006).

Problematic typological predictions of analyses of harmony in OT have also given rise to new theoretical proposals. Wilson (2003) identifies various problems associated with conventional harmony-driving constraints. A traditional analysis of harmony using AGREE(F) predicts a 'sour grapes' effect. If every vowel in the domain does not harmonize, AGREE will not drive any vowels to harmonize, because an adjacent disharmonic sequence is present in a form with partial harmony and also in a form with no harmony, although the latter may be more faithful. Since forms with partial harmony are attested, this is an undergeneration problem. On the other hand, constraints like traditional ALIGN(F) and SPREAD(F) can obtain unattested nonlocal interactions with other phonological phenomena, because they incur more violations when more vowels fail to harmonize. In a word with an opaque vowel, scenarios are predicted that reduce the number of segments that are inaccessible to harmony, such as triggering of vowel deletion and blocking of epenthesis. These are overgeneration problems.

A variety of analyses that change fundamentals of conventional approaches have been proposed to address these issues. These include modifications to the representations over which harmony operates, in the form of feature spans (McCarthy 2004) and turbid representations (Finley 2008), and changes to the way constraints are evaluated, such as targeted constraints (Wilson 2003, 2006, Hansson 2006b) and weighted violations (Finley 2008). An account in the framework of harmonic serialism has also been proposed, where each change to a form is evaluated in succession in relation to the constraint hierarchy (McCarthy 2011). No consensus on the solutions has yet been reached, but the debate is central to new developments in OT and related theories.

7. Conclusion

To conclude, the analysis of vowel harmony in OT has stimulated new insights and has facilitated the integration of longstanding markedness-based observations. Difficulties for the analysis of transparent segments under certain assumptions about locality have engendered new questions about the nature of transparency and its cause. The constraints that drive vowel harmony and the representations over which they operate are areas where the field shows some of the least convergence. Continued investigation of issues surrounding harmony will surely be pivotal in driving future theoretical advances.

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[1] On disharmonic forms in Turkish, see Clements and Sezer (1982).

[2] In some analyses of Turkish, certain features are necessarily unspecified in the input in harmonizing vowels in order to distinguish them from exceptional vowels that do not alternate in harmony (e.g. Kirchner 1993, Inkelas 1995).

[3] See Smolensky (1993, 2006) for a proposal with some similarities.

[4] For a directional version of SPREAD, see Walker (1998).

[5] α and β are used as variables over feature values {+, –}.

[6] This tableau illustrates root-initial faithfulness as an approach to trigger control. In Turkish vowel harmony, however, root-initial faithfulness might not be sufficient when disharmonic forms are taken into account (Kirchner 1993).

[7] The verb 'carry' is transcribed as [bu] by Emenanjọ (1978) and [vu] by Green and Igwe (1963). Emenanjọ describes /v/ as marginal in Modern Igbo and often spelled as [b].

[8] A hypothetical input in which all vowels lack any [ATR] specification is a special case. If binary features were adopted and specification for [ATR] were enforced in outputs in this language, then the acquired harmonizing value would be decided by the ranking of featural markedness constraints, e.g. *[+ATR] and *[-ATR], because IDENT-IO(+ATR) and IDENT-IO(-ATR) would both be obeyed. Alternatively, faithfulness constraints penalizing feature insertion could decide the outcome. Pater (1999) proposes such constraints for privative features, e.g. IDENT-O→I(ATR): If a segment is [ATR] in the output, any corresponding segment in the input is [ATR].

[9] Baković (2000) proposes restricting this constraint to nonlow vowels.

[10] On blocking effects in ABC, see Hansson (2006b, 2007).

[11] See Hayes et al. (2009) on a probabilistic treatment that uses constraints that are weighted rather than ranked.

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