What is a possible phonological rule?

. . . to abstract from the welter of descriptive complexity certain general principles governing computation that would allow the rules of a particular language to be given in very simple forms

Chomsky 2000:122, ‘Language as a natural object’

Abstract

Through an examination of vowel harmony and similar phenomena, we attempt to define a lower boundary on the computational power of phonological rules. We formalize locality and discover that the conditions in rules interact in interesting ways. We also provide a unified analysis for neutral vowels in harmony processes. The focus on computation allows for simplification in models of representation.

1 Introduction

This paper develops two research projects in phonology— substance-free phonology (Hale & Reiss 2000ab) and constraint-free phonology (Reiss 2003ab). The main idea of substance-free phonology is that phonological computation has no access to the phonetic substance which is transduced to and from the symbolic primitives of phonological representations, that is, the phonology treats any specification, [+rd], [-hi], etc. as an abstract symbol, *e.g.* [+F].[1] The operations that the grammar performs— insertion, deletion, etc.— are performed on representations without regard to their phonetic correlates. In other words, phonology is symbolic computation that does not make direct reference to the ‘semantic content’ *i.e.* phonetics, of representations.

The main idea of constraint-free phonology is that the phonological component is a procedural computational system that generates derivations without reference to constraints, that is, without explicit prohibitions on possible structures. We hope to show in this paper that adopting these two apparently abstract viewpoints ultimately leads to a deepening of our insight into attested phonological patterns.

Consider the following claim:

(1) Big data claim

In languages with vowel harmony, vowels that are underspecified with respect to some feature F ‘look for’ the closest specified value of F in the language-appropriate direction and copy that value *from* that specified source.

> It is not the case that specified vowels 'look for' the nearest underspecified targets and copy their specification *to* those targets.

We believe that this claim is true, or at least corresponds fairly straightforwardly to a formalizable true statement. One goal of this paper is to provide a basis for formalizing the claim that harmony and perhaps all assimilation rules involve copying *from* and not copying *to*. Thus explaining (**??**) is a step towards answering the question posed by our title.

Our approach in this endeavor is, we believe, the normal approach to scientific inquiry. Relying on observation and hypothesis, we inductively construct a system of theoretical primitives on the basis of their explanatory and predictive power. We take the apparently complementary question 'What is *not* a possible phonological rule?' to be answerable only derivatively, as follows.

At any given stage of scientific knowledge (which we assume always to be incomplete), an impossible rule is just one that is not expressible in terms of the primitive entities and operations that have been posited to express what *is* possible. Inductive uncertainty, uncertainty about what data may be encountered in the future, thus provides us with methodological grounds for defining the set of possible rules in positive terms – What is the minimum theoretical apparatus that the data force us to posit? – rather than in terms of the infinite set of constraints against what cannot occur in a rule.

We offer a second argument to favor our rule-based approach over a constraint-based one that attempts to define grammar by stating what is *not* possible. Just as the linguist is subject to inductive uncertainty, the child is as well. If the child were to receive negative evidence, explicit evidence about what does not occur, he or she could learn a constraint-based grammar successfully. However, it is widely accepted (see Marcus 1993) that children do not get much negative evidence, and that they cannot use that which they do get. Thus, they cannot learn the constraints. This reasoning (in more or less explicit forms) has led linguists to conclude that the very specific constraints needed to account for the variety of human languages must all be innate. Optimality Theory (Prince & Smolenksy 1993) is the most recent culmination of this line of thinking.

However, we reject this conclusion of innateness of such specific forms of linguistic knowledge, such as the constraints against voiced obstruents in codas, or front round vowels that are commonplace in Optimality Theory and other frameworks. We reject this conclusion of innateness of such specificity by rejecting the premise that grammars consist of constraints. By attributing to the human acquirer a rule-based, rather than constraint-based grammar, we are also able to posit a version of the initial state of the language faculty that is simple, yet provides the combinatorial power to develop into any attested language.[2]

We will also show that another central question is addressed when we investigate the nature of rules—we end up deriving some conclusions about the nature of linguistic representations as well. While the mutual dependency between a theory of rules and a theory of the entities that the rules operate on is hardly a new observation, we hope to show that our approach to rules leads us to a significantly simpler view of the structure of phonological representations than competing proposals.

In attempting to answer the title question, we focus, as indicated, on vowel harmony data and on two concrete domains within the formalization of such rules:

- How are the linear positions of target and trigger of a rule specified?
- What kinds of conditions can constitute the structural description of a rule?
- What kinds of scopal relations can hold among the conditions that comprise a rule ?

The first question requires that we develop an explicit notion of locality. We do this in section 5. The second question requires that we distinguish between conjoined and nested conditions. We do this in section 9. The remainder of the paper provides background and supportive data for our proposals.

2 The theoretical status of 'vowel harmony'

We must clarify immediately the status of the collection of data that we are selecting to provide evidence for the nature of phonological computation. That is, we might ask ourselves 'What kind of role might the notion of *vowel harmony* play in a theory of phonology?'. We adopt the position that the status of vowel harmony in phonology is much like the status of various *constructions, e.g.* 'Passive', in current theories of generative grammar. Syntacticians have essentially abandoned such constructions as primitives of the theory, adopting instead the viewpoint that constructions are epiphenomena of the manipulation of more basic primitives by the (syntactic) computational system of the human language faculty.

Similarly, we adopt the viewpoint that labels such as 'vowel harmony', and perhaps many of the other descriptive generalisations of phonology, are no more than pretheoretical classifications, devoid of explanatory power. We will continue to use 'vowel harmony' as a convenient descriptive term throughout the remainder of the paper, but remind the reader that it has no status within the theory that we will develop. To cite a parallel given by Chomsky (2000:8), the term 'vowel harmony' in phonology is like the term 'terrestrial mammal' or 'household pet' in biology: "taxonomic artifacts, useful for informal description perhaps but with no theoretical standing".

In the next section, we present the basic properties of what have been called vowel harmony systems, to set the stage for our discussion. Section **??** presents and develops the minimal formal apparatus necessary to analyze several harmony systems. In section **??**, we demonstrate that a particular combination of the formal primitives and relations we posit is able to account for common types of harmony systems. In sections **??**and **??**, we analyze data from a variety of languages and demonstrate that other types of harmony phenomena can be captured by different combinations of the primitives we propose. Section **??** presents our conclusions and some discussion of cross-domain convergence in formal linguistic relations.

3 A brief overview of vowel harmony

3.1 The basic data

Broadly speaking, a language is said to have vowel harmony when the vowels in some contiguous, but variable, portion of a word alternate to agree with respect to one or more vocalic features (*harmonic features*, henceforth). The definition we give is necessarily vague, as the basic phenomenon is subject to a variety of seeming exceptions and complications with respect to the set of harmonic features, the notion of contiguity that is relevant, and the identification of the relevant domain of application. The analysis we provide will resolve many of these difficult issues—they will be highlighted throughout the course of the paper as they become relevant to the discussion.

A typical example of vowel harmony based on the backness distinction is seen in Finnish, in which, roughly speaking, vowels within the relevant portion of the word must be all front, or all back:

(2) Finnish backness harmony (van der Hulst & van de Weijer, 1995)[3]

a.	**tyhmä**		'stupid'
b.	**tyhmä-stA**	**[tyhmästä]**	'stupid' (elative)
c.	**tuhma**		'naughty'
d.	**tuhma-stA**	**[tuhmasta]**	'naughty (elative)
e.	**värttinä**		'spinning wheel'
f.	**värttinä-llA-ni-hAn**	**[värttinällänihän]**	'with spinning wheel, as you know'
g.	**palttina**		'linen cloth'
h.	**palttina-llA-ni-hAn**	**[palttinallanihan]**	'with linen cloth, as you know'

Examples (b) and (d) above demonstrate the kind of alternation that is typical of the process under consideration: the vowel in the elative suffix alternates between front /ä/ and back /a/ to agree with the backness of the root vowels.

It is common in the literature to see data such as (a) and (c) above listed as examples of vowel harmony, since the vowels in these root forms are all front or all back. However, these lexical items exhibit no alternations, and thus it is unclear that any processes are involved. We are considering only cases of vowel harmony *processes* and excluding static generalizations. Thus, we take the position that the generalizations that may be made concerning data like those in (a) and (c) are not necessarily relevant to the phenomena addressed in this paper.

Examples (f) and (h) above demonstrate a common feature of harmony systems to which we shall return throughout the paper: languages with vowel harmony often have one or more vowels that systematically fail to be affected by the process. In the literature these are referred to as *neutral vowels*. The vowel in the 'as you know' suffix (-*hAn*) harmonizes with the vowel before the neutral [i], although the [i] remains [-back] after both front and back vowels. The vowel [e] is also neutral in Finnish. Note that, in choosing not to represent this vowel with a capital letter, we are explicitly claiming that transparent vowels (and neutral vowels more generally) are underlyingly specified for the harmonic feature—we assume that in Finnish the neutral [i] and [e] are underlying [-bk]. This is in direct opposition to many standard treatments, in which *underspecification* with respect to a harmonic feature is responsible for transparency (cf. Dresher & Zhang, 1996).

3.2 Harmonic features

Vowel harmony systems are often classified according to the feature that determines the alternations in the surface forms. Thus, one might refer to Tangale as having a tongue-root harmony system, since it shows alternations with respect to the feature [ATR], or to Hungarian as a mixed palato-labial harmony system, since it shows alternations with respect to both [back] and [round]. While a cataloguing of the attested types of vowel harmony may be of some interest and value, our goal here is an exploration of computationally possible languages in the spirit of the program of 'substance-free phonology". In other words, the particular content of the harmonic feature under consideration is irrelevant to the formal properties of the theory. It follows then, that *e.g.* [back] harmony is formally indistinguishable from [round] harmony from the perspective of the grammar, *qua* computational system. The grammar is blind to the phonetic substance that transduces to/from the features it manipulates. The result of our study will be to posit primitives that will also play a role in capturing phenomena that are not traditonally classified as vowel harmony—as is to be expected given the non-status of vowel harmony in the theory we propose. We hope that these primitives and the templatic rules we develop can unify a variety of phenomena in a manner that is both elegant and general enough to provide insight into the human language faculty.

3.3 Neutral vowels

Those neutral vowels which appear to not interfere with the application of harmony processes are called *transparent*. Those that appear to block the spread of harmonic features and initiate a new domain of harmony are referred to as *opaque* neutral vowels. For example, in (**??**h) above, the vowel in the rightmost suffix (-*han*) appears to be getting its backness from the last vowel in the root, or perhaps the vowel of the first suffix (-*lla*), across the intervening [i] of -*ni*. We can thus say that [i] behaves transparently in Finnish. An example of opaqueness[4] can be found in Tangale, a Chadic language that shows vowel harmony involving the [ATR] feature. The /a/ vowel fails to harmonize, and furthermore blocks spreading of a harmonic feature:

(3) Tangale ATR harmony (van der Hulst & van de Weijer, 1995)[5]

a.	**seb**-U	[**sebu**]	'look' (imp.)
b.	**kɛn**-U	[**kɛnʊ**]	'enter' (imp.)
c.	**peer-na**	[**peerna**]	'compelled'
d.	**pɛd-na**	[**pɛdna**]	'untied'
e.	**ɗob**-Um-**g**U	[**ɗobumgu**]	'called us'
f.	**ɗib-na-m-g**U	[**ɗibnamgʊ**]	'called you (pl.)'

We see in (a)-(d) that the value of the [ATR] feature spreads rightward in Tangale, but that /**a**/ does not alternate. The final three examples show that /**a**/, in addition to not alternating, blocks spreading of [+ATR] to subsequent affixes, spreading its own [-ATR] value instead.

3.4 Transparent and opaque consonants

One of the challenges that vowel harmony poses for theories of phonology is its apparently non-local character: in many cases, features appear to spread from vowel to vowel, ignoring any intervening consonants. We will return to the issue of the proper formulation of locality in harmony processes in section **??**, simply noting for the moment that the putative non-locality of vowel harmony will need to be handled.

Interestingly, it seems to be the case that there are languages in which consonants and vowels do interact with vowel harmony processes. We shall see an example of this in section **??**. While such cases have in the past been dealt with by positing various models of phonological representation for consonants and vowels (cf. van der Hulst & van de Weijer, 1995:526-530), we will show that a simpler explanation, not relying on baroque models of feature geometry, is available.[6]

4 Basic assumptions

In the following subsections we present and discuss several of the primitive entities and relations that constitute our model. Issues that arise include the featural content of phonological objects, the nature of structural descriptions, the role of precedence relations in phonology and the notion of locality.

4.1 Features

At the heart of our theory's ontology is the traditional generative assumption that all phonological objects (*e.g.* segments) are bundles of *features*, and that it is over these features that phonological rules compute. We take the features themselves to be the abstract symbols that constitute phonological representations. Thus, they are neither directly acoustic nor articulatory. In addition to constituting representations in memory, they serve as the arguments of the transductions from representation to articulation and audition.[7] Any reference in this paper to higher-level entities such as 'segments' or 'vowels' must be interpreted as shorthand for an explicit featural specification.

Related to the assumption that features are the components of all phonological entities is the notion of *underspecification*, the idea that some phonological objects may not have values specified for some of their features at an underlying level of representation.[8] We adopt here the theory of underspecification, along with the *Unified Interpretive Procedure* (UIP) for interpreting the structural descriptions of feature-filling rules, presented in Reiss (2003a). In brief, the UIP allows for a principled distinction between feature-filling and feature-changing rules, without the use of rule diacritics. Adopting the UIP means, for example, that a rule written '$V \Rightarrow [+round] \ldots$' is interpreted as a feature filling rule, affecting only vowels that have no specification for the feature round. In contrast, if we want to express a feature-changing rule, we must write something like ‘$V[-round] \Rightarrow [+round] \ldots$’ .

4.2 Richly Specified Structural Descriptions

Generative phonologists have historically striven to posit maximally general rules, by using minimally specified structural descriptions and triggering environments. Steriade (1995, p.122) states:

> [...] all other things being equal, one expects that rules which spread, dissimilate, or are otherwise conditioned by [αF] will apply to ALL SEGMENTS containing [αF]. (emphasis ours)

We find such statements to be too vague to be useful. It appears that what is meant by “all other things being equal” is just that “rules which spread, dissimilate, or are otherwise conditioned by [αF] will apply to all segments containing [αF]”. To take a commonly occurring example, coda devoicing typically affects only obstruents, and not sonorants, which are also [+voiced]. One might propose a feature theory that treats sonorants as not [+voiced], but many other rules affecting or conditioned by segments with a conjunction of features are not hard to come by—think of rules affecting the coronal nasal [n] that do not affect other nasals or other coronals.

The notion of “maximal generality” itself is unclear as well—given an alternation in which /e/ surfaces as [i] word finally, what is the ‘maximally general’ form of the rule? Here are some choices:

- /e/ $\Rightarrow$ [i] word-finally
- front vowels $\Rightarrow$ [i] word-finally
- mid vowels $\Rightarrow$ [i] word-finally
- all vowels $\Rightarrow$ [i] word-finally
- everything $\Rightarrow$ [i] word-finally
- everything $\Rightarrow$ [i] everywhere

Obviously, the data will determine a “maximum” level of generality that may differ in each case. The appropriate level of generality can only be determined in the context of a theory of phonological acquisition that posits a specific learning path.

Recently, Reiss (2003b) has argued that we must accept “complex” (*i.e.* richly-specified) structural descriptions and environments in phonological rules. Such conditions cannot be ruled out on *a priori* grounds and generally have the effect of directly constraining a rule’s output, obviating the need for external constraints. Despite the apparent increase in the “complexity” of a rule’s structural description, enriching structural descriptions may lead to *systematic simplicity* (Chomsky 1957) both in the particular grammar under analysis and in the general theory of grammar. The elimination of *external* constraints is a genuine reduction in “unnecessary entities” in the theory’s ontology. In contrast, enriched structural descriptions are built using a limited number of primitives that are needed on independent grounds.

In addition to this Ockham argument at the level of Universal Grammar, there are formal and theoretical reasons to favour the inclusion of rules that can impose specifications on both triggers and targets. Excluding *a priori* the possibility of allowing highly specified structural descriptions and environments in phonological rules leaves unexplored the full power of the formal apparatus of rule-based phonology. If we do not explore the properties of all of the constructs allowed by our overarching theory, then the validity of any particular account using this theory is undetermined, and we cannot know the extent to which our embedded theories can be deemed satisfactory.

4.3 Precedence relations in phonology

Drawing on formal and empirical considerations from reduplication phenomena, Raimy (2000) has argued convincingly that the representational apparatus of phonological theory should include an explicit encoding of immediate precedence relations, pointing out that notions of precedence have been implicitly used throughout the history of generative phonology. A phonological rule specifying X_Y as its environment of application is crucially *not* understood to be triggered in the environment Y_X.

An important point that Raimy raises in his discussion of precedence relations in phonology concerns the location of precedence relations within a phonological representation. More specifically, he asks whether precedence relations are directly encoded only on the timing tier, with all other potential ordering being derivative, or whether each autosegmental tier is independently ordered, and subsequently synchronized with other tiers by a separate mechanism. He notes the importance of this question, stating: “Whatever view of precedence turns out to be correct, [...] there will likely be discoveries about locality in phonology that result from the further study of precedence.” (Raimy, 2000:181) We shall see below that this prediction is borne out.

Once we acknowledge that precedence relations must be explicitly encoded in phonological representations, it becomes pertinent to ask *where* the precedence relations are to be encoded. On the skeletal tier? On all tiers? Goldsmith (1976, p.28) defines an autosegmental level as an ordered sequence of elements, but this view is not made explicit in most later work. A simple example from the phonology of tone languages provides empirical support for the claim that precedence relations are represented independently of one another on each tier of a phonological representation. Consider the following relatively standard representations of vowels exhibiting contour tones:

(4) Standard representation of contour tones

CV tier:	a.	V		b.	V	
Tone tier:		L	H		H	L

If linear order on the tone tier were derived strictly on the basis of precedence relations encoded on the CV tier, then the representations in (**??**a) and (**??**b) would in fact be non-distinct. It is tempting to see the tones in the pictures above as being ordered independently of the CV tier, but this is simply an artifact of the diagram.[9] If ordering relations exist only on the CV tier, then the tones in each pair are explicitly unordered with respect to one another—if both are associated to the same slot on the CV tier, then there is no way to derive an ordering for them. Crucially, though, the sequences H-L and L-H *are* distinct for speakers of tone languages. Therefore, precedence relations cannot be specified only on the CV tier and must at least exist on the tone tier as well, so a better representation of the contour tones in (**??**) would be as follows:

(5) Representation of contour tones with explicit precedence relations

CV tier:	a. V	b. V
Tone tier:	L → H	H → L

For the rest of this paper, we will assume that every tier of a phonological representation explicitly encodes precedence relations using the '→' symbol, so that $a \rightarrow b$ is read 'a immediately precedes b'.

For vowel harmony, it appears that some patterns propagate features from left to right, and others from right to left. Therefore, any account of the relationship between sources and undergoers of harmony, and more particularly any explicit formulation of a rule of vowel harmony relating them, will have to specify their relative right-left positions. In other words, both 'precedes' and 'is preceded by' (or 'follows') will be needed in our discussion of vowel harmony.

4.4 The *Closest* relations

The issue of directionality becomes increasingly important as we move towards defining the notion of locality. We will need to appeal to, and therefore be able to express formally, notions like 'closest to the right' or 'closest to the left'. We shall see in our discussion of vowel harmony that closeness needs to be defined with respect to a particular element, which we will refer to henceforth as the 'standard', denoted by ς in the following discussion.

Based on the precedence relation discussed in section **??**, we can define a relation on the segments in a phonological string that picks out the unique *closest* element, x_j, to a given standard ς.

(6) The *L(eft)-Closest* relation
Given an element ς (the 'standard') of a phonological string Σ, and a set of elements $X \subseteq \Sigma$, $x_j \in X$ is *L-Closest* to ς iff x_j precedes ς and for all $x_i \in X, x_i \neq x_j$, if x_i precedes ς then x_i precedes x_j.

In this definition, X is a class of elements definable in terms of the primitives of the theory, in particular as a conjunction of features, (*e.g.* the set of high vowels)—it defines the *type* of the set of elements it specifies. In other words, x_j is the *L-Closest* element of type X to ς if there are no elements x_i of type X that are closer (on the left) to ς.[10] Clearly, the mirror-image relation *R(ight)-Closest* is trivially definable with the 'is preceded by' relation.

When we express specific vowel harmony patterns below we will adopt ellipsis notation to express the *Closest* relations, identifying the standard with single quotation marks.

(7) The notation for *Closest*

- $x \ldots$‘ς’ ‘The x that is *L-Closest* to ς’
- ‘ς’ $\ldots x$ ‘The x that is *R-Closest* to ς’

Note that because the *Closest* relations are typed with respect to the class of participating elements, the fact that two elements are in a *Closest* relation does not imply that they are associated to adjacent timing slots, since elements of other types may intervene between the closest x_i and the standard, ς. Note also that the status of ‘standard’, which is explicitly used for computation of closeness, is *logically* independent of other phonological notions such as source/trigger or undergoer/target of a process. However, it will turn out that, empirically, the notions are correlated.

Finally note that *L(eft)-Closest* and *R(ight)-Closest* are not converse relations: if x_2 is the *L-Closest* x to y_2, that does not necessarily mean that y_2 is the *R-Closest* y to x_2, as we can see in the following sequence:

(8) $[x_1 \rightarrow x_2 \rightarrow y_1 \rightarrow y_2]$

In fact, x_2 is the *L-Closest* x to y_2, but there is no x, to which y_2 is *R-Closest*.

4.5 Adjacency

Much of the phonological literature treats long-distance or non-local interactions among segments as special or ‘marked’ or somehow complex. Having defined closeness explicitly, we now see that such long-distance effects fall under the general rubric of *Closest* relation, and that segmental adjacency is just a particular case of this same *Closest* relation. Assuming the existence of a timing tier of linearly ordered skeletal slots defining segments, we can say that segments S and Q are adjacent if the timing slot of S, T_S, is the *L-Closest* timing slot to the timing slot of Q, T_Q. Thus we reduce adjacency to a special case of closeness-based interaction. What this means is that the implicit notation adopted in phonological rules that uses, say, SQ to mean ‘S is left-adjacent to Q’ is actually an abbreviation for $T_S \ldots$‘T_Q’.[11]

4.6 Locality

Explicit or implicit mechanisms to restrict operations and relations to *local* application within representations are a prominent feature of most phonological (and syntactic) theories. These locality conditions are often presented in phonological theorizing as constraints that prevent ‘general’ phonological rules from operating on arbitrarily-separated portions of a representation. In the context of an autosegmental theory, Archangeli & Pulleyblank (1994, p.26) state:

> Allowing multiple tiers can, of course, overgenerate in a manner quite reminiscent of the overgeneration encountered in linear frameworks. To prevent such a negative result, some condition of locality must be imposed.

We propose that the *Closest* relations are the only accurate notions of locality for the *description* of phonological computation, but that these relations are in fact *not* part of particular grammars, or of UG. Rather, we will argue in the next section that they follow straightforwardly from a view in which phonology is derivational and involves procedural computation over symbolic representations.

Moreover, as suggested in (**??**), we claim that the standard in the *Closest* relation is always the rule target, that is, the segment that receives a feature value from another segment. In other words, in assimilatory processes, a target looks for a source to copy specifications *from*. It is never the case that the trigger looks for a recipient to copy *to*.

Nevins & Vaux (2003) propose a definition of locality similar to ours, which they term 'relativized locality' (in the spirit of Rizzi, 1990) in the context of an analysis of Karaim consonant harmony. The definition given by Nevins & Vaux differs slightly from ours in that the relativization is with respect to the type of *intervening* elements, rather than to the type of the non-'standard' (*i.e.* the element with respect to which *Closeness* to the standard is computed):

(9) Relativized Locality (Nevins & Vaux, 2003):
Two elements A and B are local if there is no element C of type T that intervenes between A and B

In fact, there is no notion of 'standard' in this definition, and as stated, the relation of locality it specifies is a symmetric one, unlike ours which is explicitly non-symmetric. According to our current understanding, Nevins and Vaux's version of locality is less specific than ours, and thus encompasses ours. In addition to not identifying a standard, their definition, unlike ours, clearly cannot specify that the type of T be the same as the type of either A or B, whichever is *not* the standard (given that they have no notion of standard at all). Our view of locality is thus more restrictive and consequently to be preferred if empirically adequate, an issue we leave for further research.

4.7 Why the target of a rule is always the standard

We are now ready to generalize and formalize the descriptive claim made in (**??**). We generalize beyond vowel harmony to all processes involving a target and trigger for the reasons outlined in section 3—'vowel harmony' is a pretheoretical term with no actual status in phonological theory.[12]

(10) Target as standard
In a phonological process affecting a target a in the environment of a trigger b, a is always the standard with respect to which the *Closest* relation is computed.

In other words, 'b is *Closest* of type B to a' is the relevant relation, not 'a is *Closest* of type A to b'.

It is tempting to claim (**??**) as a newly discovered property of phonological Universal Grammar. However, we shall take a less dramatic position, one that is consistent with the idea that Universal Grammar allows for potentially unattested types of computation. For example, we may have reason to believe that a gap in attestation for a particular phonological pattern is due, not to a UG incompatibility, but to the impossibility of learning the relevant pattern. This situation may reflect the nature of the systems that provide the grammar with input and output (audition, for example) or the nature of the language acquisition process. If we have reason to attribute a gap to one of these other sources, we must not duplicate explanation by building an account into the nature of grammar (see Hale & Reiss 2000ab, building on work by John Ohala).

In the present case, there appears to be an explanation from learnability considerations for why rules whose descriptions require *Closeness* computation with the *trigger*, rather than the target, as the standard are unattested.

Recall that the *Closest* relations are typed with respect to the featural content of the participants, thus allowing multiple potential triggers for a particular target. Suppose some phonological rule specifies an element of type A as its target and an element of type B as its trigger. In a particular string, these conditions may identify a unique target and several potential triggers (*i.e.* the set of elements of type B such that a is the closest element of type A). If we let each possible trigger be the standard in an application of a rule, then multiple triggers can potentially copy conflicting values for a feature $[F]$ onto the target. However, since phonological computation is *ex hypothesi* deterministic, a must ultimately surface with a particular (determinate) value for $[F]$. Consequently, a learner could never receive evidence for multiple, potentially conflicting triggers. In other words, a phonology with "trigger as standard", although *a priori* possible given the primitives of the theory, is unlearnable. The apparent validity of (**??**) thus follows from *learnability* considerations and 'target as standard' need not be specified as part of Universal Grammar.

To reiterate, we claim that *only* (**??**) is relevant in the computation of harmony in structures like (**??**). This result can be generalized by abstracting away from direction of closeness computation to derive our claim for all linguistic computation of locality. That is, "x and y are in a relation of locality" means that they are in a *Closest* relation, with either x or y as the standard. In the harmony cases we have examined, the target of a copied feature is always the standard with respect to which the *Closest* relation is computed. The trigger is always that member of a typed set which is *Closest* to the target. The fact that the *Closest* relation picks out a unique element for each standard (in particular, it is a many-to-one function from targets to triggers), means that targets must have unique triggers, but it allows triggers to have multiple targets (since the inverse of a function is not necessarily a function).

The discussion above serves to highlight some of the difficult issues that arise when we try to make explicit our notions of locality, namely that the relation of locality is sensitive to the location and type of the element that is the definitional restrictor of the local neighborhood. These points are rarely acknowledged in discussions of locality but they are important if we wish to gain a deep understanding of the ramifications of the relations and entities permitted by our theory, so we have taken the time to belabor them here.

There is another consideration that we will mention for why the target must be the standard. Note that we have not explicitly defined 'target' and 'trigger'. Instead we have been relying on the reader's intuition with respect to segments and their relations in assimilation rules. However, if we want to push the substance-free program to its logical conclusions, we may have to acknowledge that even the notions of target and trigger are somewhat informal, and cannot play a fundamental role in the theory. In the case of harmony and other assimilation rules, a valued feature [αF] is apparently copied from some source (the trigger). However, many rules do not allow for the identification of a single segmental trigger. For example, consider rules that voice or spirantize consonants between vowels—there is no single segment that we can call the trigger. The target, on the other hand, has to be identifiable as the locus of an insertion, deletion or change defined with respect to some other aspect of the representation to which the inserted, deleted or changed entity is associated.

5 An Algorithmic Theory of Assimilation

In this section we build on the explicit theoretical apparatus developed in section **??** to propose our own strongly procedural model for vowel harmony and similar processes. The following three rule templates provide a preview in schematic form of some crucial issues we will be addressing:

(11) Three rule templates:

a. Find the segment S$_i$ that is the closest segment to the left of S$_j$ with a specification [αF] and copy that specification onto S$_j$

b. Find the segment S$_i$ that is the closest segment to the left of S$_j$ with a specification [αF, βG] and copy the specification [αF] onto S$_j$

c. Find the segment S$_i$ that is the closest segment to the left of S$_j$ with a specification [αF] and copy that specification onto S$_j$ *only if* S$_i$ is also specified [βG]

It is probably clear that these rules will generate effects like those seen in vowel harmony patterns. We will show that rules with these formal structures are attested, and we will explicate the empirical differences among them. We will also see that these rules are special cases of even more abstract patterns.

We now illustrate the application of rule (**??**), instantiating template (**??**a), in which all vowels in a word that are unspecified for a harmonic feature $[F]$ receive a value for it from the nearest instantiated value of $[F]$ in the relevant direction. [13]

(12) Rightward Vowel Harmony: $V \Rightarrow$ [αF] / [αF] ... '_'

Consistent with the template in (**??**a), this rule template encodes the following procedure:

(13) Interpretation of Vowel Harmony rule (**??**)

a. select the timing slot of V as a standard; call it ς

b. identify all timing slots that are specified for $[F]$, call this set $\mathcal{F}$

c. find the unique x_i that is the *L-Closest* element in $\mathcal{F}$ to ς

d. copy the value that x_i has for $[F]$ onto ς

Together, the quotation marks around the environment slot, '_', and the ellipsis, ..., indicate that the rule finds the specification for the feature F which is *L-Closest* to the timing slot associated with the target vowel and associates this value to the timing slot associated with the target vowel.

Recall that in section **??**, we claimed that the *Closest* relations are not part of the grammar, or of UG, but instead follow from a procedural view of phonology. Thus, we must explain the use of the term *Closest* in item (c), above, before it can count as an explanatory step in the series of computations encoded by the rule (**??**). The clue to doing so lies in the word 'find'. In particular, this implies the necessity of a SEARCH operation in the computational apparatus of the phonological component.[14] Since we assume that the computations carried out by the phonology are deterministic, a search for an element satisfying a particular condition *must* stop at the first suitable candidate, or else fail to find one. This simple fact is enough to ensure that phonological computation of processes like assimilation is local in the only sense that we have argued is relevant: the grammar need not include locality constraints. This is an important point in the context of constraint-free phonology—it is true that the targets and triggers of rules can be described as being in some kind of locality relation, however, this relation is not built into the grammar, but rather derives from the nature of the SEARCH operation.

Depending on the language, we may instead (or also) find left-spreading vowel harmony, for which something like the following rule is active:

(14) Leftward Vowel Harmony
$V \Rightarrow [\alpha\mathrm{F}]$ / '_' ... $[\alpha\mathrm{F}]$

While the direction of spread is subject to crosslinguistic variation, we claim that the computation of the *Closest* relation always takes the undergoer/target as the standard, as stated in (**??**). This allows us to treat spreading of a feature to multiple targets as a *single* application of an assimilatory rule copying a feature from a source to all the targets that the source is *Closest* to. In this way, the need for iterative harmony rule application—another common feature of previous treatments of vowel harmony—is eliminated.

While the choice of target as standard is apparently not subject to crosslinguistic variation, there can clearly be variation in the amount of specification in the formulation of harmony rules. For example, there may be conditions on any element of the rule—perhaps the trigger or the target (or both) must be a non-low vowel. Some conditions may require a relationship between two elements in the rule, for example the identity and nonidentity conditions discussed by Reiss (2003b). Such conditions are a normal part of phonological rules of all types. We will see in section **??** that the possibility of having additional specification in a rule allows us to give a unified analysis of both types of neutrality, transparency and opaqueness.

6 A note on domains

Many analyses of vowel harmony systems make use of morphologically determined domains of application. To cite a recent example from a particularly clear and thorough source, Siptár & Törkenczy (2000: Chapter 6) note that vowel harmony in Hungarian does not spread from the first compound member to the second (e.g., *balta+nyél* 'hatchet handle'), or from a prefix to a root (e.g., *meg+lát* 'catch sight of'). This lack of harmony is, following tradition, attributed to the existence of a phonological word boundary that divides a stem-final root and the following suffixes from any preceding material. We adopt the view of Reiss 2003a that the failure of second compound members or post-prefixal roots to harmonize with preceding material is due to the fact that they are underlyingly fully specified, and that Hungarian vowel harmony is always feature-filling. Fully specified items are not subject to feature-filling rules.

Given our procedural view of vowel harmony, we can also explain why first compound members and prefixes do not trigger alternations in the underspecified harmonizing suffixes. It is not because the suffixes are inaccessible by virtue of being in a separate domain. Rather, the failure of prefixes and first compound members to trigger harmony is due to the fact that their vowels are not *Closest* to the suffix vowels. For example, for any suffix vowel V following *meglát*, the *á* of *lát* will be *L-Closer* to V than the *e* of *meg*.

Under the standard assumption that analyses based on purely phonological rules are preferable to those invoking morphologically conditioned divisions into separate phonological domains, our model, which does not posit domains of application, except as a last resort, is to be preferred.

7 Accounting for neutral vowels

Scholars of vowel harmony have long struggled with the phenomena of OPAQUENESS and TRANSPARENCY. In the case of opaqueness, a non-alternating "neutral" vowel blocks the spread of [αF] and spreads its own feature value. Transparent neutral vowels, on the other hand, appear to be invisible to the harmonic process, allowing features to spread "through" them.[15] Generally, the explanations for neutral vowels invoke either (i) a special property inherent to the vowels themselves, or (ii) additional rules or constraints that apply only to these vowels (Bakovic & Wilson, 2000:45). It is interesting also to note that, to our knowledge, no theory of vowel harmony has yet succeeded in giving a unified account of both types of neutrality, and the properties of opaque *vs.* transparent vowels, or the rules that apply to them are often claimed to differ in important ways. We shall show below how our theory achieves this unification elegantly, without appeal to "special" properties of neutral vowels or positing unmotivated theoretical machinery.

As discussed in section 4.1, we assume that in a language with both alternating and neutral vowels, alternating vowels are underlyingly unspecified for the harmonic feature $[F]$ and surface as $[+F]$ or $[-F]$ depending on the specification of the vowels with which they harmonize, and that neutral vowels fail to undergo harmony because they are *underlyingly already specified* for the harmonic feature, $[F]$, and the relevant rule is a feature-filling rule. We see, then, that there is nothing special about neutral vowels. In fact, they could be considered the most "normal" vowels of all, being underlyingly fully-specified.

What becomes clear at this point is that the terms "opaque vowel" and "transparent vowel" are stripped of any theoretical significance, as these labels reflect differences in properties of *rules*, rather than properties inherent to the vowels themselves (since we treat so-called opaque and transparent vowels as identical in terms of underlying feature structure). As with our earlier discussion of the theoretical status of 'vowel harmony', we see that the terms 'opaque' and 'transparent', as applied to vowels, are simply mnemonic devices describing epiphenomena of assimilatory rules.

In the remainder of this section, we show how our model accounts for neutral vowels without recourse to a difference between consonant and vowel place features or nodes (cf. Clements & Hume, 1995), or other enriched representational apparatus. Both opaqueness and transparency will be shown to follow from the nature of the rules applied to the vowel representations we posit.

7.1 Opaqueness

In this section we examine cases of vowel harmony that involve particular vowels that block the spread of harmonic features and instead spread their own values. We hope to show that various types of opaqueness arise naturally from the interaction of the primitives we have posited.

7.1.1 Tangale

Recall the Tangale vowel harmony paradigm in (**??**). Items (a) and (b) show that values of the feature [ATR] spread rightwards in Tangale, while (c) and (d) show that /**a**/ fails to alternate. Item (f) is the crucial piece of data, showing that /**a**/ not only fails to alternate, but in fact spreads its own [-ATR] value, blocking the spread of [+ATR] from previous vowels. These data are all accounted for straightforwardly with the following rule:

(15) Tangale vowel harmony rule
$V \Rightarrow$ [αATR] / [αATR] . . . '_'

This rule is simply a particular instantiation of template (**??**a) and rule (**??**). As explained earlier, V is unspecified for [ATR], α ranges over {+,-}, and the ellipsis dots signify that the feature is copied from the closest specified [ATR] value in the relevant direction, left in this case. Consider a full analysis of the suffixes of item (f) **[ɗibnamgʊ]**:

i. By assumption, the /**i**/ in the root is underlyingly specified [+ATR].

ii. The rightmost suffix -gU alternates and we therefore take it to be unspecified for [ATR]

iii. The intervening /**a**/, in the leftmost suffix, is underlyingly specified [-ATR] and therefore constitutes a *closer* (cf. our earlier discussion of locality) instance of [αATR] than that of the [i] in the root.

iv. Thus, the final suffix, in accordance with the harmony rule given above, takes its [ATR] value from the closest source, surfacing as [-ATR], and /**a**/ appears to be an 'opaque' vowel which initiates its own 'harmonic domain'.

We thus see that opaqueness can be generated in a straighforward manner using the theoretical apparatus developed thus far. The opaque vowel, like the other harmony triggers, is fully specified, but there are no underspecified vowels of the same height as the opaque one.

7.1.2 Turkish

Turkish shows clear patterns of both palatal and labial harmony.[16] In particular, all alternating vowels appear to assimilate to the backness of vowels immediately to their left, and high vowels assimilate in roundness to the vowel immediately to their left.

(16) Turkish vowel harmony data

	gen. sg.	*nom. pl.*	*gen. pl.*	
a.	**ip-in**	**ip-ler**	**ip-ler-in**	"rope'
b.	**kɨz-ɨn**	**kɨz-lar**	**kɨz-lar-ɨn**	"girl'
c.	**sap-ɨn**	**sap-lar**	**sap-lar-ɨn**	"stalk'
d.	**yüz-ün**	**yüz-ler**	**yüz-ler-in**	"face'
e.	**son-un**	**son-lar**	**son-lar-ɨn**	"end'

We account for the fact that the non-high vowels do not assimilate in roundness to a preceding vowel by positing a feature filling rule and specifying the non-high suffix vowels (as in *ler/lar*) as [-rd] underlyingly. This allows us to simply posit (**??**) as the relevant rule.

(17) Turkish [rd] harmony rule: $V \Rightarrow$ [αrd] / [αrd] ... '_'

We do not need to specify that the rule applies only to [+hi] vowels—it applies to all vowels lacking a [rd] specification, since the UIP ensures that this rule will not affect vowels with a [rd] specification. The vowel of the genitive marker, in contrast to that of the plural marker has no lexical value for [rd] and thus rule (**??**) fills in the value.

Perhaps surprisingly, the rule for [bk] harmony has exactly the same logical structure as the rule for [rd] harmony—compare (**??**) to (**??**):

(18) Turkish [bk] harmony rule: $V \Rightarrow$ [αbk] / [αbk] ... '_'

This works because we assume that all alternating suffix vowels are lexically unspecified for [bk]—so both the [+hi] and the [-hi] suffix vowels are affected.

Note that the genitive morpheme has four alternants, but that only two of these show up in the genitive plural, namely the two with [-rd] vowels. This follows from the fact that the genitive suffix vowel copies a value for [rd] from the *L-Closest* source, and since the plural suffix is specified [-rd], this is the value that the genitive plural copies.

We thus see that the vowel of the plural suffix is 'harmonic' with respect to [bk], but 'opaque' with respect to [rd]. Of course these terms just label patterns that arise from explicit rules applied to the morphological concatenation of lexical items. The opaqueness of the plural marker to round harmony follows from its lexical representation and the nature of the round harmony rule.

We turn now to see how the other type of neutral vowel can be handled.

7.2 Transparency

We will first present a case of transparency in Wolof [ATR] harmony that is very easy to account for using a rule of the format given in (**??**b). We then turn to some phenomena in Kirghiz. We revisit Kirghiz and also Finnish in the next section.

7.2.1 Wolof

In the Wolof system of ATR harmony the two high vowels /i, u/ are transparent to the harmony process, as the following data show:[17]

(19) Wolof ATR harmony

a.	/**toxi-l**EE**n**/	[**toxileen**]	"go & smoke !"
b.	/**seen-uw-**OO**n**/	[**seenuwoon**]	"tried to spot"
c.	/**tɛkki-l**EE**n**/	[**tɛkkilɛɛn**]	"untie !"
d.	/**tɛɛr-uw-**OO**n**/	[**tɛɛruwɔɔn**]	"welcomed"

We assume that the fact that /i,u/ do not harmonize indicates that they must both have an underlying specification for the [ATR] feature. Accounting for the fact that they fail to trigger harmony is then trivial. We give the harmony and the key points of the derivation of the last form, [**tɛɛruwɔɔn**]:

(20) Wolof vowel harmony rule
$V \Rightarrow$ [αATR] / [-hi, αATR] . . . '_'

i. The vowel in the rightmost suffix alternates in the data shown, and is thus underlyingly unspecified for [ATR], given the assumptions we have adopted above.

ii. The vowel /ɛ/ in the root is specified [-ATR] by assumption.

iii. The vowel in the middle suffix, *-uw*, does not alternate, thus we assume its vowel is underlyingly specified [+ATR].

iv. The final suffix, as dictated by the rule in (**??**), looks for its ATR value from the *L-Closest* [-hi] vowel that has a specification for the feature ATR.

v. The /**u**/ in the middle suffix is specified [+hi] and therefore fails to qualify as a trigger for the rule. The vowel in the final suffix must therefore copy its ATR value from a vowel further to the left of the /**u**/, that is, from the root vowel, /ɛ/.

Having illustrated how our theory of assimilatory processes accounts for the data from Tangale and Wolof, we continue with data from several other languages displaying harmonic systems, each with varying degrees of opaqueness and transparency. In each case we give some representative data, a short set of rules which account for the data, and some further explanatory comments where these are called for.

7.3 Kirghiz

Kirghiz, another Turkic language, displays a particularly quirky exception to its general pattern of palatal and labial harmony: non-high vowels do not assimilate in rounding to high back round vowels, but do assimilate to high *front* round vowels:

(21) Kirghiz vowel harmony data

	accusative	*dative*	*gloss*
a.	**taš-tɨ**	**taš-ka**	'stone'
b.	**iš-ti**	**iš-ke**	'job'
c.	**uč-tu**	**uč-ka**	'tip'
d.	**konok-tu**	**konok-ko**	'guest'
e.	**köz-tü**	**köz-gö**	'eye'
f.	**üy-tü**	**üy-gö**	'house'

Since all alternating vowels assimilate in backness to the preceding vowel, a simple rule in the form of template (**??**a) is sufficient, as in (**??**a). In order to deal with the failure of /u/ to trigger round harmony in a non-high vowel, we need a specific rule like (**??**b), which will assign [-rd] to a [-hi] vowel when the preceding vowel is /u/, that is, [+bk, +hi, +rd]. This clearly requires a conjoined condition on the trigger and thus instantiates template (**??**b). We will see below that things are a bit more complex. Once we ensure that the non-high vowels do not assimilate to an immediately preceding /u/, we can add rule (**??**c) to provide each vowel which is not specified for [rd] with the value from the *L-Closest* source.

(22) Kirghiz rules:
a. $V \Rightarrow [\alpha\text{bk}]$ / $[\alpha\text{bk}] \ldots$ '_'
b. [-hi] $\Rightarrow$ [-rd] when preceding vowel is [+bk, +hi, +rd]
c. $V \Rightarrow [\alpha\text{rd}]$ / $[\alpha\text{rd}] \ldots$ '_'

These rules generate the data, as long as rule (b) precedes rule (c).

8 Understanding the conditions

Replacing the references to features in the rule templates we developed in section **??** with variables for arbitrary phonological conditions yields three even more schematic templates:

(23) Three very abstract rule templates:

a. $S \Rightarrow$ P depending on the *L/R-Closest* unit to S satisfying condition c

b. $S \Rightarrow$ P depending on the *L/R-Closest* unit to S satisfying condition C where C is the conjunction of conditions $c_1 \ldots c_n$

c. $S \Rightarrow$ P depending on the *L/R-Closest* unit to S satisfying condition c if it is also the case that that closest unit satisfies d

The structural change P and the condition c may contain a variable. For example, P may be [αF] with α recurring in c. An example would be a rule in which an obstruent assimilates in voicing to an immediately following obstruent. It is also possible that c itself contain multiple instances of a variable, as in an identity condition. The environment 'between identical consonants' would be one such case (see Reiss 2003a).

In practice, type (a) and type (b) rules fall together, since we typically look for the nearest *vowel*, say, that has the specification [αrd]. Or we may require that the specification be linked to a timing slot. In other words, 'look for the *L-Closest* [αrd]' is typically shorthand for 'look for the *L-Closest* [αrd] segment'. This is probably an important distinction, but we set it aside for now. We will refer to type (b) rules as having *conjoined conditions* in contrast to type (c) rules, which have *nested conditions*.

To illustrate the difference between templates (**??**b) and (**??**c), consider the following scenarios. Suppose you are told to go out into the world, find a man with a hat, and take his hat. On the assumption that there are such things as men with hats and that they can be found, you can clearly always return with a hat. But the outcome is potentially different if you are told to go out, find a *person* with a hat, and take the hat *only if that person is a man*. You may in this case return hatless, if the first behatted person you met was a woman. The first task involved a conjoined condition —take the hat of the first person you meet who is both a man AND a hat-wearer; the second involved a nested condition—take the hat of the first hatwearer, if that person is a man. Thus we see that conjoined and nested conditions can give different empirical outcomes.

8.1 Referring to immediately preceding vowel in Kirghiz

We return now to consider the nature of the Kirghiz rule (**??**b). First of all, why did we not express the rule as follows: [-hi] $\Rightarrow$ [-rd] / [+bk, +hi, +rd] . . . '_' ? The reason is that this rule would look for the *L-Closest* segment that has the listed features, no matter how far away it may be. In other words, there could be other vowels closer, but lacking the conjunction of features [+bk,+hi, +rd]. But if there are such vowels, *they* should trigger harmony.

So, what we need is to have this specific rule apply just in case the *immediately preceding* vowel is /u/, so that the suffix vowel ends up as [-rd] after /u/ but otherwise harmonizes with the rounding of the immediately preceding vowel. The way to do this is to look for the immediately preceding vowel, and then apply the rule just in case it has the right features, not to go looking for such a vowel arbitrarily far away. In words, the rule then is

(24) Find the *L-Closest* vowel to the target and if that vowel is [+bk, +hi, +rd] make the target [-rd].

This is what we might have traditionally written as [-hi] $\Rightarrow$ [-rd] / [+bk, +hi, +rd] C_0 _. What we hope to convey is that even such a simple rule, of the type taught to beginning students, actually contains a nested condition.[18] Our long discussion has not complicated traditional rule-based phonology in this instance, but rather shown that the traditional notation, when unpacked, manifests a fairly complex relation among the parts of its structural description.

It is worth pointing out here that rule (**??**) is not a harmony or assimilation rule, but that these pretheoretical categories may obscure what we see as an underlying unity of logical structure in the rules we have proposed. We have attempted "to abstract from the welter of descriptive complexity certain general principles governing computation".

8.2 A nested condition in Bashkir

A case of harmony involving a nested condition (template c), is found in Bashkir, in which /w/ blocks rounding (Poppe, 1964). The suffix that derives names of professions from other nouns has the form /-sE/, where E denotes a mid vowel that can surface as [$\pm$round] and [$\pm$back] to agree with the preceding vowel. This suffix can attach to a noun like 'fish' to derive 'fisherman' or to the derived verbal nouns made with the suffix /-Ew/. However, in the latter case, the /-sE/ will never show up with a round vowel, because of the opaqueness of the /w/. The verbal root /**töð**-/ 'build' thus yields the form [**töðöwsɛ**] 'builder':

(25) /**töð**-Ew-sE/ $\leftrightarrow$ [**töðöwsɛ**]

The vowel of the first suffix harmonizes with the roundness of the root vowel, but the labial non-vocalic /w/ blocks rounding in the second suffix. Note that palatal harmony spreads [-back] to both suffixes.[19]

While at first blush it seems counterintuitive that a labial consonant should *block* rounding harmony, it is important to remember that the phonological component associates no 'phonetic content' (articulatory or otherwise) to the features over which it computes and is therefore unaffected by the alleged 'naturalness' (or lack thereof) of particular rules. Keeping these points in mind, an analysis of the Bashkir system is relatively straightforward in the context of the substance-free theory developed above.

(26) Bashkir Vowel Harmony $V_j \Rightarrow [\alpha\text{rd}]$ / $[\alpha\text{rd}]_i \ldots$ '_'
if $[\alpha\text{rd}]_i$ *is specified* [+vocalic].

This rule is interpreted as follows: find S_i, the *L-Closest* segment to V_j which has some specification [αrd], and copy that specification onto V_j, **but only if** S_i is a vowel. It is crucial to understand that the rule does not, and cannot say 'find the closest [αrd, +vocalic] segment to V_j' and copy that value of [round]. This would yield the ill-formed *[**töðöwsö**]. [20]

8.3 A special case of nesting—bisyllabic triggers

Walker (2001) discusses an interesting case of [round] harmony in the Altaic languages Manchu and Oroqen, following an observation of Dresher and Zhang (1996) and Zhang (1996). In these languages, a non-high vowel suffix copies rounding from a sequence of two preceding non-high round vowels, but not from a single one. In data from Oroqen, for example, the suffix glossed 'definite object' shows up as [wa] in [mɔː-wa] 'tree' and [tɔrɔki-wa] 'boar', but rounded to [wɔ] in [ɔlɔ-wɔ] 'fish'. Other suffixes show parallel behavior. Walker's Optimality Theoretic analysis diverges too sharply from the approach outlined here to make comparison worthwhile, but we will point out that she posits constraints that make specific reference to the feature [round] in the initial syllable. Given the standard assumption of the universality of Optimality Theoretic constraints, and given the fact that crosslinguistically there is no reason to assume that this feature has a special affinity with the initial syllable (e.g. Turkish *pilot* 'pilot' triggers round vowel harmony, as in *pilotum* 'my pilot', despite the fact that the [o] is non-initial), this kind of solution appears to us to be ad hoc and in direct conflict with the substance-free approach advocated here.

We agree with Walker that merely stipulating that the trigger of rounding harmony in these languages be bisyllabic is unsatisfactory. We propose instead to exploit the possibility of nested conditions proposed in (**??**c). Oroqen rounding harmony affects only non-high vowels and the trigger must be non-high, as well. The full rule can be stated thus:

(27) Oroqen rounding harmony with bisyllabic trigger
  [V_1, -hi] $\Rightarrow$ [αrd]
  if its (V_1's) *L-Closest* V, V_2 is [αrd, -hi]
  if its (V_2's) *L-Closest* V, V_3 is [αrd, -hi]

Writing this in traditional rule notation is too cumbersome,[21] but it is important to realize that V_1 is the standard to which V_2 is *L-Closest*, and that V_2 is the standard to which V_3 is *L-Closest*. We have only the relation of *L-Closest*, but in a nested condition. There is no direct relation between V_1 and V_3. As stated, our proposal makes no reference to initial syllables and thus it makes a different prediction from Walker's. Given a hypothetical form like [imɔkɔ], with a sequence of non-high round vowels that is non-inital, we predict that the [-wa / wɔ] suffix would show up with the round variant, whereas Walker predicts the unrounded variant, since for her, round harmony only occurs if the initial syllable has a non-high round vowel. Unfortunately, we do not have the relevant data.[22]

8.4 Finnish

We now return to the problem of accounting for transparency of /e/ and /i/ in Finnish [bk] harmony. We repeat the crucial portion of the Finnish data:

(28) Finnish transparency
  a. **värttinä-llᴀ-ni-hᴀn** **[värttinällänihän]**
  b. **palttina-llᴀ-ni-hᴀn** **[palttinallanihan]**

The harmonic feature here is [back] and we might (naively) hope that the harmony data could be accounted for with a simple rule like that proposed for Tangale, for example:

(29) Finnish vowel harmony rule, version 1
$V \Rightarrow [\alpha\text{bk}]$ / $[\alpha\text{bk}] \ldots$ '_'

Given our unification of all neutral vowels as underlyingly specified for the relevant feature(s), the problem with this rule is immediately obvious. The rule states that *all vowels* specified for [bk] (*i.e.* including /**i**/) spread their value for this feature to following vowels that are not so specified. Plainly, this is not what happens, as the vowel to the right of /**i**/ in item (**??**b) surfaces with a [+bk] specification and not in agreement with the [-bk] /**i**/. The problem of accounting for this transparent vowel thus remains somewhat mysterious.

Enlightenment, as is often the case, comes from a reformulation of the question. The crucial point to notice is *not* that [+bk] somehow magically "passes through" the /**i**/, but rather that the /**i**/, which we have suggested is underlyingly specified as [-bk] *fails to spread its own [-bk] value*. Instead of asking "Why does /**i**/ fail to harmonize?", we are now in a position to ask the more perspicuous question, "Why does /**i**/ fail to trigger harmony in subsequent vowels?" The answer, in the restrictive model we have adopted, is simply that /**i**/ does not create an environment that triggers the application of the vowel harmony rule.

Suppose that, rather than the too-simple rule adopted in (**??**), we posit the following rule with a conjoined condition:

(30) Finnish vowel harmony rule, version 2
$V \Rightarrow [\alpha\text{bk}]$ / $[+\text{lo}, \alpha\text{bk}] \ldots$ '_'

This rule, which instantiates the abstract rule template (**??**b), accounts for the data in (**??**) in the same manner as that shown above in the sample derivation of the Wolof form.

However, the rule given in (**??**) cannot be the whole story, as it fails to account for data like the following:

(31) **tuoli-lla** "on the chair'

What we see in (**??**) is that the root vowel /**o**/ spreads its value for the [bk] feature to the suffix across the /**i**/, which we already know is not a trigger for harmony. Crucially, though, /**o**/ is non-low, and should therefore not qualify as a trigger for the rule in (**??**). Recall that in Finnish the neutral vowels are /**i**/ and /**e**/, that is, the front non-low non-round vowels. To fully account for the Finnish vowel harmony data, then, we appear to need a rule that will spread the value for [bk] from any [+rd] vowel through a neutral vowel. We appear to need something like the rules in (**??**).

(32) Finnish vowel harmony rules, version 3
a. $V \Rightarrow [\alpha\text{bk}]$ / $[+\text{lo},\alpha\text{bk}] \ldots$ '_'
b. $V \Rightarrow [\alpha\text{bk}]$ / $[+\text{rd},\alpha\text{bk}] \ldots$ '_'

Each of these rules instantiates the conjoined condition illustrated in (**??**b). The trigger must be [+lo] *and* [αbk] in the first rule, and [+rd] *and* [αbk] in the second.

However, a problem remains. We are assuming that rules must be ordered, and thus if rule (a) is ordered before (b), the system will not necessarily copy the value for [bk] from the *L-Closest* source, be it [+lo] or [+rd], but rather from the *L-Closest* [+lo] vowel, thus skipping potentially intervening [+rd] vowels. Only in the absence of a [+lo] vowel will rule (b) apply.

To illustrate the problem, note that a hypothetical root like **kätutik-** would trigger [-bk] on suffixes given the rules in (**??**) if they are applied in the listed order. This is because the first rule (a) would 'find' the [+lo] /**ä**/ and thus ignore the [+rd] /u/. Switching orders would solve the problem in this particular case, but would lead to a hypothetical **kutätik-** surfacing with [+bk] suffixes. In this case, applying rule (b) first would copy [+bk] from the /u/, bypassing the [-bk] **ä**. In other words, it appears that neither order allows us to capture the supposed generalization—the value for [bk] is copied from the *L-Closest* non-neutral vowel.

We seem to need to a rule that will copy the value for [bk] from the *L-Closest* vowel that is *either* [+rd] or [+lo]. In other words, we seem to need a single rule with a disjunctive condition. However, we adopt the position that phonological rules cannot make use of disjunctive conditions. In the spirit of McCawley (1973), we consider curly bracket notation, for example, to be such a powerful device as to make the notion of rule empty. In order to avoid disjunctive rule conditions we offer three possible solutions.

8.4.1 The convenient data gap solution

It turns out that one solution to our dilemma may reside in the facts themselves—as far as we can tell, Finnish does not have any stems with the logical structure of our problematic hypothetical forms, namely a low vowel and a round vowel with opposite values for [bk]—no Finnish words contain the following vowel combinations: /**ä** ... **u**/, /**u** ... **ä**/, /**a** ... **y**/, /**y** ... **a**/. The generalization is actually broader— the only disharmonic stems in Finnish (stems in which the vowels disagree in backness) are those containing back vowels and neutral vowels—no non-neutral front vowels can occur with back vowels.

Thus we can maintain the rules in (**??**). Basically they capture the generalization that Finnish alternating suffixes surface with [+bk] vowels whenever they are preceded (at any distance within the word) by a [+bk] vowel. Either ordering will work for all Finnish words. We assume that the language faculty imposes an order, but no evidence is available to us to choose the correct ordering.

8.4.2 A solution without α values

Another way to generate the Finnish is to assume first a rule that looks for the *L-Closest* [+bk] vowel to an underspecified vowel V and assign [+bk] to V; and second a rule that fills in [-bk] as a default on remaining underspecified vowels, as in (**??**)

(33) Finnish vowel harmony rules without α values

$V \Rightarrow$ [+bk] / [+bk] ... '_'
$V \Rightarrow$ [$-$bk] /

Like the previous solution, this one crucially relies on the non-existence of stems with non-neutral front vowels to the right of back vowels. This is because such a sequence, for example, /**u** ... **ä**/, would end up with [+bk] suffixes if the rules in (**??**) applied.

8.4.3 The nested conditions solution

Theory comparison sometimes takes the form of arguments over which of several competitor theories can account for some empirical facts. However, an equally important issue in the evaluation of a theory is the problem of being so vague as to allow several analyses for a data set. Unfortunately, we must acknoweldge that we are in this situation, and that we can offer at least one more account for Finnish transparency that differs significantly from that represented by the rules in (**??**). and (**??**).

We can apply to Finnish a similar analysis to the one we proposed above for Oroqen rounding harmony. Consider the nested condition of Oroqen in (**??**). The rule identifies a standard vowel with respect to which a second vowel is identified, and then this second vowel is the standard with respect to which a third vowel is identified as the source from which a value is copied. On the simplest assumptions, the grammar places no restrictions on the depth of this type of nesting. The proper formulation of the rule, then, cannot be an infinite list of *if*-conditions, but must involve an iterative or recursive procedure.[23]

(34) Finnish with nested condition:
For a given vowel V_0, let $V_n = V_0$.
If V_n's *L-Closest* [αbk] is on a transparent (*i.e.* [-bk, -rd, -lo]) vowel, V_{n+1}, set V_n to V_{n+1} and recursively apply.
Otherwise copy the [αbk] from V_{n+1} onto V_0.

If the *L-Closest* instance of [αbk] to the standard is *not* on a neutral vowel, then the *else*-branch of the rule will apply and the underspecified vowel will copy the *L-Closest* [bk] value.[24]

This solution will work to assure harmony across arbitrarily long sequences of neutral vowels, as in the following forms cited by Krämer (2003) from Kiparsky (2000):

(35) Sequences of neutral vowels in Finnish

a.	ui-da	'to swim'	ui-ske-nt-ele-mi-se-ni-ko	'my swimming around?'
b.	syö-dä	'to eat'	syö-ske-nt-ele-mi-se-ni-kö	'my constant eating?'

In the forms in (**??**a) the alternating suffix vowels are [+bk], in agreement with the /u/ of *ui-* , no matter how many neutral vowels intervene. And in the (b) forms, the alternating suffix vowels are always [-bk] in agreement with the /ö/ of *syö-*.

This solution also works for the forms in (**??**), repeated here:

(36) Finnish transparency

a. **värttinä-llA-ni-hAn** **[värttinällänihän]**
b. **palttina-llA-ni-hAn** **[palttinallanihan]**

Consider the derivation of the value for [bk] in the final suffix:

- its vowel 'searches' to its left for an [αbk] value and finds it on the immediately preceding vowel;
- but this vowel is [-bk, -rd, -lo];
- so the search continues to the left;
- the next vowel is ignored since it has no [αbk];
- the last vowel of the root (for both (**??**ab) has an [αbk] value;
- since this vowel is not [-bk, -rd, -lo], that last found [αbk] is copied to the starting vowel.

This solution is not dependent on the non-existence of stems containing both back and non-neutral front vowels. It will always copy [αbk] from the rightmost non-neutral source. Thus, we see that choice between the solutions presented is, in principle, an empirical one.

8.4.4 Understanding transparency in Hungarian

As in Finnish, the non-low, front unrounded vowels in Hungarian can be transparent to vowel harmony. These are orthographic *i, í, e, é*. An example is found in the deverbal adjective forming suffix *-ékeny / -ékony*: *gyúlékony* 'flammable', *közlékeny* 'talkative'. The first suffix vowel *é* is transparent, whereas the second vowel harmonizes for the feature [bk].

The features of these transparent vowels are shown in (**??**):

(37) Transparent vowels of Hungarian

orthography	IPA	features	length
i	[i]	[+hi, -lo, -bk, -rd, +ATR]	SHORT
í	[iː]	[+hi, -lo, -bk, -rd, +ATR]	LONG
e	[ɛ]	[-hi, -lo, -bk, -rd, -ATR]	SHORT
é	[eː]	[-hi, -lo, -bk, -rd, +ATR]	LONG

However, unlike the transparent vowels of Finnish, some of these surface vowels can also be the surface manifestation of alternating vowels. Short *e* surfaces in alternation with *a*, as in the inessive suffix: *dobban* 'in a drum', *szemben* 'in an eye'. It also surfaces in alternation with the tense round mid vowels *ö/o*. This pattern is seen in the superessive suffix *-en/-ön/-on*: *szemen* 'on an eye', *tökön* 'on a pumpkin', *dobon* 'on a drum'. The long *é* surfaces in alternation with *á*, as in the translative suffix *-vá/-vé* (the *v* assimilates to a preceding consonant): : *dobbá* '(turn) into a drum', *szemmé* '(turn) into an eye', *tökké* '(turn) into a pumpkin'.

There is no problem with the fact that a surface vowel such as *é* can correspond to both a non-alternating vowel in a suffix or stem and also to a suffix that harmonizes. In the former case, the vowel is fully specified (with the values in (**??**)), and it does not alternate if we posit only feature-filling rules for Hungarian (see Reiss 2003a). These non-alternating vowels can also be treated as transparent using the mechanism we developed for Finnish. The latter case, in which *i, í, e, é* alternate, represents surface realization of vowels that are partially underspecified underlyingly. These missing values are filled in by rule. So the surface vowel (*é*), for example, corresponds to both a non-harmonizing, underlying fully specified, transparent vowel, and to a harmonizing, underlyingly partially underspecified vowel.

9 Conclusions: Phonology as Grammar

We have aimed to provide a novel, yet simple account of phenomena that are fairly well-known by developing a rule-based framework with a minimum of ontological structure. The main contributions we hope to have made are (i) a novel, unified treatment of neutral vowels, (ii) clarification of the notions of closeness and locality in phonology, (iii) some insight into target/trigger relations in phonological processes, and (iv) some ideas about the logical structure of rules.

In relation to (ii) and (iii), we remark here on the importance of distinguishing between descriptive and explanatory adequacy. Although our initial claims about the *Closest* conditions and the notion 'target as standard' were descriptively true statements about the phonological computational system, we showed that neither of them are properties of Universal Grammar, but rather that they follow from extralinguistic facts about the nature of computation and learnability. This refining of the boundary between ontological and epistemological facts is a clear sign of progress in the study of the properties of Universal Grammar in general, and in the pursuit of an answer to the question posed by our title, in particular.

Interestingly, the definition of locality that we adopt here shows some parallels with recent work on the locality of operations in generative syntax. Within the framework of checking theory that has been elaborated since Chomsky (1995), constraints on locality are built directly into the mechanisms of movement, via constraints like *Shortest Move* and the *Minimal Link Condition*. More interestingly from our perspective is the notion in Chomsky (1995, ch. 4) that "movement to" a checking head is in fact more perspicuously viewed as "attraction from" an uninterpretable feature. That is, both the mechanism of and motivation for movement have been revised: rather than having a category move in order to check an uninterpretable feature elsewhere in the tree, a feature that is uninterpretable attracts a category from somewhere else that is able to check it. If we abstract somewhat from the exact properties of the participants, there appears to be some convergence between the view of locality recently adopted in syntax, and that we have espoused in this paper: the behaviour of the attracting head and attracted feature in syntax closely parallel that of the underspecified vowel and copied feature value in our model of vowel harmony. In each case, an element that has a property that needs to be satisfied (uninterpretable/unspecified feature) attracts the *unique closest* feature that is able to satisfy its requirement. This type of cross-domain convergence in the definitions of theory-internal constructs is surely a positive result.[25]

We have discovered two more parallels between phonology and syntax in the course of this study. Our analysis of what appear to be long-distance effects led us to reformulate them in terms of the *Closest* relations. Articulatory factors such as gestural overlap played no role in our analysis, and neither did the (incoherent–see

Coleman & Local, 1991) constraint against crossing association lines. We consider this to be a positive result in that it demonstrates that phonology shares with syntax one of the apparently unique defining properties of human language among communication systems—the property of long-distance dependency. In a sentence like *Who*$_i$ *did Mary say Bill believes Tom saw* t_i*?*, the interrogative pronoun must be interpreted as the object of the verb *saw*, which it is not adjacent to. It must be interpreted in the position marked with the trace. In some of the vowel harmony patterns we have examined vowels copy feature specifications from non-adjacent segments. Articulatory adjacency seems to be contraindicated by the facts. Pure symbolic computation shows parallel effects in phonology and syntax. Rather than fret about violations of articulatory locality or contiguity, let us rejoice in this unity among modules of grammar.

While theoretical linguists have consistently claimed recursion as one of the defining features of the human language faculty, it has also been argued (see several of the papers in Burton-Roberts, Carr & Doherty 2000) that since phonology has no convincing cases of recursion, phonology is not part of grammar, not part of the language faculty strictly speaking. In addition to the spuriousness of this reasoning, it may simply be false that phonology lacks recursion. The iterativity in foot construction manifested by stress assigning algorithms can be expressed in terms of a recursive procedure, and thus may be sufficient to demonstrate that the phonology does have recursive capacity. This paper has offered another candidate. The nested conditions on rules, as in Bashkir, represent a kind of recursion in phonological computation—for a vowel V1, see if the closest vowel to it, V2, has some property; then see if the closest vowel to V2, V3, has some property. The simplest account of such a system would just allow for embedded conditions, not an explicit limit of two levels.

These three cross-domain insights–the nature of locality, the nature of long-distance dependency, and the presence of recursion really only arise by abstracting away from phonetic substance and examining the formal properties of phonology. In addition to the insight into the nature of vowel harmony and similar phenomena that we hope to have offered, we see these cross-domain results as an indication that substance-free phonology represents a fruitful research program within which to ask 'What is a possible phonological rule?'.

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Notes

[1]We denote a feature *qua* dimension of segmental variation by $[F]$, the *value* of a feature by $[+F]$ or $[-F]$, and use α as a metavariable ranging over $\{+,-\}$. Also, we assume for purposes of exposition that {hi, lo, bk, rd, ATR} is an exhaustive feature set. Nothing in the analysis hinges on this.

[2]For development of these arguments against constraints, see Reiss 2004; for arguments that Universal Grammar should characterize the set of languages that are computable by the human language faculty, and not just the set of attested or attestable languages, see Hale and Reiss 2000ab, Reiss 2003a.

[3]We use capital letters to denote vowels that underlyingly lack a specification for one or more features. It will always be clear from the context which feature(s) is/are missing. The forms listed as elative here are glossed incorrectly as illative by van der Hulst & van der Weijer.

[4]As the term 'opacity' has a variety of meanings in a variety of contexts in phonological theory, we will use the term 'opaqueness' to refer to this process/property. In any case, we will show below that the term is merely a mnemonic device, essentially devoid of meaning in the context of vowel harmony.

[5]Item (e) is from Bakovic (2001).

[6]See Reiss (2003) for arguments that feature geometry is insufficiently powerful as a theory of phonological representation for independent reasons.

[7]See Halle & Bromberger 1997 for arguments that features as they are used in phonological theory should be viewed as predicates over intentional states. We have not yet decided if this view is compatible with our own.

[8]We accept the arguments of Keating 1988 that underspecification may persist even in the grammar's output forms, but this issue is not relevant to our discussion.

[9]See Coleman & Local 1991, Coleman 1998 on the dangers of confusing the properties of a diagram with the properties of the object of which it is a diagram

[10]This definition and usage are foreshadowed by McCawley (1973), who says "Rules [...] may [...] call for one segment to be the closest segment of a given type before or after a given segment [...]".

[11]We use 'T' rather than the typical 'X' for timing slots to avoid confusion with our use of the latter to denote types, above.

[12]In this subsection, we assume, for ease of exposition, that *Closest* relations are computed in the course of a derivation, but we will refine this notion below.

[13]In all our examples, we assume that harmony is a purely feature-filling process, although our adoption of the *UIP* means that the model can accomodate feature-changing processes, as well, as discussed by Reiss (2003a).

[14]SEARCH is independently necessary—for example, for the identification of environments of rule application.

[15]Of course, opaque and transparent vowels are only visible when they have the opposite specification for a harmonic feature to the vowels on one or both sides of them.

[16]The data in this and the following subsections are cited by Odden (forthcoming).

[17]The data are from Archangeli & Pulleyblank (1994), but we have standardized the transcription. Small capital letters denote vowels without an ATR specification. The symbols [i, u] denote high vowels that are [+ATR], but have no [-ATR] correspondent.

[18]Of course, one could achieve the same result with a conjunction: 'Find the vowel that is both [+bk, +hi] and *L-Closest* to the target.' As discussed above, under our algorithmic approach we cannot refer to *L-Closest*, since that notion just describes the result of the SEARCH algorithm.

[19]Poppe uses a backwards E to represent the harmonizing vowel, and he uses the symbol ə for our ɛ, but it is very clear that it is a mid, front, nonround vowel (pp. 6-7). He is also very clear about the productivity of the harmony processes (p. 19) and the opaqueness of /w/ (p. 20). The suffixes in question are discussed on pages 47 and 61.

[20]The actual Bashkir rule may require that the nested condition specify [-high], since the high vowel /ʊ/ does not trigger harmony. In fact, if /w/ and /ʊ/ are both [+high], then we need not specify [+vocalic] at all. In any case, some nested condition is needed.

[21]In fact it becomes clear that the traditional notational system of rewrite rules is inadequate for the explicitly procedural view of phonology we are attempting to build here. See Mailhot (in prep.) for discussion and an attempt to alleviate the problem.

[22]We should point out that this description of Oroqen round harmony is inconsistent with that given by Whaley (2001), according to which there is no bisyllabic trigger requirement and the high vowel [u] can trigger rounding harmony: [tʃaŋkʊ-wɔ] 'bowl'. Whaley's data is based on older speakers of the Central dialect as recorded in a published source and his own field notes with Fengxiang Li.

[23]This parallels a foundational tenet of current generative syntax, in which the in-principle infinite depth of nesting is the product of a recursive structure-building operation (see Chomsky 1995 for discussion).

[24]On the explicitly procedural view of phonological computation that we are advocating here, (**??**) is more straightforwardly expressed as a recursive procedure which is called in order to assign a feature value to some vowel:

```
HARMONIZE(string Σ, standard V_n):
if L-Closest [αbk] is a transparent vowel, V_{n+1},
    return HARMONIZE(Σ-V_n, V_{n+1})
else
    return backness value of V_{n+1}
```

[25]See Mailhot (2004) for additional exploration of these points, and of the possibilities for further unification across linguistic domains.