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Authors

Bakovic, E

Wilson, C

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Transparency, Strict Locality, and Targeted Constraints

Eric Bakovic and Colin Wilson

UC San Diego and UCLA

1. Introduction

The claim that feature assimilation is strictly local, applying only between adjacent segments, appears to be contradicted by languages in which, descriptively speaking, vowel harmony passes through so-called ‘transparent’ vowels without affecting them. We illustrate this apparent contradiction with the pattern of vowel harmony and transparency found in Wolof (Niger-Congo). As described by Ka (1988), Archangeli & Pulleyblank (1994), and Pulleyblank (1996), among others, this language has a progressive (left-to-right) process of [ATR] (Advanced Tongue Root) harmony. Thus the vowel of the suffix *-ɔɔn* surfaces as [–ATR] after a [–ATR] root vowel in (1a), and as [+ATR] after a [+ATR] root vowel in (1b).

- (1) Progressive [ATR] harmony in Wolof
- | | | | |
|----|----------|--------------|---------------------------|
| a. | rɛɛr-ɔɔn | ‘had dinner’ | (examples from Archangeli |
| b. | reer-oon | ‘was lost’ | & Pulleyblank 1994: 227) |

Straightforward instances of vowel harmony such as these are readily accounted for by a number of rule-based and constraint-based approaches. We adopt the particular proposal developed within Optimality Theory (‘OT’; Prince & Smolensky 1993) by Baković (2000), according to which [ATR] harmony is driven by the markedness constraint AGREE(ATR), one of a general family of AGREE(F) constraints.¹ Crucially, following Gafos (1996) and Ní Chiosáin & Padgett (1997), we claim that AGREE(ATR) requires only *articulatorily adjacent* vowels to harmonize with one another.

- (2) AGREE(ATR). Articulatorily adjacent vowels must have the same specification for the feature [ATR].

As Gafos (1996) in particular argues at length (based largely on phonetic observations of Öhman 1966), the adjacency relationship recognized by

* We’d like to thank Bruce Hayes, Donca Steriade, Matt Goldrick, members of the Rutgers Optimality Research Group, and the WCCFL audience. Errors are ours.

1. See Alderete et al. 1999, Lombardi 1999, and Baković 2000 for AGREE(F) constraints that apply to place, voice, and other vowel features, respectively.


AGREE(ATR) obtains in examples like (1a) and (1b). The articulatory gestures of the two harmonizing vowels span the syllables that contain them, and are therefore adjacent to one another despite the presence of a medial consonant (e.g., the second *r* in *rɛɛr-ɔɔn*). In order for AGREE(ATR) to systematically compel assimilation, it must dominate the faithfulness constraint on input [ATR] specifications, IDENT[ATR].

The complication arises — not just for the AGREE(ATR) approach, but for any theory of vowel harmony that adopts an equally strict notion of locality — with respect to examples such as those in (3) below.

- (3) High vowel transparency in Wolof
- a. tɛɛr-uw-ɔɔn ‘welcomed’ (examples from Archangeli
 - b. tɛk-ki-lɛɛn ‘untie!’ & Pulleyblank 1994: 231)

In both (3a) and (3b), a high vowel (*u* and *i*, respectively) surfaces as [+ATR] despite the presence of a preceding, articulatorily-adjacent [−ATR] vowel. These examples illustrate a general fact about Wolof: high vowels are *always* [+ATR], and thus consistently fail to agree with preceding [−ATR] vowels. This fact is not problematic in and of itself; we need only assume a hierarchy for Wolof in which AGREE(ATR) is dominated by another (provisional) markedness constraint that bans [+HI,−ATR] vowels, NO(+HI,−ATR).

- (4) Non-assimilation of high vowels in Wolof²

Input: / tɛɛr-Uw-OOɲ /	NO(+HI,−ATR)	AGREE(ATR)
a. tɛɛr-uw ...	* !	
b.  tɛɛr-uw ...		*(ɛ,u)

The vowels *ɛɛ* and *u* in the optimal candidate are articulatorily adjacent, but they disagree in [ATR] because the vowel that would be created by left-to-right [ATR] **harmony**, namely *u*, violates the higher-ranked constraint.

But now observe that the mid vowel that follows the non-assimilating high vowel in both (3a) and (3b) *does* take on the [−ATR] specification of the initial vowel. Descriptively, the third vowel harmonizes with the non-articulatorily-adjacent [−ATR] vowel, not with the articulatorily-adjacent [+ATR] vowel. Adopting standard terminology, we thus call the intervening high vowel *transparent* to [ATR] harmony. This apparent agreement at a distance, which is also a general fact of Wolof, calls into question the strictly local formulation of AGREE(ATR). Adopting strict locality seems to force us to incorrectly predict that non-assimilating high vowels block [ATR] harmony — are *opaque* to it — in all languages. The following tab-

2. The ranking AGREE[ATR] >> IDENT[ATR] is omitted here and below for reasons of space. Throughout this paper, we use capital letters such as [O] and [E] to represent vowels whose input specification for [ATR] is irrelevant to the point under discussion, not (as is more common) to represent underspecified vowels.

leau shows the problem clearly: transparency and opacity fare equally on NO(+HI,-ATR), but transparency incurs one more violation of AGREE(ATR).

(5) The problem: opacity (*_{ATR}) incorrectly bests transparency (✓)

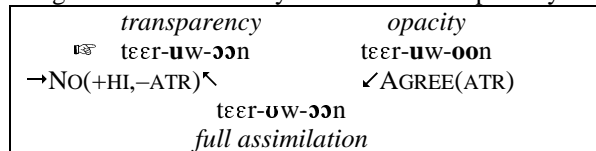
Input: / tɛɛr-Uw-OOɲ /	NO(+HI,-ATR)	AGREE(ATR)
a. tɛɛr-ɔw-ɔɲɲ	* !	
b. ✓ tɛɛr-uw-ɔɲɲ		*(ɛ,u) *(u,ɔ) !
c. * _{ATR} tɛɛr-uw-ooɲ		*(ɛ,u)

So far we have described the problem of transparency as that of one vowel harmonizing with another across a third. Stepping back from the individual segments, we can also describe transparency in terms of relationships among entire candidates like those shown in (5). Specifically, notice that the transparency candidate *tɛɛr-uw-ɔɲɲ* in (5b) is exactly like the full-assimilation candidate *tɛɛr-ɔw-ɔɲɲ* in (5a) except that the [-ATR] specification of the medial high vowel has been replaced by [+ATR]. Notice also that the difference between the opacity candidate *tɛɛr-uw-ooɲ* in (5c) and full assimilation is greater: the two candidates differ in the [ATR] specifications of *both* the medial high vowel *and* the final mid vowel.

Stated informally, our proposal is that transparency is optimal in languages like Wolof precisely because it diverges minimally from full assimilation. These languages highly value full assimilation, but they also highly value avoidance of [+HI,-ATR] vowels, which are marked for reasons we review in section 2. These two value systems interfere with one another, resulting in a pattern of [ATR] specification that is an optimal blend of assimilation and avoidance: namely, transparency.

We formalize this proposal by eschewing the provisional constraint NO(+HI,-ATR) and replacing it with a markedness constraint *that prefers only transparency, not opacity, over full assimilation*. In the terminology of Wilson (in preparation), the constraint *targets* [+HI,-ATR] vowels, forcing them to move out of their marked state while the surrounding elements — and crucially the [ATR] specifications of all other vowels — remain constant. In languages such as Wolof, the interaction between AGREE(ATR) and this constraint, referred to as →NO(+HI,-ATR) (where the prefixed arrow is to be read ‘targeted’), yields a cumulative preference for transparency over both full assimilation and opacity. We encapsulate this interaction in the following diagram, where arrows point toward preferred candidates.

(6) Targeted-constraint analysis of vowel transparency



We formally define the targeted constraint $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ in section 2 below, addressing the key question of why it prefers transparency, but not opacity, over full assimilation. Our answer draws upon both the articulatory difficulty of $[\text{+HI},-\text{ATR}]$ vowels and their perceptual similarity to otherwise identical $[\text{+HI},+\text{ATR}]$ vowels. This integration of articulatory and perceptual factors is a central property of the theory of targeted constraints, one that it shares with the Licensing-by-Cue framework of Jun (1995), Steriade (1997, 2000), and others (though the precise manner of integration differs sharply from other theories; see Wilson, in preparation, for discussion).

In section 3, we describe in detail the interaction between $\text{AGREE}(\text{ATR})$ and $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ that gives rise to transparent high vowels, and thereby give explicit content to the informal diagram in (6). We present the factorial typology generated by the constraints that are used throughout the paper in section 4, and we propose that the phenomenon of opaque (non-assimilating, non-transparent) vowels should be grouped together with other phenomena in which both the left- and the right-hand contexts of a segment play a role in forcing assimilation. Finally, in section 5, we summarize and assess our analysis of high vowel transparency, focusing in particular on the way in which it preserves the principle of strict (articulatory) locality.³

2. Articulatory and perceptual components of the targeted constraint

We define the targeted constraint $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ in terms of two components: one articulatory and one perceptual. (Our discussion in this section draws upon that of Archangeli & Pulleyblank (1994, especially §3.3), which in turn reviews work by Hall & Hall (1980), Halle & Stevens (1969), Perkell (1971), and Stevens et al. (1986), among others. We of course take full responsibility for all errors in the present exposition.)

The tongue body and the tongue root are two parts of a single articulator. Therefore, raising the tongue body, as required for a high vowel, is antagonistic with retraction of the tongue root, which is required to implement $[-\text{ATR}]$. We express this tug-of-war antagonism between $[\text{+HI}]$ and $[-\text{ATR}]$ with the articulatory markedness statement in (7), which is a ‘grounding condition’ in the terminology of Archangeli & Pulleyblank (1994).

(7) HI/ATR . A vowel that is both $[\text{+HI}]$ and $[-\text{ATR}]$ is marked.

The articulatory tension between $[\text{+HI}]$ and $[-\text{ATR}]$ is matched by an acoustic (and we assume perceptual) antagonism. All other things being equal, raising the tongue body lowers the first formant (F1) of a vowel. But, again all other things being equal, retracting the tongue root raises F1.

3. In our WCCFL talk, we compared the present analysis of vowel transparency with the analysis proposed by Walker (1998) within Sympathy Theory (McCarthy 1999). Space limitations preclude us from making this comparison here.

Therefore, when raising of the body and retraction of the root occur simultaneously, the result is an intermediate F1 value that does not provide a strong acoustic cue for either articulatory gesture. To be precise, we claim that this acoustic antagonism causes [+HI,–ATR] vowels to be non-distinct, according to the following perceptual similarity metric (‘F1-Sim’), from otherwise identical vowels with different specifications for [HI] and [ATR].

- (8) F1-Sim. Vowels that occupy the same level or adjacent levels on one of the following scales are non-distinct.⁴

(lower F1) i < ɪ, e < ε < æ (higher F1)
 u < ʊ, o < ɔ < a

Given a vowel α that appears on one of the two scales in (8), F1-Sim returns a set of vowels that it judges to be non-distinct from α . We write F1-Sim(α) to denote that set. Thus, F1-Sim(ʊ) = {u, ʊ, o, ɔ}, because *u*, *o*, and *ɔ* are all within the specified distance from *ʊ* on the second scale in (8).⁵

Perceptual similarity metrics such as F1-Sim are closely related to the Minimal Distance constraints of Flemming’s (1995) OT Dispersion Theory, which are based on binary-feature decompositions of scalar auditory dimensions, and to the licensing constraints of Steriade (1997, 2000), which are defined in terms of scales (or ‘P-maps’) that plot the perceptual distances between potentially contrastive segments in various phonological contexts. But F1-Sim is not itself a constraint, nor is the articulatory markedness statement HI/ATR in (7). Rather, F1-Sim and HI/ATR together define a single targeted constraint \rightarrow NO(+HI,–ATR), as we now describe.

Recall the full-assimilation candidate that was discussed in section 1: namely, *tɛɛr-ʊw-ɔɔn*, which is based on the actual Wolof example in (3a). This candidate contains one vowel (*ʊ*) that is articulatorily marked according to HI/ATR. According to the perceptual similarity metric F1-Sim, the set of vowels that are non-distinct from *ʊ* contains *u*, which is not articulatorily marked according to HI/ATR. Replacing *ʊ* by *u* in *tɛɛr-ʊw-ɔɔn* and making no other change creates a representation that is identical to the transparency candidate *tɛɛr-uw-ɔɔn*. We claim that it is precisely this relationship between these two representations that causes \rightarrow NO(+HI,–ATR), which is formally defined immediately below, to prefer *tɛɛr-uw-ɔɔn* (transparency) over *tɛɛr-ʊw-ɔɔn* (full assimilation).

Suppose given any candidate *x* that contains one or more vowels that are marked according to HI/ATR. These vowels are \rightarrow NO(+HI,–ATR)’s *targets* in candidate *x*, and the constraint prefers particular alternative candidates in which at least one of those targets has been changed. Specifically:

4. The idea that certain grammatical conditions treat elements that are adjacent on a scale as non-distinct has also been proposed within OT by Gnanadesikan (1997).

5. Note that *ʊ* is also a member of F1-Sim(*ʊ*), just as every α is a member of F1-Sim(α) — every vowel is non-distinct from itself.

- (9) $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$. Candidate x' is preferred over x ($x' > x$) iff x' is exactly like x except that at least one target vowel α has been replaced by a member of $\text{F1-Sim}(\alpha)$ that is not marked according to HI/ATR .

In other words, given any candidate x that contains one or more vowels that are marked according to HI/ATR , $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ prefers any alternative candidate x' that can be created from x by replacing at least one of those vowels with a vowel that is (i) non-distinct according to F1-Sim and (ii) not marked according to HI/ATR . We can also say that $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ only prefers adjustments that improve a representation with respect to HI/ATR , and furthermore only prefers those specific adjustments that create a representation that is perceptually non-distinct according to F1-Sim .

Returning to the specific case discussed above, we have already established that $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ prefers $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ (transparency) over $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ (full assimilation). Now we ask whether the constraint also prefers $t\epsilon\epsilon r-\mathbf{u}w-\mathbf{o}\mathfrak{n}$ (opacity) over $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ (full assimilation). Replacing the articulatorily-marked vowel $\mathfrak{ɔ}$ with \mathfrak{o} advances full assimilation half of the way to opacity. But there is a further difference between the two forms: \mathfrak{o} in the full assimilation candidate is replaced by \mathfrak{o} in the opacity candidate. Because \mathfrak{o} is not marked according to HI/ATR , this change is not sanctioned by the definition of the constraint, and therefore $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ does *not* prefer opacity over full assimilation. In short: \mathfrak{o} does not violate HI/ATR , therefore $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ does not target it, and therefore the constraint does not prefer *any* alternative candidate in which $\mathfrak{ɔ}$ has been replaced by a different vowel — including, crucially, the opacity candidate.

In the following diagram, the arrow (\curvearrowright) represents the preference that $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ asserts for $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ over $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$, and shading of $t\epsilon\epsilon r-\mathbf{u}w-\mathbf{o}\mathfrak{n}$ highlights the fact that this candidate is not preferred over $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ by the targeted constraint. (We henceforth use ‘preference’ and the technical term ‘harmonic ordering’ interchangeably).

- (10) $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ prefers transparency, but not opacity, over full assim.

<i>Harmonic ordering</i> by $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$	<i>transparency</i> $t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$	<i>opacity</i> $t\epsilon\epsilon r-\mathbf{u}w-\mathbf{o}\mathfrak{n}$
	\curvearrowright	
	$t\epsilon\epsilon r-\mathbf{u}w-\mathfrak{ɔ}\mathfrak{n}$ <i>full assimilation</i>	

3. Interaction of $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ and $\text{AGREE}(\text{ATR})$ yields transparency

The diagram in (11) below compares the preferences of $\text{AGREE}(\text{ATR})$ with those of $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$. As just discussed, $\rightarrow\text{NO}(+\text{HI},-\text{ATR})$ prefers only transparency over full assimilation. $\text{AGREE}(\text{ATR})$ is an untargeted constraint and its preferences were represented by marks in tableau (5). We have simply recast those preferences in the arrow notation below.

(11) Preferences of the individual constraints (not yet ranked)

	\rightarrow NO(+HI,-ATR)	AGREE(ATR)
Harmonic ordering by constraint	<i>transparen.</i> <i>tɛɛr-uw-ɔɔn</i>	<i>opacity</i> <i>tɛɛr-uw-ooŋ</i>
	<i>tɛɛr-ɔw-ɔɔn</i> <i>full assimilation</i>	<i>transparency</i> <i>tɛɛr-uw-ɔɔn</i>
	<i>tɛɛr-uw-ooŋ</i> <i>full assimilation</i>	<i>tɛɛr-uw-ooŋ</i>

Observe that \rightarrow NO(+HI,-ATR) and AGREE(ATR) disagree about the harmonic ordering of one pair of candidates. \rightarrow NO(+HI,-ATR) asserts that *tɛɛr-uw-ɔɔn* (transparency) is more harmonic than *tɛɛr-ɔw-ɔɔn* (full assimilation); AGREE(ATR) asserts exactly the opposite. This is constraint conflict pure and simple, and it is resolved in Wolof by the ranking [\rightarrow NO(+HI,-ATR) >> AGREE(ATR)]. The higher-ranked constraint prevails, and in this way it is established that transparency is more harmonic than full assimilation. The harmonic ordering asserted by the lower-ranked constraint is *cancelled*, a fact that we represent by parenthesizing the corresponding arrow:

(12) Resolution of conflict by ranking: \rightarrow NO(+HI,-ATR) >> AGREE(ATR)

	\rightarrow NO(+HI,-ATR)	AGREE(ATR)
Harmonic ordering by constraint	<i>transparen.</i> <i>tɛɛr-uw-ɔɔn</i>	<i>opacity</i> <i>tɛɛr-uw-ooŋ</i>
	<i>tɛɛr-ɔw-ɔɔn</i> <i>full assimilation</i>	<i>transparency</i> <i>tɛɛr-uw-ɔɔn</i>
	<i>tɛɛr-uw-ooŋ</i> <i>full assimilation</i>	<i>tɛɛr-uw-ooŋ</i>

We have so far determined the harmonic ordering of just one pair of candidates, *tɛɛr-uw-ɔɔn* (transparency) vs. *tɛɛr-ɔw-ɔɔn* (full assimilation). Two other pairs remain to be ordered: *tɛɛr-ɔw-ɔɔn* (full assimilation) vs. *tɛɛr-uw-ooŋ* (opacity); and *tɛɛr-uw-ooŋ* (opacity) vs. *tɛɛr-uw-ɔɔn* (transparency). \rightarrow NO(+HI,-ATR) is silent about these two orderings, preferring neither candidate in each pair over the other. But AGREE(ATR) speaks to both orderings. It prefers full assimilation over opacity, and opacity over transparency. Each of these preferences is *individually consistent* with the established ordering of transparency above full assimilation. However, they are *mutually inconsistent* with that ordering, as the following diagram shows.

(13) Improper ('circular') harmonic ordering

<i>transparency</i> <i>tɛɛr-uw-ɔɔn</i>	<i>opacity</i> <i>tɛɛr-uw-ooŋ</i>	Key: here '↖' represents the harmonic ordering established by higher-ranked \rightarrow NO(+HI,-ATR); smaller arrows represent the harmonic orderings asserted by lower-ranked AGREE(ATR).
<i>tɛɛr-ɔw-ɔɔn</i> <i>full assimilation</i>	<i>tɛɛr-uw-ooŋ</i>	

According to (13), each member of the candidate set is less harmonic than some other candidate. This result is not legitimate, because it implies that there is *no* optimal member of the candidate set (i.e., no output).⁶ Therefore, the two individually-consistent orderings asserted by AGREE(ATR), $t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n > t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$ and $t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n} > t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$, cannot *both* be upheld. The question is, which one of them should take priority over the other?

The theory of targeted constraints provides a general answer, referred to as *priority of the more harmonic*, to questions such as this one. Suppose given two orderings $x > y$ and $x' > y'$ that are individually consistent, but mutually inconsistent, with other orderings that have already been established. That is, adding either $x > y$ or $x' > y'$ to the diagram doesn't create a circle like the one in (13), but adding both of them does. Priority of the more harmonic states that the constraint hierarchy assigns higher priority to $x > y$ over $x' > y'$ iff it judges x to be more harmonic than x' .

Determining which one (if any) of a pair of candidates is judged to be more harmonic by the constraint hierarchy is straightforward. We simply locate the highest-ranked constraint (if any) that prefers one of the candidates over the other; the hierarchy has the same preference as that constraint. In our notation, this amounts to finding the first arrow (if any) between the two candidates in question and checking its direction.

Because the two mutually inconsistent orderings in the case at hand are $t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n > t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$ and $t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n} > t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$, the relevant comparison is $t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$ (full assimilation) vs. $t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$ (opacity). Distilling all unnecessary information out of the diagram in (12) gives the following picture, in which the priority judgment is self-evident.

(14) Full assimilation judged more harmonic than opacity by the hierarchy

\rightarrow NO(+HI,-ATR)		AGREE(ATR)	
<i>full assimilation</i>	<i>opacity</i>	<i>full assimilation</i>	<i>opacity</i>
$t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$	$t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$	$t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$	$\leftarrow t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$

As indicated by the shading, \rightarrow NO(+HI,-ATR) does not compare full assimilation and opacity, therefore the decision about which candidate is judged more harmonic by the hierarchy falls to lower-ranked AGREE(ATR), which of course prefers full assimilation. Consequently, the ordering that favors full assimilation ($t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n > t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$) takes priority over the ordering that favors opacity ($t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n} > t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$). The higher-priority ordering is adopted, and the lower-priority ordering is cancelled.⁷

6. We adopt a definition of optimality according to which a candidate x is optimal iff there is no other candidate y such that y is more harmonic than x .

7. Priority of the more harmonic is also crucial for eliminating silly candidates such as $t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$, in which [-ATR] has spread to the high vowel but *not* to the following mid vowel. The relevant comparison is $t\acute{e}eR-\acute{u}w-\acute{c}\acute{c}n$ (full assimilation) vs. $t\acute{e}eR-\acute{u}w-\acute{o}o\acute{n}$. The choice again falls to AGREE(ATR), which prefers full assimilation.

With this last cancellation, we now have a legitimate harmonic ordering, with transparency at the top, as shown in diagram (15).

(15) Transparency emerges as optimal

	\rightarrow NO(+HI,-ATR)		AGREE(ATR)	
Harmonic ordering by constraint	<i>transparen.</i> tɛɛr-uw-ɗɗɗ	<i>opacity</i> tɛɛr-uw-ooɗ	<i>transparency</i> tɛɛr-uw-ɗɗɗ (\rightarrow)	<i>opacity</i> tɛɛr-uw-ooɗ
	↖		(↘)	↙
	tɛɛr-uw-ɗɗɗ <i>full assimilation</i>		tɛɛr-uw-ɗɗɗ <i>full assimilation</i>	
Cumulative harmonic ordering	<i>transparen.</i> tɛɛr-uw-ɗɗɗ	<i>opacity</i> tɛɛr-uw-ooɗ	<i>transparency</i> tɛɛr-uw-ɗɗɗ	<i>opacity</i> tɛɛr-uw-ooɗ
	↖		↖	↙
	tɛɛr-uw-ɗɗɗ <i>full assimilation</i>		tɛɛr-uw-ɗɗɗ <i>full assimilation</i>	

The final row of this diagram depicts the optimization as a process of accumulating harmonic orderings. First, \rightarrow NO(+HI,-ATR) adds its preference for transparency over full assimilation. This has the result of directly cancelling the opposing preference of lower-ranked AGREE(ATR), and it also indirectly causes cancellation of AGREE(ATR)'s preference for opacity over transparency, as discussed immediately above. In the final cumulative harmonic ordering, every candidate *except transparency* is less harmonic than some other candidate. Thus, transparency emerges from the interaction of \rightarrow NO(+HI,-ATR) and AGREE(ATR) as the only optimal output.

All the details of our analysis of high vowel transparency have now been presented. We summarize and assess this analysis in the final section of the paper (section 5). At the moment, we digress briefly to present the factorial typology that arises from permutation of the constraints discussed above, and to propose a novel account of opaque vowels.

4. Factorial typology and opaque vowels

So far we have only considered the hierarchy [\rightarrow NO(+HI,-ATR) >> AGREE(ATR) >> IDENT(ATR)], which gives rise to transparent high vowels. The other possible rankings of these three constraints also yield attested patterns, as summarized in the following table.⁸

8. We have also so far only consider cases where instances of the marked combination [+HI,-ATR] are repaired by changing the [ATR] specification, not the [HI] value. In ranking terms, we have assumed that IDENT(HI) dominates AGREE(ATR). Reversing the domination relation between these two constraints in the hierarchy given for Wolof yields a language in which spreading [-ATR] to a vowel that would otherwise surface as [+HI] causes the vowel to become mid (e.g., /i/ \rightarrow [ɛ]). (Note

(16) Partial factorial typology

Crucial pairwise ranking(s)	Pattern (example language)
AGREE(ATR) >> IDENT(ATR) →NO(+HI,-ATR) >> AGREE(ATR)	[ATR] harmony; high vowels are transparent (e.g., Wolof)
AGREE(ATR) >> IDENT(ATR) AGREE(ATR) >> →NO(+HI,-ATR)	[ATR] harmony; high vowels assimilate (e.g., Maasai, Turkana) ⁹
IDENT(ATR) >> AGREE(ATR)	No [ATR] harmony (say, English)

A well-attested pattern that is missing from the table in (16) is one in which high vowels are *opaque* to [ATR] harmony. We illustrate this pattern with two examples from (Standard) Yoruba (see Baković 2000:§3 and references therein, in particular Archangeli & Pulleyblank 1989, 1994).

(17) High vowel opacity in (Standard) Yoruba

- a. $\acute{e}k\textcircled{\alpha}$ ‘pap’ (examples from Archangeli
 b. $e\textcircled{\alpha}l\textcircled{\alpha}b\textcircled{\alpha}$ ‘yam flour’ & Pulleyblank 1994: 86, 355)

In Yoruba, [ATR] harmony proceeds from right to left (regressively, not progressively as in Wolof) from final mid and low vowels.¹⁰ This is reflected by the fact that the initial mid vowel agrees in [ATR] with the vowel to its right in (17a). Example (17b) illustrates the fact that, as in Wolof, high vowels do not assimilate to adjacent final [-ATR] vowels. The same example reveals that a mid vowel that is separated from a [-ATR] vowel by an intervening [+ATR] high vowel systematically surfaces as [+ATR] — not, as in Wolof, as [-ATR]. In Yoruba, [-ATR] assimilation cannot pass through high vowels, which are therefore called *opaque*.

No ranking of the constraints discussed so far yields opacity of high vowels. In view of tableau (5), it might appear that ranking →NO(+HI,-ATR) above AGREE(ATR) would be sufficient. But, as we discussed in detail in section 3, that ranking yields transparency, not opacity.

We propose to fill this gap in the predicted typology by proposing the following constraint, which stands in a special-to-general relation with AGREE(ATR). (The double slash ‘//’ indicates a two-sided environment.)

- (18) AGREE(ATR//). A vowel that is articulatorily adjacent to two [αATR] vowels (that is, between them) must be specified [αATR].

that ε is adjacent to i on the scale referred to by F1-Sim (8), so the hypothetical lowering of /i/ to [ε] is indeed a repair favored by →NO(+HI,-ATR).) We have not yet explored this prediction in detail, but see Calabrese 1995 on some related patterns and Baković 2000 on parallel cases in Turkish, Diola Fogy, Maasai, and Turkana.

9. See Baković 2000: §4 and references therein for analyses of these cases.

10. We do not consider here the apparent fact that final high vowels do not trigger harmony; see Archangeli & Pulleyblank 1989, 1994 and Baković 2000:§3.

Constraint (18) belongs to a family of two-sided agreement constraints that is well-supported by other typological evidence. For example, Flemming (1995: §4.2.1.3) analyzes a co-occurrence restriction in Cantonese according to which back vowels are banned *between* two coronal consonants, despite the fact that back vowels and coronal consonants are otherwise allowed to be adjacent. Similarly, many languages lenite consonants only intervocally, thereby avoiding (for example) alternating [+CONT] [-CONT][+CONT] or [+VOI][-VOI][+VOI] sequences (see Kirchner 1998 and Keer 1999 for recent OT analyses of lenition). Also related is a tonal ‘plateauing’ process in KiHunde that changes High-Low-High vowel sequences into High-High-High sequences (see Goldsmith 1990: 36).

Inserting AGREE(ATR//) between \rightarrow NO(+HI,-ATR) and AGREE(ATR) in the Wolof hierarchy switches the high vowels from transparent to opaque. In the diagram below we show the interaction between the two highest-ranked constraints, AGREE(ATR//) and \rightarrow NO(+HI,-ATR), which fully determines the optimality of opacity in Yoruba forms like (17b).

(19) Optimality of opacity (Yoruba example)

	\rightarrow NO(+HI,-ATR)	AGREE(ATR//)
Harmonic ordering by constraint	<p>transparency <i>elubɔ</i> opacity <i>elubɔ</i></p> <p>↙</p> <p><i>elubɔ</i></p> <p>full assimilation</p>	<p>transparency <i>elubɔ</i> opacity <i>elubɔ</i></p> <p>↘</p> <p>(↘)</p> <p><i>elubɔ</i></p> <p>full assimilation</p>
Cumulative harmonic ordering	<p>transparency <i>elubɔ</i> Opacity <i>elubɔ</i></p> <p>↙</p> <p><i>elubɔ</i></p> <p>full assimilation</p>	<p>transparency <i>elubɔ</i> opacity <i>elubɔ</i> [☞]</p> <p>↙</p> <p><i>elubɔ</i></p> <p>full assimilation</p>

As always, \rightarrow NO(+HI,-ATR) prefers only the transparency candidate, *elubɔ*, over the full-assimilation candidate, *elubɔ*. AGREE(ATR//) prefers both *elubɔ* (full assimilation) and *elubɔ* (opacity) over the [-ATR][+ATR][-ATR] sequence found in *elubɔ* (transparency). The preference for full assimilation over transparency is overridden by the higher-ranked targeted constraint, as indicated by the parenthesized arrow, but the preference for opacity over transparency survives intact. This correctly leaves opacity as the only unbeaten candidate in the final cumulative harmonic ordering. The hierarchy just described is thus the correct one for Yoruba and other languages with [ATR] harmony and opaque high vowels. (In Wolof and other languages

with transparent high vowels, of course, AGREE(ATR//) must be ranked below AGREE(ATR.)¹¹

5. Summary and assessment

The main claims of this paper can be stated intuitively as follows. Wolof and other languages with transparent high vowels strive for *full assimilation* of [ATR]. This underlying goal is evident in the multiple roles that the AGREE(ATR) constraint plays in our analysis of high vowel transparency: it dominates IDENT(ATR), thus neutralizing certain input [ATR] specifications in favor of assimilation; it decides which of two mutually-inconsistent harmonic orderings has higher priority; and it places opacity below full assimilation in the cumulative harmonic ordering (recall (15)).

But the goal of full assimilation cannot always be met in these languages; in particular, marked [+HI,-ATR] vowels cannot be created by [ATR] harmony. Therefore, the languages settle for an outcome — transparency — that is *minimally displaced* from the desired state of unbroken harmony.

Targeted constraints have just the right character to effect such minimal displacements, because they explicitly prefer changes (or ‘adjustments’) that affect certain designated elements (their targets) while leaving the surrounding context undisturbed. Our analysis formalizes the notion ‘minimal displacement’ in terms of the perceptual similarity of [-ATR] high vowels and their articulatorily more desirable [+ATR] counterparts. The same type of perceptual targeting has also proven essential for the analysis of cases of contextual neutralization (see Wilson 1999, in preparation). It also appears to provide a general approach to transparent vowels of various kinds, an idea that we are currently exploring in on-going research.

In what sense does our analysis maintain the claim, apparently contradicted by the very existence of transparent vowels, that feature assimilation is strictly (articulatorily) local? We have, after all, said little about the *representation* of feature assimilation and transparency. Instead, we have focused on the way in which our constraints *evaluate* candidates containing vowels with various [ATR] specifications. From the perspective of evaluation, strict locality has been maintained in its strongest form: there is no constraint in our analysis that evaluates candidates by comparing the feature specifications of non-adjacent segments. In particular, the harmony imperative AGREE(ATR) only demands [ATR] agreement of vowels that are articulatorily adjacent. This constraint, like all the others we propose, is compatible with various representations of assimilation and transparency.¹²

11. The relative ranking of AGREE(ATR//) is not crucial for any of the other patterns summarized in the partial factorial typology table in (16) above.

12. For example, Baković (2000) proposes to eliminate autosegmental spreading entirely. Under his representational assumptions, full assimilation of three vowels is schematically [+ATR][+ATR][+ATR], while transparency is [+ATR][-ATR][+ATR].

Our emphasis on evaluation over representation is shared by a number of other proposals in OT (see for example Padgett's (1995) feature-class alternative to feature geometry).¹³ The general property of OT that legitimizes this perspective is the fact that constraint evaluation *re-represents* candidates as lists of marks (or, here, as sets of pairwise harmonic orderings). All and only the distinctions and relationships that are expressed in these re-representations are relevant for optimization. Obviously, this fact does not render representational assumptions unnecessary; for example, our own analysis calls upon the similarity of the acoustic/perceptual representations of [+ATR] and [-ATR] high vowels. But it does provide an evaluation-based method by which otherwise endangered principles, such as strict articulatory locality, can be preserved.¹⁴

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13. But cf. recent work by Goldrick (1998) for a representational analysis of vowel transparency within a general approach to derivational opacity effects in phonology.

14. One of the central typological arguments for strict locality of assimilation stems from the observation that no (adult) language spreads consonantal place ('C-place') across a vowel (see Gafos 1996 and Ní Chiosáin & Padgett 1997). Following the works cited, we assume that spreading C-place *to* the vowel, a move that would be required in a strictly local AGREE(PLACE) analysis, changes the vowel into a consonant (schematically, CVC→CCC). We further assume that there is no perceptual similarity metric analogous to F1-Sim (8) that judges C non-distinct from V in the context C__C. Thus there is no targeted constraint analogous to →NO(+HI,-ATR) that prefers CVC over CCC, and the unattested pattern is correctly ruled out.

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