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Vowel Harmony

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Summary and Keywords

The subject of this article is vowel harmony. In its prototypical form, this phenomenon involves agreement between all vowels in a word for some phonological property (such as palatality, labiality, height or tongue root position). This agreement is then evidenced by agreement patterns *within* morphemes and by alternations in vowels when morphemes are combined into complex words, thus creating allomorphic alternations. Agreement involves one or more harmonic features for which vowels form harmonic pairs, such that each vowel has a harmonic counterpart in the other set. I will focus on vowels that fail to alternate, that are thus neutral (either inherently or in a specific context), and that will be either opaque or transparent to the process. We will compare approaches that use underspecification of binary features and approaches that use unary features. For vowel harmony, vowels are either triggers or targets, and for each, specific conditions may apply. Vowel harmony can be bidirectional or unidirectional and can display either a root control pattern or a dominant/recessive pattern.

Keywords: dominant/recessive, height harmony, labial harmony, locality, neutral vowel, opaque vowel, palatal harmony, parasitic harmony, tongue root harmony, transparent vowel, unary features, vowel harmony, neutralization

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The subject of this article is vowel harmony (henceforth, VH). In its prototypical form, this phenomenon involves agreement between all vowels in a word for some phonological property (such as palatality, labiality, or pharyngeal width). This agreement is evidenced by agreement patterns *within* morphemes and by alternations in vowels when morphemes are combined into complex words, thus creating allomorphic alternations. Prototypical, fully regular harmony can quite easily be treated in all theoretical approaches, either in terms of rules that copy the relevant feature value from a designated vowel (usually the first vowel), or in terms of a prosodic feature (autosegment) that “spreads” or associates to all vowel positions in the domain. This article will focus on the pivotal theoretical challenges posed by VH phenomena that arise when certain vowels *fail* to harmonize. After a detailed discussion of the resulting asymmetries in the vowel harmony pattern, considering various theoretical approaches, this article will present brief discussions of other relevant aspects of VH.[1]

1. Asymmetries in Vowel Harmony

1.1 General Properties of Vowel Harmony

Vowel harmony is a widespread phenomenon in the languages of the world, even though it may be unfamiliar to speakers of many widely used languages such as English, Chinese, or Spanish. In the most general sense, VH occurs when there is a requirement in a given language for all vowels within some domain, usually the “word” to agree in a particular phonetic property, such as lip rounding or tongue position (along the dimensions of front/back, high/low, and so on). When VH applies it has two consequences. Taking front/back harmony as an example (discussed in more detailed in section 1.3, “Transparency”), a first consequence is that all vowels within root morphemes agree for the relevant property, thus all vowels are either front or back. A second consequence is that vowels in affixes will, in a chameleonic way, harmonize with the vowels of the root. This implies that vowels in suffixes will display an alternation between front and back. In principle, this second effect “ripples” through all subsequent affixes so that the entire word (root and all affixes) end up having either front or back vowels. A system of this kind is called a root-control system. It is also possible, in some cases, for affix vowels to be “dominant” and, as such, influence the vowel qualities of vowels in roots (see section 3, “Root Control vs. Dominant Recessive Systems”).

From a functional point of view, it can be hypothesized that vowels come to harmonize as a result of low-level co-articulatory effects (between vowels in adjacent syllables across intervening consonants), which we find in all languages. Such low-level effects can then be said to be elevated to a degree that makes the effect perceptually noticeable, so that speakers start treating the effect as a mandatory trait of their language. As a result, VH can come to serve as a marker of “wordhood” since a switch from front to back vowels can now indicate the division between words.

VH has attracted a lot of attention within the field of phonology because it has a number of inherently interesting and theoretically challenging properties. The harmony requirement is “unbounded” in that it affects all vowels within the word, which seems to require a special mechanism when compared to local assimilations between neighboring segments. The process is also remarkable because (usually) it disregards the consonants that intervene between the harmonizing vowels. However, one might argue that, despite these properties, a fully regular and symmetrical VH system does not warrant the degree of attention that this phenomenon has received-especially since the dawn of Generative Phonology (Chomsky & Halle, 1968). In a fully symmetrical system, there would be two sets of vowels, different in a certain phonological property, and each word would contain vowels from either one set or the other. Consider the language Anum (better known as Gua; Western Kwa spoken in Ghana; Painter, 1971), which has ten vowels:

(1)

Advanced:[2]	/i, u, e, o, ɐ/
Non-advanced:	/ɪ, ʊ, ɛ, ɔ, a/

All vowels in every word-here with a classifier prefix-either agree in being or not being advanced:[3]

(2)

ɐ-toshi	'she goat'
a-dɪdɪ	'evening'
a-kʊnta	'brother-in-law'
ɐ-dudu	'charcoal'

The VH rule, assuming that it must target all vowels when there are multiple prefixes, has to apply in such a manner that it will affect *all* vowels within the word, which suggests some sort of *iterative* procedure, that is, a segmental rule copying feature values or a suprasegmental procedure involving spreading or associating a prosody or autosegment. In a segmental approach, we need a procedure that allows the rule to apply multiple times (as often as is necessary), each rule application creating the input for the next application of the same rule. With respect to the representation of vowels, the linguist has to decide whether the prefix vowel is "underlyingly" specified as "-" or "+", but a consensus exists on representing harmonizing vowels as lacking a value for the [ATR] feature; this is called *underspecification*. We also need to consider the fact that vowels *within* the root are in harmony (see the polysyllabic roots in set 2, above). If that kind of morpheme-internal agreement is going to be analyzed with the same rule, one would have to only fully specify one vowel in the root with a value for the feature and leave other vowels unspecified (still pursuing the idea that alternating vowels in the prefixes are also unspecified for a value). Then, the VH rule can apply both within roots and to prefix vowels. However, with reference to harmony within polysyllabic roots, we then need to decide which vowel is to be specified. For Anum, since prefixes require a leftward rule, we might then consider specifying the last root vowel fully. The situation can be more complex, however. While the data in (1) show the prefix to be "chameleonic" with respect to the first root vowel, we might also have suffix vowels that harmonize to the vowels of the root. We then need to make the rule *bidirectional*; but, with a bidirectional rule (however formalized), a choice for which vowel in the root is specified (the first or the last) becomes arbitrary. The issue of treating affix harmony and root-internal harmony with the same rule or not has generated much controversy and discussion. When two separate statements are used (a constraint on root and a rule for affixes), it would seem that a single generalization is expressed twice; this has been called "the duplication problem" (Kenstowicz & Kisseberth, 1977). A "compromising" consensus view (proposed in Crothers & Shibatani, 1980, and in Stewart, 1983) is to say that the VH functions as a general constraint on the well-formedness of words, which accounts for the harmonic nature of roots (in which case, one can assume that all vowels in roots are fully specified) and which triggers a repair operation in morphologically derived environments (leaving affix vowels unspecified).

Although this brief discussion does not exhaust all the questions that could or should be asked, even a fully symmetrical VH system (in which each vowel has a harmonic match) raises several intriguing questions as to what the best analysis is:

(3)

a.	How can we explain the "skipping" of consonants?
b.	How are alternating vowels specified?
c.	How do we account for the iterative, unbounded nature of VH?
d.	How do we deal with the issue of directionality?
e.	Is root-internal harmony and suffix harmony the same "process"?

We will return to some of these issues toward the end of this article. Our attention will not be geared toward cases in which there are vowels that fail to participate in the harmony. Reviewing the literature on VH of the last five decades, it is clear that the proper treatment of so-called asymmetries involving *disharmony* have captured most of the attention. Here there have been a variety of very different theoretical approaches and, presently, there is *no* consensus on this rather crucial aspect of VH.

Since it is important that we use of a consistent terminology, let us say that the feature involved in the harmony is the *harmonic feature* and that the vowels in (1) form *harmonic pairs* such that each vowel has a *harmonic counterpart* in the other set. Assuming the “analysis” for Anum just stated, we can say that one vowel, some root final vowel, is the *trigger* of VH, while all other vowels are *targets*.

1.2 Opacity

The issue of asymmetry arises when VH systems have certain vowels that “refuse” to agree. Such refusal can have several different causes, as we will see. For example, Tangale (West Chadic spoken in Nigeria; Jungraithmayr, 1971; Kidda, 1985) has an ATR-harmony system like Anum, but its vowel system is slightly different:

(4)

Advanced:	/i, u, e, o/
Non-advanced:	/ɪ, ʊ, ɛ, ɔ, a/

The non-advanced low vowel /a/ in Tangale misses a harmonic counterpart. This is what we call a *neutral vowel*. Many phonologists use this term simply because the vowel does not participate, but we could also take this term to indicate that the ATR contrast is *neutralized* for vowels that are low. This raises the empirical question of what the distribution of this vowel is and how it behaves. Can it only occur in non-advanced words, so that all words will be fully harmonic despite this gap in the vowel system? While we expect /a/ to occur with other [-ATR] vowels (as in (5a), the example in (5b) shows that /a/ can also occur in a root with [+ATR] vowels. The example in (5d) shows that /a/, when occurring in a suffix that is attached to a root with a [+ATR] vowel, remains unchanged. We also note that, in both (5b) and (5d), the vowel following /a/ ends up being [-ATR]. It would seem that the /a/ somehow prevents the preceding /u/ or /i/ from imposing their ATR value on the suffix vowels that follow the vowel /a/, whether in the root or in a suffix, while, at the same time, apparently imposing its own [-ATR] specification on following vowels:

(5)

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a.	tɛna- nɔ	‘my mortar’
b.	kulag-dɔ	‘her frying pan’
c.	pɛd-na-n-gɔ	‘untied me’
d.	ɗib-na-g-gʊ	‘cooked for us’

We can immediately understand the behavior of /a/ if we make two assumptions:

(6)

a.	VH operates locally, that is, from vowel to vowel.
b.	VH cannot affect vowels if this leads to an ill-formed combination of feature specifications (such as [+low, +ATR]).

The assumption of locality is quite generally adopted, implicitly or explicitly, but authors vary in seeing this as an inviolable constraint or not.[4] Assumption (6b) has been called the assumption of *structure preservation* (Kiparsky, 1982), which is characteristic of the class of so-called *lexical phonological rules* to which most VH rules seem to belong.[5] Given these assumptions, there is no way that the [+ATR] value of the root vowel /o/ in (9a) can “spread” to the vowel of the suffix /gʊ/.[6]

(7)

a.	pɛd	-nA	-n	-gO	[pɛdnangɔ]
	-ATR >>>>>>>>>>>>>				
b.	ɗib	-nA	-n	-gU	[ɗibnangʊ]
	+ATR > ||				

In this article, there will be no commitment to a specific formal theory of harmony. The “>>>>” notation is merely for visual presentation of the impact of whatever kind of copying or spreading rule we formulate to account for fact that the suffix vowels come to agree with the ATR-value of the root vowel. The crucial point to observe is that this rule cannot assign [+ATR] to the vowel in the suffix /nA/ because that would create a vowel type (a low advanced vowel) that does not occur in the phoneme inventory of Tangale. While the suffix vowels in (7a) receive their value from the root vowel, in (7b), both suffix vowels remain unspecified, given the opaque behavior of the vowel in /nA/, which is due to the constraint in (8), which can be stated as either (8a) or (8b):

(8)

a. *[+low, +ATR]
b. [+low] → [-ATR]

We must then assume that constraints of this kind, which define the lexical segmental inventory of a language, take precedence over a harmony rule. We now have to answer the question of how the unspecified vowels in (7b) acquire their [ATR] value. For /a/, the value is the predictably [-ATR] (because there is no advanced low vowel). This follows from the constraint in (8a/b) if we assume that (8a/b) can, actively, assign a predictable, also called *redundant value*, that is left unspecified (this, then, must happen after spreading). For the vowel /U/ in (7b), we must assume that there are rules, called *default rules*, that assign a value to features that remain unspecified at the end of the phonological derivation (i.e., after spreading and after rules that will have applied in predictable values). In this case the *default value* that we need is:[7]

(9) [0ATR] → [-ATR]

Given rule (9), we have, in fact, the option of leaving [-ATR] for /ɛ/ in the root unspecified as well, so that the apparent state of harmony would be the result of all vowels receiving the default value for [ATR]:

(10)

pEd	-nA	-n	-gO	[pɛdnangɔ]

This idea, called *Radical Underspecification* (Archangeli, 1984; Kiparsky, 1982) as expressed in (11):

(11) Predictable AND default values remain unspecified

By a general convention, called the *Elsewhere Conditon* (Kiparsky, 1973), we may assume that the general default assignment of [-ATR] is pre-empted by the more specific redundancy rule that assigns [-ATR], although in this case that does not really matter, since both rules assign the same value.

1.3 Transparency

Pursuing the behavior of "vowels that don't play ball," we now turn to another type of case, which will be illustrated with data from Finnish, which has front-back (or palatal) harmony. Here we also see asymmetries in the vowel system (ignoring length):

(12)

Front:/ü, ö, ä, i, e/
Back:/u, o, a/

Again, we find that the vowels that lack a harmonic counterpart (/i/ and /e/) can occur together in a word with vowels of both classes. This time, when such a vowel stands in between a front or back trigger and a target, it does *not* seem to block the value of the preceding trigger; if the trigger is back, this value thus seemingly passes right through the /i/ or /e/ without affecting these vowels which themselves are front:

(13)

a.	lyö-dä-kse-ni-kö	'for me to hit'
b.	lyo-da-kse-ni-ko	'for me to create'

How can we account for this apparent transparent behavior of /e/ and /i/? The spreading in (13a) is unproblematic. The vowels /i/ and /e/ are themselves predictably [-back], hence unspecified and spreading this same value to them does not violate the constraint on the combinations of feature specifications that bars back counterparts of /i/ and /e/:

(14)

a. *[-low, -round, +back]
b. [-low, -round] → [-back]

In other words, structure preservation does not block these vowels from undergoing spreading:

(15)

lyö	-dA	-ksE	-nI	-kO	[lyödäksenikö]
[-back] >>>>>>>>>>>>>>>>>>>>					

The case in (13b) is problematic, however. Seemingly, the [+back] value has to reach the rightmost suffix vowel, so that it will acquire the value [+back], but if spreading is local, as assumed for the purpose of explaining the opacity of /A/ in Tangale, spreading would have to stop at /E/, as per structure preservation induced blocking:

(16)

lyo	-dA	-ksE	-nI	-kO	[lyodakseniko]
[+back] >>>>>>>>||					

While /E/ and /I/ will acquire their front values through (14b), it is unclear how /O/ will end up being [+back].

Transparency has been accounted for in several ways. First, one might assume that the vowels in question are turned into [+back] vowels only to change them to [-back] by a rule of *absolute neutralization* after VH has applied. This solution rejects the notion of *structure preservation*, and it requires *extrinsic rule ordering* because the neutralization rule must apply after the VH rule. Early analyses in generative phonology would adopt an approach of this kind, which was designated as “abstract” in Kiparsky (1968). If this approach is adopted, we no longer have a principled account for the opacity of /A/ in Tangale, which postulates a crucial role for structure preservation, and we would have to conclude that any neutral vowel can behave either opaquely or transparently, depending on the language, which would, of course, predict a language just like Tangale, in which / a /would behave transparently, and a language like Finnish in which /I/ and /E/are opaque.

A second approach to account for the transparency of /I/ and /E/ is to give up locality and allow /I/ and /E/ to be “skipped.” Since /A/ in Tangale is not skipped, skipping would have to be a possible option that languages can choose, leading once more to the conclusion that neutral vowels of any kind can be opaque or transparent, depending on the language.

Either approach has far-reaching consequences that have been deemed undesirable. Rules of absolute neutralization have been charged with allowing overly abstract analyses

(Kiparsky, 1968), while abandoning locality is a big step in itself, given that locality has been widely held to be a characteristic property of linguistic rules.

We must note, however, that there is a third alternative (in line with the approach adopted for the ATR systems discussed above), which allows us to maintain both structure preservation and locality (and thus the account of opacity presented earlier). Let us suppose that the default value for [back] is [+back]:

(17) [0back] → [+back]

We can then represent the Finnish situation as follows:

(18) Finnish (default [+back])

a.	lyö	-dA	-ksE	-nI	-kO	[lyödäksenikö]
	[-back] >>>>>>>>>>>>>>>>>>					
b.	lyO	-dA	-ksE	-nI	-kO	[lyodakseniko]

To account for (18b), we assume, as before, that the general default assignment of [+back], due to (17), is pre-empted by the more specific redundancy rule that assigns [-back] to vowels that are [-low, -round], like (14b). Together, the redundancy rule and the default rule take care of example (18b). This account adopts the same theoretical stance with respect to underspecification as the analysis of Tangale.[8]

As shown, opacity and transparency can be accounted for while maintaining:

(19)

a.	Locality
b.	Structure preservation
c.	Underspecification of redundant and default values

The difference between Tangale and Finnish is that in Tangale the redundant value for /a/ is the same as the default value, namely [-ATR], while in Finnish the redundant value is [-back], while the default value is held to be [+back]. This difference may cause the illusion that in Tangale the neutral vowel /a/ imposes its value on subsequent vowels.

We must note that while the term *opaque* is adequate to the extent that it refers to vowels that block the spread of a harmonic feature, we cannot say the same for the term *transparent*, at least not if we accept the radical underspecification account given here in (18). When vowels in a palatal system show up as back preceding and following a neutral front vowel (as in 18b), there is, in fact, no spreading of backness through the front vowel. The idea that such spreading does occur has suggested the term *transparent*, but in the account presented in (18), there is no spreading of backness through neutral front vowels and hence, no transparency. We can, of course, continue to use the term *transparency* as a descriptive label for a certain type of situation, but we must bear in mind that this term is heavily based on the idea that both values of a harmonic feature spread, rather than just one as following from the radical underspecification approach.

We must note that the radical underspecification approach that we have applied to Tangale and Finnish suffers from a defect. Its success depends on selection of [-ATR] and [+back] as default values. Underspecification approaches are, however, not necessarily committed to the claim that default values are universally determined, and this allows, in principle, the reverse of Tangale and Finnish, with transparent /a/ and opaque /i/ and /e/, respectively. Contrary to the prediction that neutral vowels can behave opaquely or "transparently," irrespective of their surface value, one might want to claim that the behavior of neutral vowels in Tangale and Finnish is *not* accidental, which would be supported by the belief (expressed in van der Hulst, 1988; and van der Hulst & Smith, 1986) that the reverse of Tangale and Finnish, with transparent /A/ and opaque /I/ and /E/, respectively, does not exist. (We will see that this belief might be wrong.) A principled way to exclude the reverse of Tangale and Finnish is to postulate that phonological features are universally *unary*, following the lead of Dependency Phonology (Anderson & Ewen, 1987) and Government Phonology (Kaye, Lowenstamm, & Vergnaud, 1985).[9] For the cases discussed, this means that we need two unary primes:[10]

(20)

|ATR|
|FRONT|

If the unary primes in (20) are adopted, it would seem that neutral vowels, lacking the harmonic value *must* act opaquely (as in Tangale), whereas neutral vowels that possess (at least on the surface) the harmonic value are expected to act transparently (as in Finnish). Note, also, that the unary account does away with default rules. While it may require rules that assign *predictable* specifications of harmonic features (such as the frontness of [i] and [e] in Finnish), it will be suggested below that both defaults and predictable phonetic properties can be relegated to the level of "phonetic implementation" that follows the phonology. An argument for this will be provided.

In the remainder of this article, I will use this unary approach when discussing further examples. Arguably a unary feature approach, being more restricted than a binary approach, must be adopted until proven wrong (Kaye, 1988).

1.4 Disharmonic Morphemes

We have seen that both opaque vowels (vowels that are incompatible with the harmonic element) and transparent vowels (vowels that are compatible with the harmonic element) are potential targets for VH that fail to alternate because they *cannot* alternate, given that their harmonic counterpart is missing in the vowel system and given that VH is structure-preserving. In the cases discussed, refusal to alternate is phonologically systematic in that it results from a constraint on the vowel system (a *paradigmatic constraint*). We will now see that refusal to harmonize can also be caused by a positional restriction on the distribution of a vowel (a *syntagmatic constraint*). We can refer to this as *neutralization-by-position*. Votic, for example, while having the vowel phoneme /ö/, disallows this vowel to occur in any other than the first syllable (Blumenfeld & Toivonen, 2009). Votic also has a front-back harmony system and, as in Finnish, the neutral vowel /I/ is transparent. Our focus here is on the fact that if this /o/ is followed by yet another vowel that can alternate, the latter vowel is always back, which seems to indicate that the /o/ vowel acts opaquely, as predicted:

(21)

leip**o**-i-ta	'loaves of bread'
ein**o**-i-lla	'hay' (oblique case)

In addition to being based on paradigmatic or syntagmatic constraints, refusal to harmonize can also be *idiosyncratic*, namely when languages with harmony have morphemes containing vowels that do not submit to the harmony regulations even though participation is not in violation of any phonological constraint. This possibility occurs in two situations. Many languages with VH have a number of roots that contain vowels from different harmonic sets. Such roots are called *disharmonic roots* (which are often loanwords). As shown in Clements and Sezer (1982), Turkish, which has both palatal and

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labial harmony, contains a rather large number of such roots, showing many disharmonic combinations:

(22) Turkish disharmonic roots with /u/followed by a front vowel

lutfen	'please,'	bobin	'spool,'	otel	'hotel,'	muzip	'mischievous'
suret	'manner,'	polis	'police,'	rozet	'collar pin,'	kulis	'stage wing'

(23) Turkish disharmonic roots with /i/ or /e/ followed by a round vowel

pilot	'pilot,'	mevzu	'topic,'	petrol	'petrol,'	billur	'crystal'
cinko	'zinc,'	memur	'official,'	peron	'platform'	(rare)	

However, such roots productively engage in VH in the sense that suffix vowels will harmonize with the last root vowel. That the last root vowel determines the harmonic value of suffix vowels (rather than, let's say, the first root vowel) is fully consistent with the theory that rests on the assumption of locality. If the root vowel ends in a front vowel, its |FRONT| feature will spread to the suffix, while this is not possible (given locality) when the words ends in a back vowel that is preceded by a front vowel; in that case, the back vowel (/u/ in 24b) acts opaquely:

(24)

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a.	rO	zet	- lAr	‘collar pin PLUR’
		FRO >>>>>>>>>>		
	ROU			
	[ro	zet	ler]	
b.	mez	zU	-lAr	‘topic PLUR’
	FRO			
		ROU		
	[mez	zu	lar]	

At this point, one might wonder how disharmonic roots are represented such that the |FRONT| element in (24b) cannot spread to the /U/ (or to /O/ in 24a), given that there is no phonotactic constraint in Turkish to preclude that. Here it has been postulated that spreading can only occur in a morphologically derived environment. If VH is a lexical process, then the condition of being restricted to a derived environment is expected (Kiparsky, 1982).[11] This condition is consistent with the idea that there need not be any root internal harmonic spreading if we adopt the position, mentioned earlier, that the harmony rule functions as a constraint on roots. It could be argued that non-application of VH to roots can be made to follow from root vowels being fully specified in a binary feature approach, assuming that both values can be specified in roots, as well as assuming that VH cannot overrule lexically specifications. However, a unary model must adopt the derived environment condition for the cases in (25).

The second situation in which vowels refuse to harmonize on idiosyncratic grounds involves affix vowels that fail to harmonize. Such vowels or affixes are also called disharmonic, although in this case, that term does not refer to morpheme-internal disharmony (as in the case of disharmonic roots) but to disharmony across morpheme-boundaries.[12] For example, in Baiyinna Orochen (a Tungusic language), which has ATR harmony, some suffixes with /ɔ/ refuse to alternate with /o/. As expected, these /ɔ/s block spread of the element |ATR| (Li, 1996). In the following two examples, the root contains ATR vowels (/ə/ and /u/). The suffixes that contain /wO/ and /dU/ would normally alternate (between [wo-wɔ] and [du ~ dʊ]). After the invariant suffix /nɔr/, however, they show up as /wo/ and /du/, after an ATR root. Thus, since the non-alternating /nɔr/ intervenes, the

ATR feature of the last root vowel is unable to "reach" the alternating suffixes, as locality would have it:[13]

(25)

ətʃəxə-nɔr-wɔ-t	'paternal uncles DEF ACC'
ATR >>||	
nəxu(n)-nɔr-dʊ-t	'younger brothers DAT'
ATR>>||	

1.5 Anti-harmonic Vowels

The literature on VH has delivered various other labels for the behavior of vowels that somehow do not behave as expected, given the theory developed in the previous section. Here, I focus on the case in which certain vowels in roots seem to impose a harmonic feature *that is opposite to their own value* on vowels that follow them (assuming a left-to-right system). A well-known case in point is provided by Hungarian, which has a small class of roots that contain a neutral front vowel (/I/ or /E/), which take back suffixes, (26b), while the regular behavior for roots with neutral front vowels is to take front suffixes, (26a):

(26)

a.	vi:z-nAk	[vi:znɛk]	'water DAT'
b.	hi:d-nAk	[vi:znak][14]	'bridge DAT'

Törkenczy (2011) refers to the irregular roots such as /hi:d/ as anti-harmonic roots.[15] In various analyses, anti-harmonic roots have been treated in several different ways. First, one could imagine marking them simply as an exception to the harmony rule so that these roots will get the back variant of the suffixes as the default. Second, one could also provide the roots in question with a "floating feature"[16] [+back], which "docks on" the suffix vowel. Third, one could say that the vowels in these roots are lexically [+back]. In generative works (such as Vago, 1973), this would entail that these roots contain an "abstract vowel" /ɨ/, which never reaches the phonetic level. Hence, after harmony, a rule of absolute neutralization would convert every /ɨ/ into [i]. In a model that uses unary features, anti-harmonic roots simply lack the harmonic feature |FRONT|. The vowels /I/ and /E/ will be specified as front by a phonetic implementation rule. This analysis comes close to the abstract approach, but since it attributes, as a general matter, predictable values to phonetic implementation, it does suffer from the defect of needed and extrinsic ordering of the default rule after the harmony rule.

We have now discussed the various reasons for why asymmetries in VH systems can arise, and we have suggested a theory (albeit informally) that combines a specific form of strict locality and either radical underspecification or unary features that account for the fact that non-harmonizing vowels behave as either opaque or transparent in a predictable way. If the neutral vowel predictably lacks the harmonic feature (such as non-advance /a/ in an ATR system), it will act opaquely, but if it predictably bears the harmonic feature (such as front /e/ and /e/ in a FRONT system) it will act transparently. We will now consider cases that do not conform to this generalization, which necessitate some refinements of the theory.

2. Potential Problems

Although the approach that emerged in the preceding sections looks like a reasonably successful starting point for the development of an explicit formal theory of vowel, as for any theory that makes explicit predictions, counterexamples are to be expected. I will indicate the direction in which the approach suggested here offers ways of dealing with the problematic cases, although, as we will see, some cases remain problematic.

2.1 Unexpected Behavior of Neutral /i/ and /e/ in Palatal Systems

Contrary to what we observed for Finnish, there are other Uralic languages, such as Khanty (formerly Ostyak) (as discussed in Kiparsky & Pajusalu, 2002), in which neutral vowels impose their frontness property on subsequent suffix vowels:

(27)[17]

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Khanty						
a.	lyö	-dA	-ksE	-nI	-kO	[lyödäksenikö]
	FRONT >>>>>>>>>>>>>>>>>>					
b.	lyO	-dA	-kse	-ni	-kO	[lyodaksenikö]
			FRO FRO >>>>			

In Khanty, the frontness of the suffix /kö/ is required. I suggest that the frontness of [kö] can be derived by allowing the frontness of the preceding neutral vowel /i/ to spread. While this is unexpected because the frontness if the neutral vowel /i/ is predictable, it does not invalidate the notion of locality. We simply have to assume that predictable features are not necessarily phonologically inactive; that is, they can be specified in the lexical representation.

Kiparsky and Pajusalu (2002) also discuss the case of Mulgi, another Uralic language belonging to the Finnic subgroup, which requires all vowels following /i/ and /e/ to be back, even when these vowels are preceded by harmonic front vowels. In other words, in Mulgi, all neutral vowels are anti-harmonic. While also unexpected, this situation again does not entail a violation of locality, since the backness of vowels that follow neutral front vowels is not related to the quality of vowels that precede the neutral vowels.

An account of the two kinds of behavior of [i] and [e] is possible if we assume the following:

(28)

a.	Khanty: [i] and [e] derive from underlying /i/ and /e/ (specified as FRONT)					
i.	lyö	-dA	-ksE	-nI	-kO	[lyödäksenikö]
	FRONT >>>>>>>>>>>>>>>>>>					
ii.	lyO	-dA	-kse	-ni	-kO	[lyodaksenikö]
			FRO	FRO		
b.	Mulgi: [i] and [e] derive from underlying /ɨ/and /ə/(not specified a FRONT)					
i.	lyö	-dA	-ksə	-ni	-kO	[lyödäkseniko]
	FRONT >>>>> ||					
ii.	lyO	-dA	-ksə	-ni	-kO	[lyodakseniko]

In this account, both Khanty and Mulgi differ from Finnish in that the neutral vowels are *un*ambiguous in the former (front in Khanty and back in Mulgi), whereas in Finnish these vowels have two sources: one with |FRONT| (lexically specified or resulting from spreading) and one without. As a generalization we can state that, in Finnish, neutral vowels are non-front after non-front harmonic vowels and front otherwise:

(29) a. Finnish: [i] and [e] derive from underlying non-front after harmonic non-front vowels (case ii), else from front vowels (case i):

i.	lyö	-dA	-kse	-ni	-kO	[lyödäksenikö]
	FRONT >>> FRO FRO >>>>>					
ii.	lyO	-dA	-ksE	-nI	-kO	[lyodakseniko]

The “elsewhere” cases account for the fact that roots with only neutral vowels always take front suffixes in Finnish.

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We now expect a fourth type, which differs from Finnish in taking a different “elsewhere” statement, namely taking back suffixes after neutral vowel roots. This type is instantiated by the language Uygur, which operates like Finnish, except for the fact that neutral vowel roots always take back suffixes. This case, then, instantiates the fourth logical possibility (e.g. 30b):[18]

(30) A typology of the behavior of neutral front vowels in patalal harmony (taking [i] as representative):

a: Khanty: [i] is always /i/	(context-free frontness)
b: Uygur: [i] is /i/ after a front vowel, else /ɨ/	(context-sensitive frontness)
c: Finnish [i] is /ɨ/after a back vowel, else /i/	(context-sensitive backness)
d: Mulgi: [i] is always /ɨ/	(context-free backness)

The cases (a) to (d) show an increase in violating “the naturalness condition” (Postal, 1968), which demands the underlying representation to be the same as the phonetic representation. This is fully observed in (a) and fully violated in (d), with (b) and (c) being the only two possible intermediate cases. We thus expect case (d) to be the most “unnatural” (and thus perhaps unstable, rarer etc.), as well as more difficult case to learn.

In Hungarian, which would be analyzed as Finnish, following (30c), so-called neutral vowel roots come in two categories. The regular case (in which such roots take front suffix vowels) is as in Finnish, whereas the irregular case (in which such roots, being anti-harmonic, take back suffix vowels) is as in Uygur. We can account for this by representing the anti-harmonic words without the feature |FRONT||, which makes them violations of generalization (30c), thus explaining their exceptional character.

2.2 Unexpected Transparency and Opacity: The Case of Khalka (Mongolian)

In Khalkha (Mongolian), two harmonies are operative, ATR and labial harmony. Labial harmony raises some interesting issues. The vowel system of Khalkha is as in (31a); (31b) shows the harmonic pairs for labial harmony (Svantesson, 1985):

(31)

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a.	Vowel system (KM)
i	u
	ʊ
e	o
a	ɔ
b.	Harmonic pairs for labial harmony
e-o	
a-ɔ	
Unpaired: i, u, ʊ	

As shown, labial harmony does not affect high vowels, but given that this is so, these vowels behave unexpectedly, in that [u] and [ʊ], which obviously bear the rounding property, are opaque for the propagation of roundness. This is unexpected because thus far we saw that neutral vowels that are compatible with the harmonic value act transparently (as [i] and [e] in Finnish, for example). Nor do they cause roundness on the vowels following. Even worse, the vowel [i], which is incompatible with the spreading value, acts transparently. Here strict locality seems to be clearly violated. The vowel /i/is not affected by roundness, but non-high vowels following it become round:

(32) Transparent [i] (with respect to labial harmony)

piir-ig-e	'brush ACC RFL'	pirr-e	'brush RFL'
suuʒ-ig-e	'tail ACC RFL'	suuʒ-e	'tail RFL'
teeʒ-ig-e	'gown ACC RFL'	teeʒ-e	'gown RFL'
poor-ig-o	'tail ACC RFL'	poor-o	'tail RFL'
mʊʊr-ig-a	'cat ACC RFL'	mʊʊr-a	'cat RFL'
cʰaas-ig-a	'paper ACC RFL'	cʰaas-a	'paper RFL'

If there is an appropriate use for the term transparency, then it would seem that the behavior of Khalkha [i] qualifies as an excellent candidate. It has been suggested by various researchers that the key to understanding the unexpected behavior of the high vowels lies in the fact that VH is restricted to non-high vowels. Only vowels that already agree in being non-high agree in roundness. Steriade (1981) has insightfully termed harmony that is dependent on agreement for some other feature *parasitic harmony*; also see Cole and Trigo (1988). Parasitic harmony has a natural basis in the sense that it is easier for units that are already in agreement on one point to also agree on a second point. (As always, phonemes are just like people.) Ultan, in his survey of VH, captured the central idea as follows: "the lesser the phonetic distance between opposing members of potential vowel grades the more prone they will be to harmonize" (Ultan, 1973, p. 53).

Whatever the functional bases of parasicity, it would seem that the dependence of one agreement relation on another agreement relation opens the possibility to say that locality for the former is defined with reference to the later. Concretely, if we assume that the labiality relation is parasitic on agreement in being non-high, we can say (and formally express) that high vowels are invisible (/i/), unless, of course, those vowels contain the property that is being spread (as do /u/ and /ʊ/):

(33)

a.	|R| >>>>>>>>>>>>>>>>>>>>>		
	|L|		|L|
	/o/	/i/	/a/
b.	|R| >>>>>>>||	|R|	
	|L|		|L|
	/o/	/u/	/a/

As shown in (33a), [o] can spread its roundness (the feature |ROUND|) to [a] because the two vowels are adjacent on the |LOW|-tier. The intervening vowel is simply invisible, having no presence of either the |LOW|-tier or the |ROUND|-tier. In (33b), however, while the vowel [u] is not present on the |LOW|-tier, it is present on the |ROUND|-tier where it blocks the communication between [o] and [a].[19] With agreement on the |LOW| being a condition for |ROUND|-spreading, [u] and [ʊ] cannot induce |U|-spreading themselves. In the terminology of Charette and Göksel (1998), the agreement in having the property |LOW| creates a "bridge" for labial harmony.

2.3 Unexpected Transparency of /a/ in Tongue Root Systems

We have seen that, in a language with ATR harmony, the low vowel [a], when missing an advanced harmonic counterpart, acts opaquely. For a while it seemed as if the harmony system of Kinande presented a counterexample to this claim (Schlindwein, 1987). The crucial issue in this case is that, while VH in most cases is considered a *lexical rule*, subject to *structure preservation*, VH in Kinande must be analyzed as *a post-lexical rule*. This is evidenced, among other things, by the fact that it produces allophonic vowel qualities, namely raised mid vowels, that are thus not lexically contrastive. In addition, it turns out that the low vowels are not transparent in the intended sense of being unaffected and "skipped." Rather, the long low /a:/ is clearly affected by ATR-spreading, and this effect is less noticeable on short /a/ due to its shortness (Gick, Pulleyblank, Campbell, & Mutaka, 2006).

However, there are other cases with reported transparent [a], in systems in which this vowel also misses an advanced counterpart. Kutsch-Lojenga (1994) reports on a tongue root harmony system in Kibudu (a Bantu language spoken in Zaire). She states that /a/ is transparent to [+ATR] spreading, which is illustrated by the following examples:

(34)

a.	mʊ-kanɪ	mɪ-kanɪ	'stone, pip of a fruit'	noun classes 3/4
b.	mu-tanji	mi-tanji	'type of wild animal'	noun classes 3/4

As shown, the noun class prefix vowels harmonize with the vowel that is to the right of the vowel /a/; see Kutsch-Lojenga (2008) for another case of this kind.

To analyze such data, while preserving locality as understood here, it would have to be assumed that the spreading element is not |ATR|, but |RTR|. To postulate two apparently opposing unary features involves a weakening of the unary hypothesis.[20] Archangeli and Pulleyblank (1994) handle cases of this kind by a rule that inserts [+ATR] "on the other side" of the neutral vowel, thus avoiding spreading across it.

Having discussed a possible account of asymmetric aspects of VH, we now turn to a brief overview of some other general properties of VH systems.

3. Root Control vs. Dominant Recessive Systems

In all examples that were given in sections 2 and 3, harmonic alternations can be found only in affixes. This pattern is usually referred to with the term *root control*. It can be said that, in such systems, the harmony starts with the first affix that attaches to a root, such that the affix vowel harmonizes with the root vowel that it is closest to. This is not, however, how it always works. In the domain of VH, we also find cases in which roots can alternate due to the influence of affixes. In Hall, Hall, Pam, Myers, Antell, and Cherono (1974), the example of Kalenjin is provided. This language has ten vowels:

(35)

Advanced:	/i, u, e, o, ɐ/
Non-advanced:	/ɪ, ʊ, ɛ, ɔ, a/

The following examples are cited from Lodge (1995):

(36)

a.	ke:r	-ʊn	→ [ke:run] ‘see it from here’
	‘see’	directional suffix	

b.	kʊ:t	-ʊn	→ [kʊ:tʊn] ‘blow it here’
	‘blow’	directional suffix	

c.	ka-	a-	kʊ:t	-e	→ [kɐ:ɤu:te] ‘I was blowing’
	past	l sg subj	blow	continuous suffix	

d.	kɪ-	a-	un	-kɛj	→ [kiɐungej] ‘I washed myself’
	past	l sg	‘wash’	reflexive	

e.	ka-	- **ka**:	kɔ-	ke:r	-a	→ [kaɤa:ɤoɤe:rɐ]
	perfective		aspect	1 sg obj		‘he had seen me’

As shown, in Kalenjin, the presence of any morpheme with an ATR vowel will cause all vowels in the word to be advanced; the ATR vowel can occur in roots or in affixes. A few morphemes have non-alternating [a], and these block the propagation of ATR, as would be expected. This is shown in (36e). The fact that VH in Kalenjin seems to be triggered by the presence of any [+ATR] vowel suggests the idea that this value is “dominant” over the “recessive” [-ATR] value. As a consequence, systems of this sort have been called dominant-recessive systems in Halle and Vergnaud (1981).[21] Aoki (1968) calls them *asymmetrical*, and he refers to root-control systems as symmetrical or equipollent since, as he sees it, in the latter systems, both values of the feature have equal status. In the preceding section, I have shown that root control systems can be analyzed with only one value being specified. So how should we understand the difference between root control and dominant/recessive systems given such a model? Anderson (1980) makes the following proposal. While in root control systems only roots can possess the element ATR, there is no such restriction in dominant/recessive systems. In Kalenjin, roots can alternate because there *are* affixes (albeit only suffixes)[22] that contain the ATR element. This viewpoint predicts that in the so-called root-control systems, no affixes can be found that are inherently specified with the harmonic element. There may be empirical problems with this prediction, however. For example, a problem for the idea that there are no affixes that invariantly have the harmonic feature in root controlled systems can be found in Turkish, which has suffixes that have /i/'s (see Kabak, 2011).

A very different angle on the distinction between both types of systems is offered in Casali (2003, 2008). Based on a large corpus of African languages, Casali concludes that dominance of [+ATR] correlates with vowel systems that distinguish two series of high vowels, [+ATR] and [ATR]. In Casali's approach, the presence of this contrast necessitates the use of the feature [±ATR]. Casali provides evidence that in such systems [+ATR] is "marked value" (for vowels that have this value in the surface). In systems that have no such contrast, the alleged difference in ATR (among mid vowels) can be represented without "activating" the feature [±ATR], and those systems are claimed to use the feature [±RTR], with [+RTR] being the marked value. Casali's claim is that [+ATR], when present in a system, can lead to dominant/recessive patterns. This account does not necessarily explain why there would be no dominant/recessive systems in which, say [+RTR] is dominant. Arguably, a unary approach would explain this if there were no such feature, that is, if tongue root oppositions in mid vowels (in systems lack the opposition among high vowels) were made in some other way. Also, it remains unexplained why we do not find dominant/recessive systems in harmonies that involve other features.[23]

4. Terminology and Typology

Commenting on terminology, Ultan (1973) shows that the term "harmony" has often been associated with progressive (left-to-right) directionality, whereas *metaphony* and *umlaut* have been associated with regressive interdependencies between vowels. It is not clear that such statements have a convincing empirical basis. More crucially, the latter labels have been used where stress is a necessary property of either the trigger or the target.

While there are many languages with VH, it seems that, in terms of genetic distribution, palatal harmony mostly occurs in Altaic and Uralic languages, which may imply that all these cases go back to a single case in the Altaic-Uralic protolanguage (Anderson, 1980). Mongolian-Tungusic languages, which fall within the Altaic group, have palatal systems or pharyngeal width systems, with the latter sometimes seen as developments of a prior palatal system (see Svantesson, 1985). "ATR" harmony is pervasive in African languages, specifically in the Nilotic Niger-Khordofanian and Nilo-Saharan families. In all systems that involve pharyngeal width, the question comes up whether advancement or retraction is the dominant value or element. Various Paleosiberian and Asian languages display harmony involving aperture or pharyngeal width (often analyzed in terms of tongue root retraction); see Kim (1978). Vowel raising and lowering (aperture) harmonies occur in many Bantu languages. Isolated cases of harmony occur in other families (Dravidian, North American languages), while stress-related cases of VH (i.e., umlaut and metaphony) occur in Germanic (Klein, 2000; McCormick, 1982) and Romance languages (Calabrese, 2011), involving palatalization and raising, respectively.[24]

In principle, one might expect to find cases of harmony (as a lexical process) for every property that vowels can have distinctively. However, while tones can spread from vowel to vowel, no language has been reported to have tonal harmony such that, for example, all vowels within some domain must have the same tone; see Hyman (2002) for a discussion of differences between tonal spreading and VH. Likewise, although phonation properties can act as distinctive for vowels, no case has been made for phonation harmony.

We have encountered cases of harmony based on palatality (front), labiality (round), height (high/low), and pharyngeal width (ATR/RTR). We also find harmony based on the tense/lax distinction (Hooper, 1976 on Grenada Spanish; and Zubizaretta, 1979 on Andalusian Spanish). It has been explicitly claimed that height and tongue root are phonetic manifestations of one phonological category (Clements, 1991). Schane (1990) also includes tense/lax in this category.

Another category of VH, often called total VH, occurs in various Australian languages,which have three vowels (/i/, /u/, and /a/) and harmony among those; see van der Hulst and Smith (1985) and Pensalfini (2002).

The language Yoruk (Robins, 1958; Smith, de Wit, & Noske, 1988) presents an isolated case of VH that involves the property of retroflexion (also known as r-coloring). Nasality can also have an extended domain, but nasal harmony systems usually affect both vowels and consonants (although not all consonants) in such a manner that certain types of consonants will block the propagation of nasality, which starts either at an edge or from a nasal consonant. Systems in which nasality harmonizes purely with reference to vowels have not been reported. See Piggott (1988) for an overview of nasal harmony systems.

5. Mechanisms of Vowel Harmony

Thus far, we have hardly discussed how VH should be formally represented. In section 2 “Potential Problems,” I used certain notation (“>>>>”) for the sole purpose of introducing some basic properties of VH spreading. In this section, partly following Anderson (1980), I will briefly review four types of approaches:

(37)

a. Iterative linear (assimilation) rules
b. Copy rules
c. Spreading rules
d. Rules of prosody assignment

Assimilation rules cause a change in the feature specification of a target in some environments using the format: A → B /X-Y, based on Chomsky and Halle (1968). While the rule format of Chomsky and Halle allows operations that assign values to targets that are unrelated to the triggering environment (i.e., assign nasality in the context of round vowels), "copy" models for VH, using the same rule format, have been proposed with the added stipulations that VH rules can only be feature-filling *copying* rules (Mailhot & Reiss, 2007; Nevins, 2010). Vowels that are unspecified for a feature value initiate a "search" for a value that they can copy.[25] The idea of feature *spreading* is inspired by the study of tone, where many cases of tonal assimilation suggest that the tone from a trigger literally extends its domain to neighboring vowels (as in the autosegmental approach proposed in Goldsmith, 1976; and see Clements, 1976).[26] Anderson (1980) expresses reservation about the appropriateness of the spreading model for VH. The fourth approach, (37d), recognizes the specification of the harmonic property at the level of the morpheme, which then calls for a procedure to transfer this morphemic property to the vowels. Lightner (1965), who adopts this approach, which is also promoted in Chomsky and Halle (1968), even suggested that the morphemic specification is not a phonological feature, but rather a diacritic (which, nonetheless, he provided with names that are also used for features).[27] In between the third and fourth approach, we could place the so-called metrical approach to VH (see McCarthy, 1979; Zubizaretta, 1979). Vergnaud (1977, 1979) proposes a formal model that incorporates aspects of both autosegmental association (root internal harmony) and "metrical" binary branching structure (for suffix harmony). Tohsaku (1983) proposes a variant of the metrical approach (using flat structure, called *tellis structures*) and a recent revival of using binary trees can be found in Jurgec (2011).

While in SPE, constraints (called segment structure and morpheme structure conditions) bear on lexical-underlying representations, which are subsequently modified by rules, various phonologists argued early on for a different conception of phonology. They argued that rules should be represented as attempts to bring underlying representations that result from morphological concatenation, into conformity with constraints that define the well-formedness of the “surface representation” (Kisseberth, 1970). This eventually led to the so-called *constraint-and-repair model* (already alluded to in section 2.1, “*Unexpected Behavior of Neutral /i/ and /e/ in Palatal Systems*”) of phonology (Calabrese, 2005). I review these developments, with additional references in van der Hulst (2011). In an output-oriented approach, VH is stated as a constraint of some sort, most typically one that demands feature value identity between adjacent vowels. This constraint would account for the state of root internal harmony directly without the need for a procedure that brings the harmony about. In this approach, roots can simply be lexically fully specified. When morphemes are concatenated, a violation of harmony may occur, and repair rules will fix the problem by either filling in values or changing value (depending on whether or not use is made of underspecification). Crothers and Shibatani (1980) and Stewart (1983) make the important point that, in this approach, morpheme-internal and inter-morphemic harmony is captured by a single constraint. In other words, there is no duplication problem if roots are fully specified. Government phonology (Kaye, Lowenstamm, & Vergnaud, 1985, 1990) is a constraint-based model, but it does not have repair rules. There is only one level of representation-thus, no derivation; see Ritter (1999) and Charette and Göksel (1998) for approaches to VH in this model. All apparent repairs are the result of “phonetic interpretation.”

Over the last decades, phonological work has been dominated by Optimality Theory (OT) (Kager, 1999). This model uses constraint ranking as the principal tool. In a language with VH, there will be a high-ranked constraint (that demands harmony) that selects for any given word, the potential output that maximizes harmony. There have been many different proposals to implement this approach. This means that, in this approach, no consensus has been reached on the central issues discussed in this article, which is mainly due to the fact that OT approaches focus on selecting optimal outputs, not on the representational properties of input and the procedural mechanisms that account for the observed harmonic patterns, both symmetrical and asymmetrical. Polgárdi (1998) combined an OT approach with government phonology. OT does not promote a specific theory of representations or appeal to underspecification. Since the early 1990s, OT has formed a dominant paradigm.

In this article, we have taken a representational, constraint-and-rule-based approach to VH (Calabrese, 2005). The idea has been that a constraint bearing on the word requires that vowels be harmonic for some feature (or features), accounting for harmony in roots and triggering a rule that specifies a harmonic value in affixes. This approach to VH, combined with the use of radical underspecification or unary features and a principle of locality, has emerged as the consensus view of (generative) phonology, whether the harmonic feature is treated segmentally or suprasegmentally.

Here I also mention computational approaches. Despite appearances, most formal treatments of VH (and other phonological processes) are quite informal, often using notational devices that are well intended, but not precisely defined. While this does not necessarily mean that such approaches have no value (which would dismiss most work in generative phonology to date) or cannot be made precise, some phonologists focus precisely on stating the relevant generalization in a "language" that is formally understood and defined. Attempts to this end are found in Johnson (1972), Vergnaud (1977), and more recently Heinz and Lai (2013), who study VH patterns in the context of subclasses of regular functions. Their analyses suggests that the computational complexity of phonology can be reduced from regular to weakly deterministic.

Finally, various authors have focused on questioning the psychological reality of harmony rule (Campbell, 1980), using language games evidence (Vago, 1973), or focusing on learnability issues (Finley, 2008; Heinz & Riggle, 2011; Mailhot, 2011).

6. Some Other Aspects of VH

6.1 Conditions on Triggers and Targets

As we have seen, there are VH systems in which all vowels, including neutral vowels, are fully involved. In many other cases, triggers and target are subject to limiting conditions (see Archangeli & Pulleyblank, 2007; Reiss, 2003). Both triggers and targets can be defined (a) with reference to a specific position (edge/stress); (b) with reference to the harmonic feature being distinctive or not; or (c) with reference to the presence of another feature on either trigger or target. In cases of parasitic harmony, trigger and target must share a condition. Various authors also refer to *sonority-related conditions* (Aoki, 1968; Nevins, 2010).

6.2 Directionality

In the preceding sections, we have implicitly assumed that harmony is bidirectional. While this is often the case, a great number of factors have been suggested as possible determinants for the directional of harmony, which is not always bidirectional:

(38) Factors relevant to directionality:

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- Morphology (root outward, root control).
- Dominance of a harmonic value.
- Underspecification (targets are unspecified).
- Privileged positions/positional faithfulness (first/last; stressed).
- Default direction (e.g., leftward).
- Stipulated direction (leftward/rightward).
- Positional target specification (left/right of trigger).

Hyman (2002) reports that the unmarked direction is right-to-left. A question that is also relevant here is whether VH rules apply cyclically or post-cyclically (see Bakovic, 2001).

6.3 Harmonic Domains

It is generally recognized that phonological processes can be confined to either phonological domains or morpho-syntactic domains. We have thus far assumed that domains were (mostly) the "word," making reference to the word as a morphological domain (i.e., root plus affixes). However, we must also reckon with the relevance of phonological (or prosodic) domains. Van der Hulst and Smith (1982) offer several examples of harmonic processes that are conditioned by prosodic domains of various sizes, and Flemming (1993) offers a general study of the role of metrical structure in phonological processes. The foot can be designated as the domain of VH for the metaphony cases in Romance languages (Calabrese, 2011; Hualde, 1989; Majors, 1998, 2006; Zubizaretta, 1979) and Umlaut in Germanic languages (Klein, 2000; McCormick, 1982) The next domain up would be the "word," and here it becomes difficult to make a clear distinction between the word as a phonological domain or as a morpho-syntactic domain, in particular since the definition of both notions is very much dependent on one's theories in both dimensions.

6.4 Consonants

While consonants, as we have seen, are typically transparent, there are various types of cases where consonants interfere.[28] I refer to Ultan (1973, p. 49, ff) for a number of cases that display trans-laryngeal or trans-guttural harmony, many of which concern local vowel assimilations that, arguably, do not qualify as proper VH. More relevant to the study of VH are cases in which consonants display apparent participation in what looks otherwise like unbounded proper VH. One might suggest that such participation can be attributed to universal co-articulation or can be language-specific as an allophonic process, not part of the lexical VH rule. Another type of interference occurs when consonants block harmony or impose their own value on subsequent vowels. I refer to Mahanta (2007) (and Rhodes, unpublished communication, 2010) for general discussions of such cases and to Kabak (2011) for the specific case of Turkish. This influence of consonants can be due to secondary articulations of these consonants or to their primary place articulation. Another type of blocking is due to intervening consonants clusters, including geminates (see Krämer, 2001, 2003, p. 14).

7. Data and Methods

Rose and Walker (2011) provide a good overview of recent developments in the methods that are now being used to gather data in the domain of VH. Several studies focus on the phonetic grounding (see Gordon, 2006; Linebaugh, 2007). Benus and Gafos (2007) find that anti-harmonic vowels in Hungarian (25a) are not phonetically identical to regular harmonic. Likewise, phonetic studies of Kinande provide evidence against the claim that the low vowel /a/is unaffected by the harmonic spread of ATR (Gick, Pulleyblank, Campbell, & Mutaka, 2006). A similar study done by Gordon (1999) showed how the transparent /i/ in Finnish is affected by its surrounding neighbors. In the examples given, the challenge is, however, to separate phonetic effects that can be attributed to co-articulation and fast speech processes from those that reveal properties of phonological (i.e. lexical-phonemic) processes.

Another line of experimental work involves the use of questionnaires, digital databases and Google searches. Where data display variability (as in Hungarian vacillating roots), large-scale experiments have been done with native speakers (Ringen & Kontra, 1989). Additionally, Hayes and Londe (2006) and Hayes, Siptar, Zuraw, and Londe (2009) use statistical methods to show the role of root final consonants. A recent corpus-based study of Hungarian VH (Forró, 2013) confirms some, but not all, of the tendencies that have been observed in previous studies. For variability and gradience in Finnish VH, see Anderson (1980), Ringen and Heinämäki (1999) and Mahonen (2011).

A different approach uses computer programs that analyze patterns in data from the vocabulary of languages to detect whether there are systematic co-occurrence patterns. This approach has been taken in Mayer, Rohrdantz, Butt, Plank, and Keim (2010), Knowles (2012), and Archangeli, Mielke, and Pulleyblank (2012). The latter publication is also concerned with emergence of VH generalizations in acquisition (based on statistical learning and pattern recognition). Ohala (1994) discusses the emergence of VH from a historical and phonetic point of view.[29]

There are many introductions to the phenomenon of VH that provide a basic characterization of it, focusing on the general agreement that must hold between vowels, while only hinting at what happens when certain vowels behave in a disharmonic fashion. In this article, we have specifically focused on such circumstances that, admittedly, have made it necessary to go into details, both in terms of what the relevant facts are and which theoretical approaches have been proposed to deal with asymmetries in VH. As might be expected, fully symmetrical systems, while interesting for several reasons, can be handled in most formal theories with relative ease. In my view, theories are "forced" into making special assumptions and proposing special mechanisms when they want to account for asymmetries. While reviewing some of the more common approaches to vowels that "do not play ball," I have also made some specific proposals that, in my view, are promising, focusing on the important issue of locality. It is to be expected that further and especially *detailed* descriptions and analyses of more harmony systems (taking into account how VH interacts with morphological structure), which are badly needed, will allow researchers to develop more complete accounts and thus, most likely (because more facts lead to narrowing the hypothesis space), convergence of theories.

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Notes:

(1.) All major linguistics encyclopedias contain entries about vowel harmony. Longer general introductions include Anderson (1980); see also R. Vago (Ed.), *Issues in vowel harmony*. Amsterdam: John Benjamins; Tohsaku (1983); van der Hulst and van de Weijer (1995); Archangeli & Pulleyblank (2007); Krämer (2003); Gafos and Dye (2011); and Rose and Walker (2011).

(2.) There is much variation in how to denote the advanced low vowel. In this study I have chosen to use the “upside down ‘a’ symbol,” “ɐ.”

(3.) Examples from languages are meant to be in phonemic notation, unless otherwise indicated.

(4.) A different understanding of locality is presented in Nevins (2010).

(5.) At this point it is not obvious why vowel harmony could not be an allophonic process in at least some languages.

(6.) To represent unspecified vowels, phonologists often use capital letters, reminiscent of the notion of archiphoneme adopted in Trubetzkoy (1962); see Hooper (1975).

(7.) This rule could also account for the [-ATR] value of /a/, but we will see below that predictable values are not always identical to default values.

(8.) Roots that only contain neutral vowels in Finnish take front suffixes, which means that, in that case, neutral vowels must be specified with their predictable value [-back]. Underspecification approaches must stipulate this fact; [-back] cannot be the default specification, since the proposed analysis designated [+back] as the default value. In section 5.1, I offer a more principled account.

(9.) See van der Hulst (2015a) for remarks on earlier suggestions to use unary features. It would seem though, that only Dependency and Government Phonology have incorporated this idea as a fundamental principle of phonological organization. Schane (1984) also adopts both the idea and the specific subset of unary features that these models advocate. See den Dikken and van der Hulst (1988) for a comparison of these various frameworks.

(10.) In unary models this primitive is usually referred to as |I| or |i|. See Anderson and Ewen (1987); Harris and Lindsey (1995); and van der Hulst (1989).

(11.) The derived environment condition is similar in spirit (and perhaps identical to) the Strict Cycle Condition (Kean, 1974).

(12.) It is, of course, also possible that an affix is disharmonic in both senses, by being polysyllabic and disharmonic, and by failing to harmonize with the root.

(13.) We need to ask how the vowel in the disharmonic suffix is specified such that it will refuse the ATR feature, there being no general constraint against an ATR counterpart to the vowel /ɔ/. In a unary system, this vowel cannot be specified as [-ATR].

(14.) Phonetically, [a] is in fact rounded [ɔ].

(15.) Hungarian also has so-called *vacillating* vowels, although a better term would perhaps be *ambiguous vowels*. The short vowel "e" (phonetically [ɛ]), while displaying transparent behavior, also acts as non-neutral (namely as the harmonic counterpart of short/a/in suffixes):

(a)	agnes-nAk	[agnɛsnɛk]	'Agnes DAT'
(b)	agnes-nAk	[agnɛsnak]	'Agnes DAT'

A possible approach here is to analyze the phonetic vowel [ɛ] as having two phonemic representations, much as, in syntax, an ambiguous sentence has two different underlying structures. The factors that determine the choice between both behaviors are complex (see Ringen & Kontra, 1989).

(16.) This term is used in so-called autosegmental approaches, which allow features in lexical representations of morphemes that are to be not associated with segments within the morpheme itself. The original motivation for floating features came from tonal phenomena; see Goldsmith (1976).

(17.) For ease of comparison, I am using the Finnish examples to demonstrate how these forms *would* sound in Khanty. So I did not attest to these specific word forms in the Khanty description.

(18.) For more details of this approach I refer to van der Hulst (2015b) where this analysis is offered as an alternative to Rébrus and Törkenczy (2015).

(19.) The present account is reminiscent of invoking a difference between minimal and maximal scansion, as proposed in Archangeli and Pulleyblank (1987). Limiting visibility to the tier that is spreading would be an instance of minimal scansion in that model.

(20.) In this particular case, postulating spreading |RTR| is problematic because Kibudu has three numeral prefixes that are invariantly ATR and impose their ATR value on roots that they combine with. This suggests dominance of ATR; see section 6.

(21.) Casali (2003) investigates ATR harmony in a great number of African languages with specific reference to the issue of “dominance.” However, his use of the term refers to the question of whether the plus or minus value of this feature is the active value in the harmony process, and not to the difference between root control systems and dominant-recessive systems. Casali takes one value to be dominant (irrespective of whether the system is root control or not), and he shows that the dominance of either [+ATR] or [-ATR] is related to the type of vowel system that the language has. I will return to his important work below.

(22.) We also know of cases in which prefixes can induce harmony; for example Tunen, analyzed in Mous (1986) and van der Hulst, Mous, & Smith (1986). Casali (2008) refers to other examples of dominant prefixes.

(23.) Bakovic (2001) attributes the difference to the VH rule being cyclic (root control) or post-cyclic (dominant-recessive).

(24.) Typological overviews or typologies are offered in Ultan (1973); Aoki (1968); Anderson (1980);van der Hulst & van de Weijer (1995); Krämer (2003); and Rose & Walker (2011). Overviews of specific families, regions, or kinds of harmony are offered in Ard (1981); Li (1996); and Zhang (1996) for Tungusic; Hall et al. (1974); Jacobson (1980); and Casali (2003, 2008) for ATR harmony in African languages; Hattori (1982) and Ko (2012) for various kinds of RTR/retraction harmony in Asian languages; Korn (1969) and Kaun (1995, 2004) for labial harmony, mainly in Turkic languages.

(25.) This approach is, in several respects, very similar to the underspecification approaches of the early 1970s (e.g., Ringen, 1975).

(26.) The autosegmental approach was anticipated in Harris (1944) and Anderson (1976); and in the so-called prosodic school of D.R. Firth (Firth, 1948).

(27.) The autosegmental approach (Clements, 1976; Goldsmith, 1976), which I classified as a spreading model, can also be understood as seeing the harmonic feature as a morpheme level specification, but now this specification is taken to be a genuine phonological feature (or autosegment) that associates with all vowels in its “reach.” The association procedure using “association lines” gives this approach a clear “feature-spreading” flavor.

(28.) See Rose & Walker (2011), who state the interesting generalization that, while consonants can often be shown to interfere (block or participate) in vowel harmony, vowels never interfere with consonant harmony. For consonant harmony, see Hansson (2001) and Rose & Walker (2004).

(29.) The converging of historical emergence, decline of vowel harmony, is addressed in Korn (1969) for Turkic languages, and in Greenberg (1990) for Chukchi–Kamchatkan languages.

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