

Input-Driven Opacity

by

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Abstract  
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This study addresses the issue of phonological opacity. While many previous proposals have attempted to offer all-encompassing theories of opacity, the goal of this study is more modest based on the belief that further understanding of the phenomenon of opacity will come from looking at specific types of phonological processes and their interactions, as opposed to looking at all cases of opacity as a singular phenomenon. To that end, I introduce a new set of generalizations by focusing on cases involving harmony and tonal interactions. Indeed, this particular empirical domain suggests a different understanding of what it even means to be opaque. Furthermore, the general typological finding is that cases of opacity involving tonal interactions and harmony reflect greater faithfulness to the underlying representation. This can be formalized within OT by expanding on two-level markedness constraints (McCarthy, 1996) and Correspondence Theory (McCarthy & Prince, 1995) to include diagonal correspondence, a two-level faithfulness constraint. A specific prediction this approach makes is that certain types of feeding and bleeding relationships should not be found when harmonic and tonal interactions are involved. Instead, opacity is the preferred type of process interaction i.e. harmony is generally

counter-fed and counter-bled by other processes, contra the hypothesis that opaque interactions are marked (Kiparsky, 1971).

One of the challenges opacity presents for theories of phonology is a learnability problem. Indeed, a theory based on increased faithfulness to input forms requires that language learners be able to abstract underlying representations for words despite potentially never hearing them. Using an artificial-grammar learning paradigm, I show that language learners are indeed able to do so. These results suggest that some process of abstraction is needed to augment theories based on surface-derived generalization such as Natural Generative Phonology (Hooper [Bybee], 1976), exemplar-theory (Pierrehumbert, 1991; Johnson, 1997), statistical theories of phonology (Goldsmith, 2005) and indeed, OT. Furthermore, under-application/counter-feeding opacity was more learnable than over-application/counter-bleeding opacity for harmony contra the hypothesis that under-application is more marked (Kiparsky, 1968). Finally, the results make predictions as to the maximum proportion of opaque to transparent forms allowed in a language.

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## CHAPTER 1

### THE LOGIC OF OPACITY

#### 1.1. INTRODUCTION

Opaque interactions present a significant problem for surface-based theories of phonology. While this study primarily focuses on the problems it presents for Optimality Theory (OT), opacity is challenging for any theory that seeks to express generalization based solely on output forms, or what speakers hear.

In Shimakonde; Manus, 2003), for example, vowel harmony and mid vowel reduction combine to yield opaque forms:

(1) Shimakonde opacity (data from Liphola, 2001):

<u>Transparent</u>		<u>Opaque</u>	
a) kú-páát-a	‘to cut’	kú-péét-a	‘to separate’
b) kú-pát-ííl-a	‘to cut for’	kú-pát-éél-a	‘to separate for’
c) kú-pát-íl-áána	‘to cut for each other’	kú-pát-él-áán-a	‘to separate for e.o.’

The forms in (b) and (c) are opaque because the applicative suffix, /-il-/, is the target of mid vowel harmony due to the mid vowel in the verb root and surfaces as *-el-*, but the triggering root vowel is reduced to *a*. Thus, there is no surface-transparent way to account for why the applicative suffix surfaces as *-el-* without reference to the underlying mid vowel in the verb stem.

Now juxtapose the behavior of two different kinds of a tone shift: shift to

prominent position as found in Zulu (Downing, 1990a) versus a shift one tone-bearing unit (TBU) to the right as found in Jita (Downing, 1990b):

(2) Two different kinds of tone shift:

a) Zulu tone shift (Downing, 1990a):

<u>u</u> -kú-hlek-a	‘to laugh’
<u>u</u> -ku-hlék-is-a	‘to make laugh
<u>u</u> -ku-hlek-ís-an-a	‘to make each other laugh’

b) Jita tone shift (Downing, 1990b):

o-ku-β <u>ón</u> -a	‘to get/see’
o-ku-β <u>on</u> -ér-a	‘to get for’
o-ku-β <u>on</u> -ér-an-a	‘to get for each other’
cf. o-ku-lim-a	‘to cultivate’
o-ku-lim-er-a	‘to cultivate for’

In Zulu, the underlying high tone from the *u-* prefix shifts to the anti-penultimate syllable and the location of the underlying high tone is not relevant. This is a generalization that is expressible in terms of the final output form, and so the tone shift is therefore said to be surface-transparent.

In Jita, high tone, which is on the underlying verb root, *βon*, shifts on tone-bearing unit to the right from its origin. When there is no high-tone on the underlying stem, no high-tone surfaces on the adjacent TBU (e.g. *ku-lim-er-a* ‘to cultivate for’) Despite the

simplicity of the description of this interaction, there is no way to express where the high tone surfaces without reference to the underlying representation. Jita is therefore opaque since the realization of high tone is not resolvable solely by reference to the surface form.

Tone shifts are generally not often considered in the literature on opacity (cf.; Chen, 2002; Lin, 2004 are exceptions), but despite significant differences between the Shimakonde and Jita examples, including the fact that Shimakonde involves two phonological processes, whereas Jita involves only one, they both share a common characteristic: Being able to reference the underlying form in these two cases of opacity allows for an exceedingly simple definition of the morphophonology of Jita tone and Shimakonde affixation. In Jita, the generalization is to shift high tone one syllable to the right of its input source, while in Shimakonde the generalization is that the applicative allomorph agrees in height with the underlying form of the verb root. Graphically, this can be represented with the following mappings:

(3) Graphical representation of

a) Jita tone shift

/ku-βón-er-a/



[ku-βon-ér-a]

b) Shimakonde Harmony

/ku-pet-il-a/



[ku-pat-eela]

This type of relationship cannot be formalized in exclusively surface-based theories of phonology, such as standard Optimality Theory, but can be accommodated through the introduction of what I shall term Diagonal Correspondence Theory (DCT). DCT, defined in detail in chapter two, represents an amendment to OT combining the insights of two-level markedness constraints (McCarthy, 1996) and Correspondence Theory (McCarthy

& Prince, 1995) and is briefly defined as follows:

Faithfulness constraints (more detail in §1.3.3 on OT) are based on a relationship between equivalent segments on the input and output. For example, for the UR-SR pair of /pet-il/~[pateel], /p/ corresponds with [p], /e/ with [a], /t/ with [t], /i/ with [ee] and /l/ with [l]. Any changes in corresponding segments from input to output incur a violation of these input-output faithfulness constraints.

Graphically, correspondence among equivalent segments can be represented with vertical arrows or by indexing corresponding segments:

(4) Graphical representation of standard correspondence:

a) /p<sub>1</sub>e<sub>2</sub>t<sub>3</sub>-i<sub>4</sub>l<sub>5</sub>/  
    ↓ ↓ ↓ ↓ ↓  
    [p<sub>1</sub>a<sub>2</sub>t<sub>3</sub>ee<sub>4</sub>l<sub>5</sub>]

DC establishes a correspondence relationship among non-equivalent input-output segment pairs. As with input-output faithfulness (i.e. faithfulness among equivalent segments), DC faithfulness constraints incur violations when segments that are in diagonal correspondence are different. This can capture opaque generalizations as illustrated in (3), for example, where in (3a) output *ér* must agree with respect to tone with input *βón* and in (3b) where the applicative suffix, *-el-*, must agree in height with the vowel in the input verb root, *pet*.

In this chapter, I set up the argument for DCT by highlighting four empirical observations concerning opacity. First, I suggest a refinement of the definition of opacity. Instead of a rule-based definition, where feeding and bleeding are transparent and counter-bleeding and counter-feeding are opaque (Kiparsky, 1971, 1973) or a surface-

truth-based definition where surface-true generalizations are transparent and over-application and under-application of generalizations are opaque (McCarthy, 1999), I argue that the opacity can also be defined as input-determined output while transparency can be defined as output-determined. Second, I argue that the generalization captured by rule-based approaches to opacity that use alpha-rules (Chomsky & Halle, 1968) or autosegmental notation (Goldsmith, 1976) is one of input-output mapping of the sort in (3). Third, I show that for harmony and tonal interactions, opacity is the unmarked and more common process interaction, rather than surface-transparent interactions. Finally, I show that there are cases of within-stratum opacity at the post-lexical and word strata, suggesting that serial ordering of strata (Bermudez-Otero, 1998; Kiparsky, 2000) is an inadequate solution to the problem.

## **1.2. DEFINING OPACITY**

In this section I present previously proposed definitions for opacity and suggest a refinement to the current definition of opacity within OT for cases involving tone shifts and vowel harmony. Doing so involves a number of steps. First, I summarize the rule-based definition of opacity introduced by Kiparsky (1971, 1973) and highlight some of its shortcomings. Second, I discuss some of the motivation for moving from a rule-based approach to phonology to an approach involving constraints on surface forms. This is relevant to opacity because whereas rules could accommodate opaque interactions, surface-based approaches cannot. I argue that this is, in part, because of the theoretical imperative of merging phonotactics and morphophonological alternations. Third, I introduce Optimality Theory, the current dominant constraint-based theory. This is

necessary because DCT is an amendment to OT and establishes the framework within which DCT fits. Fourth, I demonstrate how OT cannot deal with opaque interactions. Finally, I show how focusing on tone shifting and vowel harmony leads to a different definition of what it means to be opaque with transparent processes, like shifts to prominent position, being output-defined processes and opacity being input-defined.

### **1.2.1. Rule-Based Opacity**

The original conception of opacity was as a type of interaction between phonological processes. Processes interact when one alters the target or environment of another, affecting whether it applies or how it applies. The target refers to the phonological material that changes as the result of some process and the environment refers to the phonological structure that defines when the process occurs.

Early ruled-based typologies of these interactions include the pioneering works of Kiparsky (1968, 1971, 1973), which suggest two different ways two rules could interact: opaquely and transparently. Transparent interactions were meant to describe situations where evidence for the application of both rules is apparent or evident in the final output – to the linguist and more importantly, to the language-learner. This is hypothesized to be the unmarked, or preferred, type of interaction.<sup>1</sup> Using a rule-based approach, Kiparsky further divided transparent interactions into feeding and bleeding rule ordering, which yielded (or rather, as discussed below, tended to yield) transparent surface forms. A feeding relationship describes a situation where one rule creates the environment or target for a subsequent rule. For example, Kiparsky (1968) presents two processes in Finnish,

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<sup>1</sup> This is the case in Kiparsky (1973). Earlier accounts (1968) deemed maximal rule application, e.g. feeding and counterfeeding, unmarked.

intervocalic consonant deletion and diphthongization, which must be extrinsically ordered in a feeding relationship for the correct derivation of surface forms:

(5) Finnish feeding (Kiparsky, 1968):

	/teye/		/teye/
$\gamma \rightarrow \emptyset / V\_V$	tee	ee $\rightarrow$ ie	--
ee $\rightarrow$ ie	tie	$\gamma \rightarrow \emptyset / V\_V$	tee
	[tie]		*[tee]

The second type of transparent relationship is bleeding where one rule eliminates the environment or target of a second, which consequently ends up not applying. For example, in Alsatian German (Kiparsky, 1968), there is a process of final devoicing and a process of spirantization of post-vocalic voiced stops, with the former bleeding the latter:

(6) Alsatian bleeding:

a) Spirantization:	/tag-ə/	tayə
Devoicing:	/tag/	tak
b) Rule ordering:	/tag/	/tag- ə/
Devoicing	tak	--
Spirantization	--	tayə
	[tak]	[tayə]

For *tak*, devoicing bleeds spirantization as it eliminates the voicing feature that defines the target for spirantization. This is transparent in the sense that, as with feeding, there is no surface phonotactic violations for the final form; it is also evident in the output form *tak* why devoicing applied (the velar is word-final in the output) and spirantization did not (the velar is not voiced in the output).

Thus, transparency was defined in two ways. First, as a particular interaction between two processes, defined by rules, based on their order of application, and second in terms of the final outcome of the two rules.

Opaque relationships were similarly defined according to two different criteria in Kiparsky (1971, 1973) with the assumption that the two definitions were equivalent. One way was to articulate two types of opaque rule ordering that were the opposite of the rule orderings for transparent interactions. So, counter-feeding rule ordering is the reverse application of rules that would otherwise be in a feeding relationship such that the first rule does not apply and counter-bleeding rule ordering is the reverse application of rules that would otherwise be in a bleeding relationship such that the first rule does apply. The second definition focused on the ultimate outcome, or output, of these interactions and defined opaque relationships as follows:

(7) Kiparsky's(1973) definition of opacity:

A phonological rule:  $A \rightarrow B/C\_D$

is opaque to the extent the that there are surface forms in the language having either:

- a) A in any environment  $C\_D$
- b) B in any environment other than  $C\_D$

Type 1 (7a) opacity generally coincides with counter-feeding rule ordering and describes the situation where a rule that creates a target or environment for another rule applies afterwards, and therefore does not trigger, the other rule. In Mafa (Barrateau & Le Bleis, 1990; Ettliger, 2005) there is a process of palatal harmony where all vowels and stridents in a word agree with respect to the palatal feature (a) and a process of assimilation where high vowels adjacent to the palatal glide are palatalized (b):

(8) Mafa counter-bleeding:

a) Front harmony affix allomorphy:

ðək-a?a	‘He sows it’	ʃɪd-e?e	‘He thanks it’
pəz-a?a <sup>2</sup>	‘He cultivates it’	piʒ-e?e	‘Cultivate it!’

b) High vowel glide assimilation

gudzə	‘to tremble’	gudzij	‘tremble!’	
sə	‘to drink’	si-j	‘drink!’	*ʃi-j

c) Opaque interaction of harmony and palatal assimilation

si-j-a?a	‘drink it!’	*ʃij-e?e
bi-j-a?a	‘big (DEF)’	*bij-e?e

In the surface forms in (c), local palatalization of high vowels to [i] does not trigger

---

<sup>2</sup> Both schwa and barred-i have been used as transcriptions for the same high, back, unrounded vowel. The barred-i notation is more clear from the perspective of distinctive features in that it is one of the non-front high vowels in the IPA. The use of schwa is clearer from a visual perspective, more clearly distinct from *i* with which it alternates, and is also more in line with the Chadic tradition of analyzing vowel systems as reflecting an opposition between /a/~ə/, or /a/~ø/ with word-level palatal and labial harmonies (Wolff, 2004).

palatal harmony in the initial /s/ in [sijaʔa], (changing it to [ʃ]), nor does it result in the palatal [eʔe] allomorph of the object clitic. Therefore, local palatalization is said to counter-feed palatal harmony: local palatal assimilation occurs after the process of palatal harmony. This interaction is opaque in the sense of (7a) in that there are back vowels and [-palatal] stridents in the surface despite the existence of the triggering environment in the guise of the front [i].

Type 2 opacity (7b) generally coincides with counter-bleeding rule ordering and describes the situation where a rule eliminates the target or environment of another rule, but the latter rule applies anyway, suggesting that the former applied after the latter. Shimakonde (Liphola, 2001, Manus, 2003), mentioned above and taken up in much greater detail in chapter 3, serves as an illustrative example. Shimakonde exhibits what Hyman (1999) refers to as canonical Bantu vowel height harmony (VHH). The applicative suffix *-il-* surfaces with a mid-vowel when preceded by a root with a mid-vowel:

(9) Shimakonde VHH

a)	kú-píít-a	‘to pass’	kú-pít-ííl-a	‘to pass for’
	kú-púút-a	‘to get’	kú-pút-ííl-a	‘to get for’
	kú-páát-a	‘to wash’	kú-pát-ííl-a	‘to wash for’
b)	kú-péét-a	‘to sift’	kú-pét-éél-a	‘to sift for’
	kú-tóót-a	‘to sew’	kú-tót-éél-a	‘to sew for’

When the root vowel is high or low, the suffix surfaces as *-il-*, whereas a mid-vowel in

the root causes the suffix to surface as *-el-*. Rendering this process opaque is an optional process of vowel reduction whereby pre-penultimate mid vowels are reduced to *a*.

(10) Shimakonde mid-vowel reduction

- a) kú-pétáána ~ kú-pátáána ‘to sift each other’  
 kú-téléláána ~ kú-táláláána ‘to cook each other’  
 kú-tótáána ~ kú-tátáána ‘to sew each other’

When reduction applies to the VHH forms above, an opaque relationship obtains:

(11) Opaque interaction of VHH and vowel reduction in Shimakonde

- | <u>Unreduced</u> | ~ | <u>Reduced</u>  |               |
|------------------|---|-----------------|---------------|
| a) kú-pét-éél-a  |   | b) kú-pát-éél-a | ‘to sift for’ |
| kú-tót-éél-a     |   | kú-tát-éél-a    | ‘to sew for’  |

The reduction of underlying *e/o* to surface *a* eliminates the environment triggering vowel harmony resulting in the satisfaction of the definition in (8b): A mid vowel surfaces in an environment other than after a root mid vowel.

Despite the usefulness of a rule-based rubric for describing opaque interactions, there are three problems with this approach.

First, it is primarily descriptive and ultimately does not make predictions with respect to the type of opaque interactions we should or should not expect to find. Kiparsky (1973) originally hypothesized that opaque interactions are more marked and

that innovative dialects or languages should ultimately eliminate opacity. While he cited a number of examples, a larger body of evidence suggests that opaque relationships persist, that innovative dialects or languages can easily create opaque relationships (Idsardi, 2002), that some languages seem to prefer opaque relationships across the board (Hyman, 2002; Hyman & Van Bik, 2004), and that other considerations, such as recoverability and contrast preservation are what dictate the markedness of process interactions (Kaye, 1974; Lubowicz, 2003). Indeed, this study argues that harmony and tone interactions are generally opaque and that the feeding of vowel harmony, for example, is rare (§1.4).

Furthermore the same ordered interaction between rules can be both transparent and opaque in the same language depending on the underlying form. In Shimakonde, the rule ordering of harmony followed by reduction yields an opaque form in for the underlying form /ku-pet-il-a/, whereas for the underlying form /ku-pet-il-an-a/ harmony feeds reduction with respect to the applicative suffix:

(12) Feeding and counter-bleeding interactions for the same pair of rule in Shimakonde:

a) Counter-bleeding

	/ku-pet-il-a/		/ku-pet-il-a/
Harmony	ku-pet-el-a	Reduction	ku-pat-il-a
Reduction	ku-pat-el-a	Harmony	--
	[kúpátééla]		*[kúpátííla]

b) Feeding

	/ku-pet-il-an-a/		/ku-pet-il-an-a/
Harmony	ku-pet-el-an-a	Reduction	ku-pat-il-an-a
Reduction	ku-pat-al-an-a	Harmony	--
	[kúpátáláána]		*[kúpátíláána]

This presents a problem for being able to identify a rule ordering as marked or unmarked in and of itself without reference to a particular underlying form.

Thus, the majority of evidence suggests that a rule-based typology of opaque interactions must rely on extrinsic, i.e. language-specific, rule ordering (cf. Koutsoudas *et al.*, 1974 for an attempt to eliminate the extrinsic nature of rule ordering) providing little insight into what type of orderings we should expect to find or what type of ordering is more natural or learnable.

Finally, while most cases of opacity result from counter-feeding and counter-bleeding rule ordering, this is not always the case and so there is no equivalence between type 1 opacity and type 2 opacity and counter-feeding and counter-bleeding rule ordering, respectively (Bakovic, 2007). For example, in Turkish (Sprouse, 1997) there is a process of epenthesis that feeds a process of intervocalic velar deletion – epenthesis creates an environment for intervocalic velar deletion that did not exist in the underlying form - yet the result is an opaque form, *bebeim*, in the sense of (7b): An epenthetic *i* surfaces in an environment other than between word-final consonants.

(13) Turkish feeding opacity

a) Epenthesis:

baş ‘head’ baş-im ‘head-1sg-poss’

kedî ‘cat’ kedim ‘cat 1sg. poss.’

b) Velar deletion

bebek ‘baby’ bebe-i ‘baby-3 sg. poss.’

c) Feeding rule ordering yielding opaque surface form:

/bebek-m/

Epenthesis bebekim

Velar deletion bebeim

[bebeim]

### 1.2.2. From Rules to Constraints

In this section, I present some of the motivation for shifting from a rule-based framework to a framework based on constraints on surface forms. This serves as background to the subsequent sections that introduce the OT formalism and articulate why theories like OT are incapable of dealing with opacity. The inability to do so is in part the same as the reasons for shifting to surface constraints in the first place – the duplication problem. Finally, an examination of what OT can and cannot account for leads to the slightly different definition of opacity presented at the end of §1.2.

In addition to the problems associated with rule-based frameworks discussed in §1.2.1 – extrinsic ordering, and the lack of an isomorphism between rule orders and surface-truth of generalizations - a crucial questions facing phonologists shortly after the

introduction of Generative Phonology (SPE, Chomsky & Halle, 1968) was the problem of what Kisseberth (1970) referred to as conspiracies: the phenomena where a distinct set of rules in some language, or even across languages, conspire to yield the same result of eliminating a particular marked structure. McCarthy (2003) succinctly described this as Homogeneity of Target, Heterogeneity of Process. For example, there are two rules in Si-Luyana (Pater, 1999) that both eliminate nasal + voiceless obstruent sequences (25a, b). The same prohibition against this marked consonant cluster is also the driver of rules in a number of other Bantu languages including Yao (25c) and Mandar (25d), and this cluster is indeed marked phonetically (Solé, 2008).

(14) A diverse set of rules eliminating the same marked structure:

Si-Luyana

a)  $T \rightarrow \emptyset / N\_$                       /N-tabi/ → nabi

b)  $N \rightarrow \emptyset / \_ S$                       /N-supā/ → supā

Yao

c)  $T \rightarrow D / N\_$                       /ku-n-tum-a/ → kuundúma ‘to order me’

d)  $N \rightarrow \emptyset / \_ S$                       /ku-n-sóosa/ → kuusóosa      ‘to look for me’

Mandar

e)  $N \rightarrow T / \_ T$                       /maN-tunu/ → mattunu ‘to burn’

A subset of the conspiracy problem is referred to as the duplication problem, where a rule driving a morphophonological alternation duplicates a constraint on the structure of morphemes themselves (Kenstowicz & Kisseberth, 1977; see also Matthews, 1972 and

Sommerstein, 1974 on phonotactically motivated rules). For example, as discussed above, the vowels in Mafa verb and noun stems agree with respect to frontness (a). Front harmony also extends to suffixes (b) leading an SPE-style rule of the sort in (17).

(15) Mafa stems and affixed forms:

a) mbulom	‘pottery’
tuk <sup>w</sup> ats	‘stick (v.)’
mətsar	‘thief’
k <sup>w</sup> etʃepe	‘bacteria’
pirek	‘noon’
pytʃæk <sup>w</sup>	‘blink’
b) ðək-aʔa	‘He sows it’
pəz-aʔa	‘He cultivates it’
ʃid-eʔe	‘He thanks it’
piz-eʔe	‘Cultivate it!’

(16) Mafa fronting rule:

a) [-cons] → [+front]/[-cons, +front] C<sub>0</sub> \_\_

While the rule accounts for the morphological alternation, this generalization is

redundantly expressed in the lexicon (15a). Lexical items have either all [+front] or [-front] vowels, a generalization that can be captured by a morpheme structure constraint (MSC; Halle, 1959), which express constraints on the UR of any morpheme.

If morpheme structure constraints are eschewed in favor of only rules, phonotactic generalizations of a language that do not reflect alternations – either allophonic or morphophonological – would be missed. For example, in English *bd* is not a valid syllable onset. This is a productive generalization, as evidenced by the experimental results in Berent *et al.* (2008) where *bda* is heard as bi-syllabic *bə.da*, and should therefore be included in any description of the phonological knowledge of an English speaker. There are no URs with a *bd*- onset assuming lexicon optimization, however, nor can one arise by combining two morphemes, so a rule inserting an epenthetic schwa between *b* and *d* is unnecessary from the perspective of allophony or allomorphy.

So, rules alone cannot fully account for the range of phonotactic and morphophonological generalizations in a language, but a combination of rules and morpheme structure constraints would be redundant and therefore create ambiguity as to where the actual generalizations of a language are expressed. The use of both rules and constraints may ultimately prove necessary, but this dual-mechanism approach was perceived as a fault.

One final problem with rule-based approaches to phonology that is tangentially related to opacity is the problem of naturalness (chapter 9 in SPE; Kean, 1974; Cairns & Feinstein, 1982; Cairns, 1988; Archangeli & Pulleyblank, 1994). Whereas most phonological processes reflect the fact that certain sounds or sequences of sounds are natural, functionally motivated or grounded in phonetically-driven notions of markedness

as compared to others, rules are purely symbolic manipulations, absent any substantive basis.

Myriad proposals (Stanley, 1967; Postal, 1968; Paradis, 1988; Scobbie, 1993; see LaCharité & Paradis, 1993 for a useful, albeit slightly outdated review) have been advanced to ameliorate these problems (including Kisseberth's (1970) discussion of *derivational constraints*) through the use of constraints in lieu of rules to define a grammar. These efforts culminated with the current dominant theoretical paradigm, Optimality Theory (OT; Prince & Smolensky, 1993/2004). In the next section, I show that while OT offers a compelling solution to the duplication problem, the universal markedness problem and conspiracies, they exacerbate the problems associated with opaque relationships precisely because certain types of opacity reflect the relationship between input and output forms discussed above.

### **1.2.3. Optimality Theory**

OT is an analytical framework in which the output, or surface representation, of a phonological form is selected from multiple possible candidates that are all simultaneously evaluated and compared to the underlying representation (the *input*) by a ranked set of universal and violable constraints (Prince & Smolensky 1993; McCarthy & Prince 1993 are the best original sources for learning about OT; Kager 1999 is an excellent reference which summarizes the standard theory; McCarthy, 2002 is the most comprehensive and recent survey of the theory).

The adoption of a purely constraint-based theory of phonology has two implications for opacity. First, to solve the duplication problem, OT merges allomorphy

with phonotactics. Second, without any sort of mapping, or rule-like relationship between input and output, step-wise derivations are replaced by evaluations that make use of language-wide phonotactic generalizations alone to repair marked structure. These two properties have negative in terms of selecting opaque output forms, explored in the §1.2.4.

#### *1.2.3.1. The Unification of Phonotactics and Morphophonology*

Motivating alternations through the use of universal surface constraints addresses the issue of conspiracies by representing the formal specification of the homogenous target, mentioned in McCarthy (2002), that different rules conspire to create or avoid. To motivate the four rules in (25) we can posit a constraint, \*NC<sub>0</sub> banning voiceless stops following nasals, which is a type of markedness constraint. This constraint is never violated in these languages since no combination of morphemes can yield a nasal+voiceless stop sequence. If a grammar consisted only of markedness constraints, however, then the output of every form would be the least marked form, *baba*, *tata* or *?a?a*, depending on ones definition of markedness. Furthermore, some languages do allow nasal+voiceless stop sequences, therefore any formalism making use of a universal constraint set must have some mechanism for overriding markedness constraints.

Thus, OT also makes use of faithfulness constraints, constraints that require elements of the output to maintain, or remain faithful to, elements on the input. The choice of whether stop-deletion (Si-Luyana), nasal deletion (Si-Luyana), voicing (Ciyao), or denasalization (Mandar) is the repair for nasal + voiceless stop clusters is determined by the relative ranking of these faithfulness constraints in each language. In Ciyao, it is more important to maintain the specification of sonority from the input and to not delete

segments than it is to maintain the voicelessness of the stop and so *nd* is the output of an input /nt/; conversely, in Mandarin maintaining voicelessness and not deleting segments is more important than maintaining the non-sonority of stops, and so *nn* is the output, with the stop becoming a nasal.

So, while the substantive aspect of the phonological system is implemented by the ranking of universal markedness constraints, input-output relationships, or correspondences, are realized by faithfulness constraints. In the earliest manifestation of OT, the relevant constraint was PARSE. PARSE requires the parsing of input features in the output which is essentially equivalent to rule stating  $A \rightarrow A$  or  $[\alpha F] \rightarrow [\alpha F]$ . Unparsed features are still technically in the output string, but are not parsed into the output form. Because PARSE is a ranked constraint like all of the others, it can be violated:

(17) Constraint ranking for post-nasal voicing in Ciyao

/-n-tum- /	PARSE[SEG]	PARSE[-SON]	*NC <sub>o</sub>	PARSE[-VOICE]
ntum			*	
→nd<-voice>um				*
num	*!			
nn<-son>um		*!		

In addition to the ranking of \*NC<sub>o</sub> » PARSE[-VOICE], the above tableau shows PARSE and PARSE[-SON] as undominated which dictates that the mapping of both the segmental slot and the feature [-SON] from input to output must hold, respectively.

1.2.3.2. Correspondence Theory

McCarthy and Prince (1995) introduce a near-universally adopted framework (cf.

Oostendorp, 2006 for a recent argument for the PARSE/FILL framework) which replaces PARSE with a set of faithfulness constraints that make the mapping from input to output more explicit. The family of correspondence constraints includes IDENTITY and MAX, which require a correspondence of features and segments, respectively, between two strings, and DEP, which prevents the insertion of segments that are not part of the input. This approach eliminates the necessity of covert structure in the output in addition to unifying the analysis of reduplication and basic input-output derivations, as is discussed in chapter two. This theory also predicts that opacity should be much more common among segmental interactions than it actually is since covert structure influences the output much more rarely than expected (McCarthy, 2007).

In Correspondence Theory, a constraint such as IDENT[VOICE]-IO requires that an input voicing feature specification map, or correspond, to an output feature specification, effectively replacing PARSE[VOICE] in the tableau above, while MAX-C, which requires that a consonant in the input be realized in the output replaces PARSE. Thus the tableaux for the examples in (14) are as follows:

(18) Constraint rankings for the different resolutions of nasal+voiceless stop clusters

Ciyao:/nt /	MAX-C	ID[-SON]	*NC̥	ID[-VOICE]
nt			*	
→nd				*
n	*!			
nn		*!		

Mandar:/nt /	MAX-C	ID[-VOICE]	*NC̣	ID[-SON]
nt			*	
nd		*!		
n	*!			
→nn				*
Si-Luyana:/nt/	Id[-Son]	Id[-Voice]	*NC̣	Max-C
nt			*	
nd		*!		
→n				*
nn	*!			

This use of constraints on output forms, paired with the concept of Richness of the Base (P&S, 1993/2004) serves to address the second issue with rules, the duplication problem. Richness of the Base (ROB) specifies that regardless of the input to the phonological grammar, i.e. the constraint ranking, the output should be well formed with respect to the phonological grammar. Thus, in Mafa, *bebi*, *bebə babi*, and *babə* can all be underlying forms in the language. A constraint against vowels having non-identical [front] specification (or: for vowels having identical [front] specifications) changes all of these forms to either *bebi* or *bəba* while also selecting the correct allomorphs above. Because of ROB, we a priori know that none of the generalizations in the grammar are captured in the lexicon since any input form yields a grammatical output. So, all the generalizations are necessarily expressed in the constraint ranking and not in the lexicon.

Eliminating rules in favor of only constraints therefore has the effect of saying that morphological alternations are driven by the surface phonotactics of the language – that phonotactics, allophony and morphophonological alternations are all the same thing.

#### 1.2.4. Where Constraints Fail

Defining a grammar as consisting exclusively of universal constraints on surface forms

has been an exceedingly insightful formal solution for capturing the long-observed generalization that morphophonological alternations often duplicate the phonotactics constraints of a language and that the same phonotactic constraints are found across languages. The problem is these observations are not always true. There are constraints on lexical items that do not drive morphophonological alternations and there are morphophonological alternations that are not driven by the same phonotactic constraints that govern lexical or surface forms. Cases of the former include examples of non-derived environment blocking (NDEB; Kiparsky, 1993) that do not motivate alternations, and cases of the latter include crazy rules and opacity (discussed further in chapter two).

A surface-based phonology also shifts the definition of opacity from the feeding/bleeding versus counter-feeding/counter-bleeding rule ordering typology to the output-based definition of under-application (or type 1 opacity; 7a) and over-application (or type 2 opacity; 7b) (McCarthy, 1999). In this section, I show how standard OT is unable to account for both under-application and over-application opacity.

#### *1.2.4.1. Over-application in OT*

Recall, from above, the following example of over-application in Shimakonde:

(19) Over-application in Shimakonde:

- a) Transparent forms: /ku-pat-il-a/ → kúpatíila
- b) Over-application (harmony & reduction): /ku-pet-il-a/ → kúpatééla

Over-application is problematic for any surface based approach because the mid vowel

trigger of VHH is no longer present in the surface representation. So, while roots with an underlying and surface vowel of /a/~[a] transparently receive the *-il-* form of the applicative suffix (b), the opaque over-application form with underlying /e/ and surface [a] takes the *el* form of the suffix. Thus, contra Natural Generative Phonology, for example, which posits that the only phonological generalizations that are acquirable are those that are surface true, it is not the surface form of the verb that determines the realization of the suffixes, which are identical in (19), rather it is the underlying form.

The OT formalism appropriately captures the difficulty that surface based approaches have with over-application through a constraint-ranking problem for the opaque surface forms. As with all cases of over-application, the problem is one of harmonic bounding of the actual form by an ungrammatical transparent form. Harmonic bounding refers to the condition where one form incurs a proper subset of violations of another form, and is therefore always more optimal, regardless of the constraint ranking.

The actual constraints are precisely formulated in chapter three, but for the time being, to demonstrate this problem, Shimakonde harmony can be modeled through the interaction of a constraint enforcing harmony and a faithfulness constraint maintaining the underlying heights of vowels. The selection of [pétél] from the underlying form /-pet-il-/ would be as follows:

(20) Tableau for OT derivation of [pet-el] from /pet-il/

/-pet-il-/	HARMONY	FAITH
(a) →peteel		*
(b) petiil	*!	

The tableau shows that, for Shimakonde, the constraint that high-vowels harmonize to

mid-vowels is ranked higher than the constraint that vowels retain the same height in the output as they have in the input, or in shorthand HARMONY » FAITH.

Reduction reflects the domination of a faithfulness constraint by a markedness constraint. The surface form [kú-tátáána] can be obtained from the underlying form /ku-tetana/ by the ranking REDUCE » FAITH.

(21) Tableau for reduction

/ku-tet-ana/	FAITH <sub>TONIC</sub>	REDUCE	FAITH
(a) kutetaana		*!	
(b) kutataana			*

A problem is encountered with the rankings obtained above when considering the opaque forms above. The tableau for the surface form [kú-pát-éél-a] combines the above rankings into a single tableau:

(22) Tableau for opacity

/ku-pet-il-a/	ID(HEIGHT) <sub>TONIC</sub>	HARMONY	REDUCE	ID(HEIGHT)
(a)←kúpátééla				*!*
(b) kupátáála	*!			*
(c) kupétééla			*!	
(d)⊗kúpátííla				*
(e) kúpétííla		*(!)	*(!)	

This tableau selects the incorrect surface form, *kúpátííla* (d) for the UR /kú-pét-íl-a/; the actual output *kúpátééla* (a) is less optimal than (d) because it violates more faithfulness constraints. Whereas in (d), only the vowel height of UR /e/ changes, in (a), both the root vowel and the vowel of the applicative suffix are different than the corresponding underlying forms.

The constraint ranking for VHH requires HARMONY » FAITH and REDUCE » FAITH, but the actual ranking is immaterial for this opacity because the SR *kúpátééla* incurs more faithfulness violations than the transparent, but ungrammatical, form *kúpátíila* without improving the overall harmony<sup>3</sup> of the SR in any way. No conceivable ranking of constraints will result in *kúpátééla* being a better candidate than *kúpátíila*. This constraint violation pattern does highlight the basic problem: In the surface form, with the VHH trigger reduced to *a*, there is no reason for the suffix to incur a faithfulness violation and surface with a mid-vowel.

This example also highlights the importance of the underlying representation – and not surface phonotactics alone – in assessing what constitutes a valid or invalid output form when juxtaposed with the transparent /kú-pat-il-a/~[kú-pat-íila], which has the same output as the most optimal output in the tableau in (22). Thus, while [kú-pat-íila] is a valid form in Shimakonde, and does not violate any surface phonotactic constraints, it is not the correct output for the input in question.

#### 1.2.4.2. Under-application in OT

The other type of opaque is under-application and results in a ranking paradox only when juxtaposing opaque and transparent forms. Recall from above that Mafa has palatal harmony that is reflected in both verb stems wherein all vowels must agree with respect palatality and in the morphophonology:

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<sup>3</sup> Harmony in the general OT sense, not in the VHH sense.

(23) Palatal harmony

Lexical

- a) pambaz      ‘blood’      pembe<sub>3</sub>      ‘hew wood’

Morphological

- b) ðək-aʔa      ‘he sows it’      ʃid-eʔe      ‘he thanks it’

There is also a process of local assimilation wherein high vowels adjacent to a palatal glide are palatalized; this, too is reflected in both the lexicon and in morphophonological alternations:

(24) Palatal assimilation in Mafa:

- a) Lexical:

gəlɨjpa      ‘rich’

syj<sub>6</sub>      ‘sorrel (Fr.: oseille)’

- b) Morphological:

gudzə      ‘to tremble’      gudzi-**j**      ‘Tremble!’

sə      ‘to drink’      si-**j**      ‘Drink!’

The surface form *sij-aʔa* reflects under-application opacity in that the front vowel that results from glide assimilation does not trigger palatal harmony:

(25) Opaque interaction between assimilation and harmony in Mafa:

a) sij-aʔa                      ‘drink it!’

These two alternations can be accounted for by ranking two constraints – simplified here as \*əj and HARMONY – above a faithfulness constraint for maintaining the underlying the front feature:

(26) \*əj, HARMONY » ID(FRONT)

Combining the two rankings into a single tableau yields the selection of the transparent, but invalid form *fij-eʔe* over the correct, opaque form *sij-aʔa*:

(27) Tableau for opaque Mafa form

/sə-j-aʔa/	*əj	HARMONY	ID(FRONT)
(a) səjaʔa	*		
(b)←sijaʔa		*	*
(c)⊗sijeʔe			***

(28) Incorrect tableau for transparent Mafa form with opaque constraint ranking

/ʃid-aʔa/	*əj	ID(FRONT)	Harmony
(a) ⊗ʃid-eʔe			*
(b)←ʃid-aʔa		*i	

So, in contrast with the previous instance of opacity where no constraint ranking possible could generate the correct output, it is only by comparison with existing transparent forms do the forms become opaque since the reverse ranking (of HARMONY, ID(FRONT))

would produce the correct opaque form, but the incorrect transparent form (28).

#### *1.2.4.3. Tone shifts as over-application*

Finally, tone shifts are also opaque and therefore problematic for OT as pointed out by Kisseberth (2007). In Jita, the underlying high tone of verb stems shifts one TBU to the right (29b,c) so long as it does not result in a high tone on the final vowel in which case it stays on its TBU source (29a):

(29) Jita, repeated

- a) o-ku-β<sub>ón</sub>-a            ‘to get/see’
- b) o-ku-β<sub>ón</sub>-ér-a        ‘to get for’
- c) o-ku-β<sub>ón</sub>-ér-an-a    ‘to get for each other’

There have multiple constraints suggested to motivate the spreading of a tone to an adjacent TBU including LOCAL (Myers, 1997), EXTEND (Bickmore, 1998) and \*MONO (Cassimjee & Kisseberth, 1998).

(30) One-TBU high tone spreading in Kikewere:

- a) ku-bóh-a            ‘to tie’
- b) ku-bóh-él-a        ‘to tie for’
- c) ku-bóh-él-an-a    ‘to tie for each other’

These can successfully account for one-TBU tone spreading as found in languages like

Kikewere (Odden, 1998) with the constraint SPREAD used as a cover term for these constraints in the tableaux below.

In these tableaux, this constraint stands in opposition to a faithfulness constraint, such as \*DEP(A), banning added association lines for any tone (Myers, 2000; same as NOSPREAD, Poletto, 1998; \*ASSOCIATE, Yip, 2008; \*SPREAD, Ito, Mester & Padgett, 1993; and is a type of the basic \*STRUC constraint).

(31) Tableau for Kikewere

/ku-bóh-él-an-a/	SPREAD	*DEP(A)
(a) ku-bóh-él-an-a	*!	
(b) →ku-bóh-él-an-a		*
(c) ku-bóh-él-án-a		**!

The problem arises in the evaluation of these SPREAD constraints when the original tone is de-linked from the original TBU in a tone shift. With the original high tone de-linked, there is no source tone to motivate the realization of a high on the adjacent TBU. Any evaluation of a SPREAD-like constraint based on surface forms would either require surface tone-doubling (as in Kikewere) or faithfulness constraints would require that the input high remain on its surface segment:

(32) Incorrect tableau for Jita tone shift

/ku-βón-er-an-a/	MAX(H)	*H	SPREAD	ID(H)
(a) ☹ku-βon-ér-an-a		*	*	*!
(b) ku-βon-er-an-a	*!			*
(c) ku-βón-ér-an-a		**!		
(d) ←ku-βón-er-an-a		*	*	
(e) ku-βon-ér-án-a		**!		*

The phonetic grounding for tone shifts comes from the fact that a rise in tone occurs relatively slowly, and so a high tone following a low may not reach a peak within the span of the source TBU (Silverman, 1997). This behavior may be represented by a constraint such as \*H/NONHEAD (Cassimjee & Kisseberth, 1998) where a head is defined as the second in a two-TBU unit, \*ALIGN(H,L,So,L) (the left edge of a H must not align with the left edge of its lexical source Bickmore, 1996) or even \*H which incurs a violation for each surface H (regardless of its autosegmental association.).

Regardless of the particulars of the actual constraint, it must ultimately be resolved with respect to the input form. This is explicitly acknowledged by Hyman (2005) with the constraint LAG or Myers' (1997) LOCAL:

(33) Input-based formulation of Tone shift

- a) LAG( $\alpha$ T): An input tone should reach its target on the following output TBU.
- b) LOCAL: An output TBU *a* bearing tone *t* must be adjacent to TBU *b*, where [input] *b*' bears *t*'.

It may not be completely obvious as to what sort of opaque interaction tone shifts should be classified as. In terms of rule ordering, if we assume tone shifting as a process of spreading, followed by de-linking, this would be classified as counter-bleeding, since if de-linking had applied first, it would bleed spreading. This suggests that tone shifting is a case of over-application (see §2.1). Further evidence comes from thinking of this in a manner similar to other featural processes, such vowel harmony, or nasal harmony. If a nasalized vowel triggered nasalization in an adjacent vowel, then was denasalized, this

would represent a clear case of over-application. Thus, in the case of tone shifting, we can think of it as a high tone spreading to an adjacent TBU, then deleting from the initial TBU, yielding over-application.

Returning to the definition of over-application in (7) reveals the answer to be more complex, however, since tone-shifting does not represent a case of two independently motivated processes interacting with each other, with one eliminating the environment for the application of the first. That is, there is not a regular process of tone doubling in Jita that is rendered opaque by some other process that deletes the first tone. Instead, tone shifting in and of itself is an opaque process. In the next section (§1.2.5), I explore how this yields a slightly different interpretation of what it even means to be opaque.

#### *1.2.4.4. Interim Summary*

These cases, and myriad others, beg the question of whether OT's problem with opacity says something significant about phonology in general or whether this simply represents a problem with the implementation of the theory itself. The answer to this question is partly answered by the fact that the identification of opacity as an interesting phonological phenomenon predates OT. As stated in Kiparsky (1971):

The general claim is that opacity adds to linguistic complexity. This amounts to saying that one thing which makes it relatively hard to learn a rule is a relatively abstract indirect relationship between the form of the rule and the surface forms of the language. [...] Opacity is intended [...] as a measure of one of the properties of a rule which determine how hard it is to learn: the 'distance' between what the rule says and the phonetic forms in the languages. [emphasis his].

OT's problem in accounting for opacity is not simply a consequence of the

implementation of the theory, but rather is representative of a problem that any surface-based approach to phonology would have with relationships of this sort. Any surface-based theory is unable to account for cases where the input determines the output in ways beyond simple input-output correspondence – i.e. when the determination of where high tone is expressed via a relationship to where the input tone is located, or when an allomorph reflects harmonic agreement with the input form of the root, and not the output form.

That this problem exists in OT does serve to highlight the problem these data present for the language learner. In an example like (25a) where harmony is not true of surface forms, surface based approaches to phonology, such as NGP or un-augmented OT would be required to posit that the harmony process is not a productive generalization of the language. However, the example in (24c) and the productivity of the harmony process suggest otherwise. Similarly, a learner that is extracting phonotactic generalizations from surface forms alone (Boersma, 1998; Pater, 1998; Tesar, 2000; Hayes & Albright, 2002; cf. Bermudez-Otero, 2003) would also miss crucial elements of a language's phonology. Thus, the phonological system and the phonological learner must be able to employ some process of abstraction, and not simply derive input representations from heard output forms, as per lexicon optimization (P&S, 2004; Inkelas, 1995). This requirement is further explored in chapter four.

### **1.2.5. Redefining Opacity**

Defining opacity as consisting of either cases of under-application or over-application is problematic in light of the tone shifting and opaque harmony examples above when

juxtaposed with cases of positional licensing of vowel features (PL; Beckman, 1997; Walker, 2002, 2005) and tone (de Lacy, 1999). PL is similar to tone shifting in that it allows for the realization of a feature on a different segment than is originally specified on the input. The difference is that instead of being defined as, say, a shift of one TBU to the right of the input tone, PL is defined as a shift to a position, generally prominent. This allows standard OT to account for the tone shifting in Zulu, repeated from above:

(34) Zulu tone shift:

- a) u-kú-hleeka            ‘to laugh’
- b) u-ku-hlék-iis-a        ‘to make laugh
- c) u-ku-hlek-ís-aan-a    ‘to make each other laugh’

High tone is retained in the output (MAX-H), but not on the original input syllable since that violates a constraint against high tones on non-antepenultimate) syllables (\*NONHEAD/H; DeLacy, 1999, 2008). So, the high tone is shifted to the antepenultimate syllable in violation of the low-ranked constraint requiring that features do no shift (LINEARITY or ANCHOR-T)<sup>4</sup>.

(35) Constraint rankings for the rules in (20)

/ú-ku-hleka /	MAX-[H]	*NONHEAD/H	LINEARITY
(a) ú-ku-hleka		*	
(b) →u-kú-hleka			*
(a) u-ku-hleka	*		

<sup>4</sup> Constraints like LINEARITY or ANCHOR-T are input-output constraints in that they compare the surface realization of tone with its original input source, assigning violations when the tone shifts.

It should be noted that the formalization of this type of phenomenon in Yip (2008) is not appropriate for these data. Yip suggests a HEAD=H constraints, which outranks the constraints ASSOCIATE and DISASSOCIATE which ban the association of a tone with a different TBU and the disassociation of a tone from its original TBU, respectively. While this works for words with one or more TBUs separating the input and target syllables, including the example she cites, it does not work for Zulu when the input H tone is adjacent to the stressed, or prominent syllable. Therefore, the constraint \*NONHEAD/H is more appropriate for this particular instance.

(36) From Yip (2008): Correct association of H tone with prominent syllable when prominent syllable is not adjacent to input TBU:

/ú-ku-hlek-is-a /	HEAD=H	*ASSOC	*DISASSOC
(a) ú-ku-hlek-is-a	*!		
(b) ú-kú-hlék-is-a		**!	
(a)→u-ku-hlék-is-a		*	*

(37) Incorrect evaluation using Yip's (2008) constraints for one-TBU shift to prominent position:

/ú-ku-hleka /	HEAD=H	*ASSOC	*DISASSOC
(a) ú-ku-hleka	*!		
(b)←u-kú-hleka		*	*
(a)⊗ú-kú-hleka		*	

Notice that a comparison of the transparent relationship of Zulu and the opaque relationship in Jita does not reflect a difference in the type of rule ordering relationship; in both instances the order of the autosegmental processes is spreading followed by de-linking which counter-bleeds it. There is also no particular difference between Zulu and

Jita with respect to McCarthy's (1999) definition of over-application in the sense that in both the transparent Zulu tone shift and the opaque Jita tone shift, the conditioning environment for the realization of the surface high tone – the underlying high tone – does not appear in the surface. Rather, what differentiates the opaque Jita data from the transparent Zulu data is whether the ultimate location of the surface high tone can be expressed exclusively with respect to the output. In the transparent interaction the realization of the high tone can be expressed via reference to the output, while in the opaque interaction the determination of where high tone lands must necessarily refer to the input. This suggests a refinement of the definition of opacity is necessary in terms of a contrast between output-defined optimization (transparent) versus input-defined (opaque).

The Zulu data also partially reflects the principle of the emergence of the unmarked (McCarthy & Prince, 1994; TETU), an observation within OT that the repair of some marked structure is dictated by the overall phonology of the language and not by a specific rule associated with the marked structure. While prototypical examples generally refer to replacing some marked segment with the least marked segment in the language by virtue of it violating the lowest ranked markedness constraints, here, the marked word-initial high tone is repaired by shifting the high tone to a prominent position, yielding the least marked output. Thus, in standard OT tone can either surface on its underlying TBU, or shift to some TBU as dictated by the phonotactics of the language.

A similar phenomenon is found in certain cases of harmony. In Lena Spanish (Hualde, 1999; Walker, 2005), final high vowels marking the masculine singular trigger raising of non high stressed vowels:

(38) Lena Spanish metaphony

a) Metaphony of adjacent stressed vowel:

kordir      ‘lamb (m. sg.)      kordéros      (m. pl.)

gétu      ‘cat (m. sg.)      gátos      (m. pl.)

b) Metaphony of non-adjacent stressed vowel

burwíbanu      ‘wild strawberry(m.sg.)      burwébanos      (m. pl.)

While this is different from the tone examples in that the trigger remains, the basic idea that the target of harmony is defined with respect to the output form (the stressed syllable) is the same.

A harmony example where the trigger does not surface in the output is found in Esimbi (Hyman, 1988; Walker, 2001), which has an infinitive prefix, /u-/, that is underlyingly high and exhibits a three-way variation in vowel height in SRs. This variation is determined by the root to which it is affixed (39).

(39) Esimibi prefix alternation:

a) High: u-ri    /u-ri/    ‘eat’

u-zu    /u-zu/    ‘kill’

b) Mid: o-si    /u-se/    ‘laugh’

o-tu    /u-to/    ‘insult’

c) Low: ɔ-ri    /u-rɛ/    ‘daub’

ɔ-hu    /u-rɔ/    ‘knead’

ɔ-bi    /u-ba/    ‘come’

This same behavior is exhibited for the nominal class 9 singular prefix (e.g. /i-sò/ è-su ‘hoe’) and there is also a height down-step for the nominal class 6 plural /a/ prefix (e.g. /a-to/ ɔ-tu ‘ear’), which I do not discuss here. As is evident in the surface forms, the underlying features of the verb stem are transferred to the prefix, then neutralized to high in final position. In the definitions of both Kiparsky (1973) and McCarthy (1999), this would be opaque since the conditioning environment for height harmony – the vowel height of the stem – is eliminated (b, c) due to positional neutralization. Walker shows that there is no problem in accounting for this type of interaction in OT, however, through the use of a positional licensing constraint licensing the feature [-high] in word-initial syllables: LIC([-high], <sub>wd</sub>[σ]), combined with a constraint requiring that the high feature from the root not be deleted (MAX<sub>RT</sub>(HIGH)):

(40) Successful evaluation of opaque harmony in Esimbi using positional licensing:

/i-so /	MAX <sub>RT</sub> (high)	LIC(-high)	ID(high)
(a) i-so		*!	
(b) → e-su			**
(c) i-su	*!		

Contrasting this example with one like Shimakonde, where there is no way of expressing where the mid vowel should surface with respect to the surface form alone yields the same similar problem as when Jita is juxtaposed Zulu in terms of the current definition of opacity.

These examples show that the difference between transparent and opaque is definable in terms of being able to specify the results of a phonological process in terms of the output or in terms of the input in addition to the traditional over- and under-

application rubric. In Zulu and Esimbi, the realization of high tone or high vowels can be articulated with reference to the output in terms of referencing prominent positions. In contrast, high tone and mid vowel harmony in Jita and Shimakonde, respectively, can only be defined with respect to the input forms.

### **1.3. OPACITY AS INPUT-OUTPUT MAPPING**

In this section, I discuss a second generalization concerning opacity involving harmony and tonal interactions. This generalization comes, in part, through exploring what was captured in rule-based approaches to opaque harmony using alpha-rules or autosegmental notation as well as through the alternate definition of opacity as input-driven phonological processes discussed above. The generalization is that opacity, in these instances, reflect a mapping from input to non-equivalent output segments.

#### **1.3.1. Alpha rules**

The main mechanism with which to account for phonological alternations and allophonic distributions in early generative grammar was by a rule (Chomsky & Halle, 1968; cf. Wells, 1949 for early discussion of alternations motivated by markedness constraints). A rule expresses an input-output relationship whereby some element of the input changes to something else when the input matches the structural description of the rule. A problem with SPE rules, first noted in chapter 9 of SPE, is that they allow for substantive arbitrariness and do not capture cross-linguistic markedness generalizations in a clear, intuitive way. Consider, for example, vowel umlaut in Icelandic (Anderson, 1969; Kiparsky, 1984) where a round vowel triggers rounding in a preceding vowel:

(41) Icelandic umlaut:

a) Umlaut of vowel triggered by subsequent *u*

kalla	‘I call’	kœllum	‘we call’
salat	‘lettuce’	salœtum	‘lettuce (dat. pl.)’
kaka	‘cake’	kœkur	‘cakes’

b) Icelandic umlaut as a rule:

$[-\text{high}, +\text{back}] \rightarrow [+ \text{round}, -\text{back}] / \_ \_ C_0 [+ \text{high}, + \text{round}]$

This formulation of the rule gives no indication as to whether it is an arbitrary Icelandic-specific rule or a typologically common process grounded in cross-linguistic universals. The phonology of a language described with this sort of mapping relationship can have the input-output mapping  $a \rightarrow \text{æ}$  in the environment  $\_ \_ Cu$  just as easily as it can have one of  $\text{æ} \rightarrow a / \_ \_ Cu$ .

Some degree of naturalness is introduced into rules and mappings through the use of alpha-notation whereby the particular feature specification of some portion of the input structural description can be referenced in the output. This allows the representation of harmony, for example, to be represented by the following alpha-rule in as compared to arbitrary feature specifications:

(42) Icelandic umlaut using alpha-notation

a)  $[-\text{high}, +\text{back}] \rightarrow [\alpha \text{round}] / \_ \_ C_0 [+ \text{high}, \alpha \text{round}]$

Input	Output	Input SD
-------	--------	----------

This also has the effect of introducing a correspondence between non-equivalent segments: The realization of a feature on the output is dependent on the featural specification of a segment in the input structural description. Here, the [round] specification of the output references the [round] specification on the input structural description as opposed to the equivalent input segment.

This becomes crucial in Icelandic because of this process's opaque interaction with several other processes. In particular, unstressed vowels are deleted before coronal-vowel sequences where the trigger of umlaut may be deleted:

(43) Icelandic opacity

a) /bagg-ul-i/    bœggli

The deletion rule eliminates the original source of the round feature, which is retained on the vowel targeted by umlaut. This represents a case of over-application opacity in that the suffix undergoes umlaut in the surface form despite the absence of trigger vowel.

### **1.3.2 Autosegments**

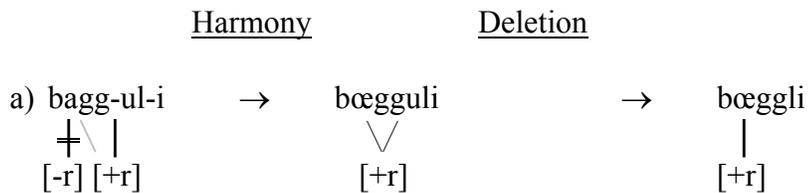
The added naturalness of the type of relationship expressed by alpha rules, where a feature specification is shared between two segments can be expanded further through the use of autosegments.

Autosegmental Phonology (AP; Goldsmith, 1976) establishes more complex relationships between features and segments than is established in SPE. A single feature could be associated with multiple segments, and a single segment could be associated

with multiple features through the use of geometrical phonological representations, which could more elegantly, and naturally, account for harmony and tonal interactions.

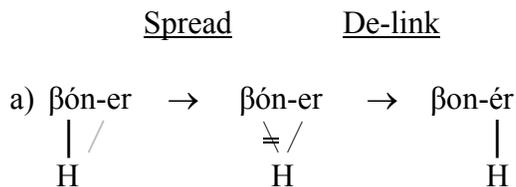
The use of AP remedies the phonetic arbitrariness problem for harmony and umlaut by virtue of constraining possible featural transformations to either the spreading or de-linking of autosegmental features. For example, the spreading of [+round] in Icelandic is a formally simple – and therefore natural – process within AP. AP would rule out an unnatural change such as  $\alpha \rightarrow a / \_ Cu$  since it would not reflect feature sharing or spreading and would instead reflect an arbitrary insertion and deletion of features.

(44) Autosegmental representation of Shimakonde harmony and reduction



This is similar to the Jita example where tone from a verb root shifts one syllable to the right, which would have the following autosegmental representation:

(45) Autosegmental representation of Jita tone shift



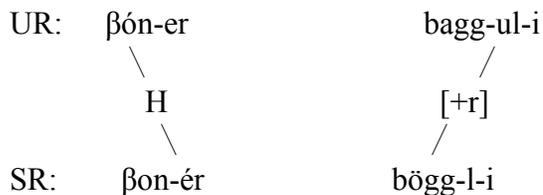
The use of AP is orthogonal to the choice of formal processes over representations. Here,

the accounts of umlaut and tone shift are in fact a sequence of two autosegmental rules: spreading followed by deletion or de-linking.

### 1.3.3. Input-Output Mappings

These accounts establish a crucial relationship between input and output forms: The output root vowel takes on the [+round] feature from the *u* in the suffix in Icelandic and the affix TBU takes on the high tone from the verb stem in Jita. Thus, even if the original feature is deleted, the original autosegment that initially started on the trigger remains on the target, represented by the persistence of the same autosegment across the initial and final states of the derivation. So again, as with accounting for opacity using alpha notation, the basic generalization is that the featural specification of the input verb stem determines the featural specification of the affix. This can be represented graphically by skewing and stacking the output forms in the autosegmental account of tone shift and umlaut yielding the same type of correspondence relationship shown in (3):

(46) Merging input and output representation:



Under-application reflects essentially the same generalization. In the Mafa example above, harmony can be represented by the autosegmental correspondence of the [front]

feature in underlying representations with the output suffix.

(47) Mafa harmony:

	a) Opaque	b) Transparent
UR:	ɓɔj-aʔa	ʃid-aʔa
	\	\
	[-front]	[+front]
	\	\
SR:	ɓij-aʔa	ʃid-eʔe

In (a), because the vowel in the verb stem is not underlyingly front, the suffix does not surface as front, regardless of the realization of the surface realization of the stem vowel.

However, when the verb stem is underlyingly [+front], in (b), the suffix is also [+front].

The examples here serve to illustrate the observation that opaque interactions involving tone and harmony generally reflect a mapping or correspondence between some feature in the input onto some non-original segment on the output. In cases of over-application (Icelandic, Jita) the original input feature no longer surfaces on the original segment, while in cases of under-application (Mafa), the feature is not in the input to begin with, despite the surface realization of a feature normally triggering an alternation.

#### 1.4. TYPOLOGY OF HARMONY INTERACTIONS

Kiparsky's early work on opacity wavered with respect to which types of rule interactions were more natural. In Kiparsky (1968), he claimed that the principle of maximal rule application (see also Anderson, 1971) is what dictated whether a rule interaction was natural, with feeding and counter-bleeding natural, and bleeding and

counter-feeding marked. In Kiparsky (1971) this was revised with the focus placed on the language learner and on what types of interactions were easier or harder to learn. This leads to feeding and bleeding being natural, and counter-feeding and counter-bleeding being marked based on the idea that opaque interactions are more difficult to learn because it involves the additional step of undoing a rule to get at the underlying generalization.

Parker (2008) surveys the rule ordering interactions of seven languages suggests and found that this latter rubric is indeed correct. Feeding came out as the most common rule interaction across the seven languages, followed by bleeding, with counter-feeding and counter-bleeding relatively uncommon.

This raises the question of whether the opaque interactions described above are rare phenomena. In this section, I show that opacity is, in fact, relatively common and that certain types of transparent process interactions do not occur when harmony is involved.

#### **1.4.1. Cross-linguistic typology**

Harmony can conceivably interact with a number of other phonological processes, including feature changes, epenthesis, deletion and changes in prosody, through these processes targeting the focus or environment of harmony. Focus refers to the segment that changes as a result of harmony and environment refers to the structural description that leads to application of harmony. So, if an instance of vowel harmony causes high vowels to agree with respect to roundness, then the focus is a target high vowel, while the environment is the trigger high round vowel. Using a rule-ordering rubric, feeding on

focus would be a process that yields a high vowel (e.g. epenthesis) that can then be targeted by a high round vowel for harmony. Feeding on environment would be a process that yields a high round vowel (e.g. assimilation of *i* to *u* from an adjacent *w*) that then triggers rounding harmony in other high vowels.

For harmony, the environment can be further decomposed into two components: the trigger vowel and whatever is specified as potentially intervening material. This distinction is critical for understanding the examples below.

The following tables show a survey of thirteen languages and 20 process interactions that show how different phonological processes interact with harmony:

(48) Feeding

Type	Process	Example rules	Form
Focus	Pal. Arabic (Shahin, 1997): lengthening	V→V:/ __]σ V[-long]→[-ATR]/ [-ATR] C__	/t-ʃI:bIʃ/→ʔItʃɪbi:ʃ (cf. nʃi:b)
	Yokuts epenthesis	ø→i/C__CC V[ahi]→[+rd]/[ahi, +r] C__	/ʔugn-hin/→ʔugunhun
	Turkish epenthesis	ø→i/CC# V[+hi]→[ɑr, ɑbk]/ [ɑr, ɑbk] C__	/hykm/→hykym /metn/→metin
Env.	Icelandic deletion	V[-stress]→ø/ __ [COR] V V→[+rd]/ __ C <sub>0</sub> u	/bagg-il-u/→bægglu

(49) Bleeding

Type	Process	Example rules	Form
Focus			
Env.	Yokuts epenthesis	V[ahi]→[+rd]/[ahi, +r] C__ ø→i/C__CC	/logw+ʔas/→logiwʔas *logiwʔos

## (50) Counter-bleeding

Type	Lg./Process	Example rules	Form
Focus	Yokuts epenthesis	V[ $\alpha$ h]→[+r]/[ $\alpha$ h, +r] C __ [+hi, +lg]→[-hi]	/c'uyi:+l/→c'uyol *c'uyal
Env.	Shimakonde reduction	V→[-high]/[-high, +lo] C __ V→[+lo]/ __ $\sigma\sigma$ ] <sub>wd</sub>	/ku-pet-il-a/→kupateela
	West Greenlandic (Cearley, 1976) epenthesis/deletion	V→[+phar]/ __ q q→ $\emptyset$ / __ C $\emptyset$ →i/CC#	/alq-t/→al̥it /taliq-t/→tal̥it
	Canadian French (Poliquin, 2007) Pre-fricative tensing	V→[-tense]/ __ C [-tense] V→[+tense]/ __ [+cont]	/mi.siv/→misi:v *mi.si:v cf. sty.pid

## (51) Counter-feeding

Type	Lg./Process	Example rules	Form
Focus	Mafa epenthesis	V→[-bk]/ __ C [-bk] $\emptyset$ →ə/CC	/ðek-d-a/→ðekəda *ðekida
	Maltese (Puech, 1978) shortening	V→[+rd]/[-lng, +rd] C _ V:→V/ __ $\acute{\sigma}$	/kitib-u:-l-ok-ʃ/→kitibulékʃ (cf. kitib-om-l-ok)
	Agulus (Armenian) Vaux, 1998) epenthesis	V→[+bk]/[+bk] C <sub>0</sub> __ $\emptyset$ →ə/C_C#	/sur-ats/→suratəs *suratus
Env.	Mafa assimilation	V→[-bk]/ __ C [-bk] [+hi]→[-bk]/ __ j	/sə-j-aʔa/→sijaʔa *ʃijeʔe
	Yokuts lowering	V[ $\alpha$ h]→[+r]/[ $\alpha$ h, +r] C __ [+hi, +lg]→[-hi]	/cu:m+al/→co:mal *co:mol
	Shimakonde coalescence	V→[-high]/[-high] C __ [+lo][+hi]→[-hi, -lo, +lng]	/vanda-ip-il-a/→vandeepiila *vandeepiela
	Icelandic epenthesis	V→[+rd]/ _ C <sub>0</sub> u $\emptyset$ →u/C_r	/dag+r/→dagur *dögur
	Kalong (Hyman, 2002) tensing	V→[+ATR]/ [+ATR C <sub>0</sub> __ V→[+ATR]/ __ ] <sub><math>\sigma</math></sub>	/kù-lik-a/→kù-lik-a (cf. /kù-tím-à/→kù-tím-è)
	Sea Dayak (K&K, 1979) deletion	V→[+nasal]/ [+nasal] __ C {+voice}→ $\emptyset$ /N__	/naŋga/→nāŋa *nāŋā

**1.4.2. Gaps in the typology**

Overall, counter-feeding is quite common (9 cases), while bleeding is exceedingly rare (1 example), with bleeding on focus unattested. Furthermore, an analysis of feeding on environment reveals that there are no cases of feeding of the trigger vowel.

For example, the feeding on environment in Icelandic involves the deletion of a vowel such that the (pre)-existing trigger is now adjacent to the target (separated by a C), while the bleeding on environment in Yokuts involves the epenthesis of a vowel so that target and trigger are no longer adjacent and harmony does not apply. However, there are no cases where a process creates a vowel that can trigger harmony, or changes a trigger vowel such that harmony does not apply. With respect to feeding, no epenthesized vowel triggers harmony in another vowel nor does some assimilatory process ever yield a vowel that can trigger harmony. With respect to bleeding, there are no cases where a trigger vowel is deleted or a trigger vowel's features change such that harmony does not apply in the surface form.<sup>5</sup>

There are plenty of cases of the opposite interactions, with counter-feeding or counter-bleeding on trigger as in the Mafa counter-feeding case where glide assimilation yields a front vowel that does not trigger front harmony in the other vowels. The lack of the reverse ordering requires an explanation.

Harmony driven exclusively by input forms, as discussed in §1.3, can account for this typological gap. If harmony involves correspondence and agreement with some input segment and there are only two levels of representation – input and output – then no process can feed or bleed the segment triggering harmony. Feeding and bleeding can affect the rest of the environment or focus, though, while still remaining compatible with the input-based approach. The Icelandic example simply dictates that adjacency is

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<sup>5</sup> A potential counter-example is found in Icelandic where vowel raising and umlaut create a trigger vowel for subsequent umlaut of another vowel: /fátnað+um/ → fœtnuðum. The suggested derivation (Anderson, 1974) is /fátnað+um/ → fátnaðum → fátnoðum → fátnuðum → fœtnuðum. This example is used as evidence for cyclicity, which is problematic for surface-based theories of opacity and is not solved through the use of a set of strata. As such, it is assumed that cyclicity represents an aspect of lexical phonology that must be incorporated into surface-based theories of phonology. This can be done with co-phonologies (Inkelas, 1998), but not stratal-OT (Kiparsky, 2000).

determined relative to the output, and not input forms, as does bleeding in Yokuts. The feeding on focus examples similarly create a target for harmony, which can be in correspondence with the input.

Furthermore, there are examples of both over-application and under-application in the same language in Shimakonde, providing further evidence for an input-driven theory of opacity. In Shimakonde, in addition to the over-application of vowel harmony with respect to vowel reduction (2a) there is also an instance of under-application of vowel harmony with respect to vowel coalescence:

(52) Interaction of low+high coalescence and VHH:

	<u>Unreduced</u>		<u>Reduced</u>	
a) /vandá-ep-íla/	vandépeéla	~	vandaápeéla	‘they will harvest for’
b) /vandá-im-il-a/	vandémííla	~	vandeemííla	‘they will dig’

The first example reflects the over-application opacity from above – the *-el-* applicative suffix surfaces in an environment other than after a surface mid vowel because *a+e* coalesces to *ee*, which is then reduced to *aa*. The second example reflects under-application opacity – mid vowel harmony fails to apply to the applicative suffix despite the coalescence of *a+i* to *ee*, normally the trigger of vowel harmony. Mid vowels that result from the coalescence of low+high vowels also happen to be immune to reduction.

There is, in other words, a conspiracy of sorts in Shimakonde in that regardless of the process that interacts with harmony, harmony is determined by the underlying form and not the surface form.

## **1.5. OPACITY AND DOMAINS OF APPLICATION**

The final empirical observation concerning opaque interactions relates to the relationships between different phonological processes and their domains. As discussed above, the sequential application of rules can account for why opaque interactions are found. Furthermore, there is substantial evidence that different processes apply within different domains. If it is hypothesized that the phonological processes for different domains apply in a temporally sequenced order, with the lower levels applying first then it can conceivably be argued that opacity arises from the application of processes for one domain applying before another. Therefore, to motivate a theoretical account based on input-output mappings, and not serialism, it is necessary to show that opacity can arise from the interaction of phonological processes within a single domain of application.

### **1.5.1. Lexical Phonology**

Lexical Phonology (Kiparsky, 1982; Mohanan, 1986) argues for different domains, or strata, for the applications of rules: a set of lexical levels, where generalizations hold for words, and a post-lexical level (or two) that articulates generalizations that hold across words. Expanding on the concept of rule ordering, the assumption was that all rules associated with words apply before those that apply across words. The well-motivated set of generalizations that results from this stratification is that there are certain properties for rules associated with the word levels that are different than those that apply at the post-lexical level. Post-lexical rules are not cyclic, apply across-the-board, and can be structure-creating while word-level rules can refer to word-internal structure, can be cyclic, and are structure-preserving, among other differences. A crucial aspect of this

enterprise was being able to provide external evidence for the existence of different strata.

For example, in English, tri-syllabic laxing applies to vowels that are followed by two other vowels in the same word (e.g. *div*[a]n, *div*[ɪ]nity, *cl*[ij]r, *cl*[æ]rify). There are exceptions (e.g. *bravery*) and no new vowels can be created by this process (i.e. it is structure preserving). In contrast, flapping is exceptionless, it creates a new phoneme, and occurs across words (*hi*[ɾ] *it*).

Relevant to the discussion of opacity is the assumption that the application of processes at different levels are sequentially ordered. Thus opacity can arise from the extrinsic ordering of levels, which can be justified through external evidence similar to that demonstrated above. This is the case for Dutch, which has word-final devoicing that over-applies when cliticization leads to re-syllabification:

(53) Dutch opacity explainable through strata:

a) Opaque devoicing with cliticization:

/hɛb ət/      [hɛ.p ət]      ‘have it’

/hɑd ət/      [hɑ.t ət]      ‘had it’

/hɛb ər/      [hɛ.p ər]      ‘have her’

b) Transparent lack of devoicing with affixation

/hɛb ərɔd/      [hɛ.bərɔt]      ‘greedy person’

/hɛb ən/      [hɛ.bən]      ‘have (PL.)’

An account of this opacity may be based on the fact that devoicing applies at the lexical strata while re-syllabification due to cliticization applies afterwards, at the post-lexical strata. Evidence for this comes the lack of devoicing found within the word (53b) which contrast with the across-word re-syllabification in (53a).

To rule this out as an explanation for the opaque examples discussed in the previous sections, it is either necessary to show that the two interacting processes are at the same stratum. While this may not be possible for each of the examples above due to a lack of definitive evidence as to which stratum the different processes apply to, it is sufficient to show that there are at least some clear cases of within-strata opacity involving harmony and tonal interactions, eliminating the use of strata as a solution to all cases of opacity for this empirical domain.

### **1.5.2. Lexical opacity**

An example of opacity involving harmony that can be shown to occur within the lexical strata is found in Canadian French (CF; Poliquin, 2007). Vowels are generally lax in final closed syllables (56a) and tense in open syllables (56b). There are exceptions to these generalizations, however. First, there is a process of pre-fricative tensing, which requires that vowels in closed final syllables with fricative codas be tense and long (57a). Second, there is a variable process of regressive lax harmony targeting high vowels. This can result in lax vowels in open syllables, (57b). These two processes interact opaquely resulting in an over-application of harmony (58a).

(54) Canadian French open/closed vowel tensing and laxing:

a) Final closed syllable laxing:			b. Open Syllable Tensing		
<u>Tense</u>	<u>Lax</u>		<u>Tense</u>	<u>Lax</u>	
be.ni	e.lɪt	*lɪt	mi.tɛn	*mɪ.tɛn	
kry	a.nɪl	*nɪl	ky.lɔt	*kɪ.lɔt	
de.gu	e.gut	*gut	ku.te	*kɔ.te	

(55) Motivated exception to open-tense/closed-lax generalization

a) CF pre-fricative tensing			b. CF Lax Harmony		
<u>Tense</u>	<u>Lax</u>		<u>Harmonized</u>	<u>Unharmonized</u>	
sa.li:v	*sa.lɪv		fɪ.lɪp	~	fɪ.lɪp
e.kly:z	*e.klɪz		stɪ.pɪd	~	stɪ.pɪd

(56) Canadian French lax harmony opacity:

a) Pre-fricative tensing			b. Affixation-triggered opacity		
<u>Harmonized</u>	<u>Unharmonized</u>		<u>Harmonized</u>	<u>Unharmonized</u>	
bɛy.ly:ɤ	~	bɛy.ly:ɤ	mɪ.zi.kal	~	mɪ.zi.kal
mɪ.si:v	~	mi.si:v			

In (58a), despite the surface realization of the closed final syllables vowels as tense, the open syllables are (optionally) lax, a condition only permitted by lax harmony. Affixation

creates a similar opacity when a suffix resyllabifies a stem's coda creating an open syllable (58b). The stem-final vowel, now in an open syllable, is tense, yet the harmonized word-initial vowel remains lax.

Final closed syllable laxing must be word level based on words like [fin.mã] 'nicely' which surfaces with a tense high vowel. Because open-syllable tensing is not applicable (the stem is closed), it must be the case that final closed-syllable laxing did not apply to the bare stem /fin/, otherwise the surface form would have been required to be lax [finmã]. Instead, closed-syllable laxing applies at the word level which feeds harmony (/mi.siv/→mi.si:v<sup>6</sup>), so harmony must also be at the word level.

Further evidence for harmony being word-level comes from the fact that harmony is triggered by certain suffixes ([-ISM] 'DOCT.', [-IST] 'ADJ.' and [-YI] 'DIM.'). In a form like *illuminisme* [I.lY.mi.nism], the lax penultimate syllable is only possible because of harmony triggered by the lax vowel in the suffix.

However, based on opaque forms like *musical* [mY.si.kal], harmony must also apply prior to the affixation of derivational suffixes (-al). Suffixation triggers resyllabification resulting in the penultimate syllable being open, and therefore tense. Yet, the initial vowel is lax so it must be the target of harmony triggered by the lax vowel in the bare stem [mY.sik]. Therefore, at the word level, harmony and affixation interact opaquely representing a case of intra-level opaque rule ordering.

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<sup>6</sup> This analysis (Polliquin, 2007) suggests a Duke of York derivation (Pullum, 1976) is present where an underlying tense vowel changes to lax by word-final closed-syllable laxing triggering harmony in the initial syllable. Subsequent pre-fricative tensing (and lengthening) returns the vowel to its initial status of tenseness.

### 1.5.3. Post-lexical opacity

An entire class of examples of opacity within the post-lexical domain is found in the Sino-Tibetan language family, particularly among the Chinese (Chengdu, Lin, 2004; Min/Taiwanese, Chen, 2000; Tianjin, Lin, 2004) and Chin (Zahao, Yip, 2003; Falam; Obburne, 1975; Hakha Lai, Hyman & Van Bik, 2004) languages. This is in part due to the fact that these languages are relatively isolating; words are often mono-syllabic and many words are formed through the compounding of other mono-syllabic words. They also have elaborate tone-sandhi systems, so any tone sandhi necessarily applies across word boundaries, and is therefore post-lexical.

The opaque tonal interaction in these languages is essentially variations on a similar theme, and has already been addressed specifically for Hakha Lai (Hyman & Van Bi, 2004), Taiwanese (Lin, 2004), and Tianjin (Lin, 2004) as instances of opacity. So, in this section I will focus on Boshan, a northern Mandarin dialect of Chinese (Qian, 1993).

Boshan has three citation tones, LM, H and ML (also marked as 214, 55 and 31). Boshan, as well as the rest of these languages, have tone sandhi to repair adjacent identical tones to avoid violations of the OCP. In Boshan, the tone sandhi can be captured by the following rules, which can also yield HM and MH (53 and 24) tones.

(57) Boshan tone sandhi rules:

a)  $LM \rightarrow H / \_ LM$  (e.g. /t un/+ /fen/  $\rightarrow$  t un.fen) ‘spring equinox’

$LM \quad LM \rightarrow H \quad LM$

b)  $H \rightarrow HM / \_ H$  (e.g. /qi/+ /ma/  $\rightarrow$  qi.ma ‘horse riding’)

$H \quad H \rightarrow HM H$

- c) ML→MH/ \_\_ ML (e.g. /ban/+ /je/→ ban.je ‘mid-night’)
- ML ML → MH ML

These interaction may also be seen in the following tables:

(58) Tabular representation of Boshan tone sandhi:

	2 <sup>nd</sup> tone		
1 <sup>st</sup> tone	LM	H	ML
LM	H LM		
H		HM H	(MH ML)
ML			MH ML

In tri-tonal sequences, the final output depends on the direction of application of the rules; this factor also leads to the opaque interactions in Hakha Lai and Tianjin. In Boshan, both directions of application - left-to-right and right-to-left – are found:

(59) Right to left directions of application of Boshan tone sandhi:

- |         | <u>Bracketing</u> | <u>1<sup>st</sup> sandhi</u> | <u>Re-bracketing</u> | <u>Output</u> |
|---------|-------------------|------------------------------|----------------------|---------------|
| a) R→L: | H (H H)           | → H (HM H)                   | → (H HM)H            | → H HM H      |
| *L→R:   | (H H) H           | →(HM H) H                    | → HM (H H)           | →*HM HM H     |

Right-to-left application (59) yields transparent output forms because tone sandhi in Boshan targets the left-hand tone in a OCP-violating pair. Therefore, the application of a rule does not alter the environment of application of sandhi that already applied – only sandhi that will apply. So, the first tone change targets the left-hand tone in pair of H tones on the right, which is the middle tone. This changed tone is then evaluated in the

second bracketing, and would feed or bleed whatever process happens next.

(60) Left to right directions of application of Boshan tone sandhi:

	<u>Bracketing</u>	<u>1<sup>st</sup> sandhi</u>	<u>Re-bracketing</u>	<u>Output</u>
a)	L→R: (H LM) LM	→ (H LM) LM	→ H.(LM LM)	→ H H LM
	* R→L: H (LM LM)	→ H (H LM)	→ (H H) LM	→*HM H LM
b)	L→R: (LM LM) LM	→ (H LM) LM	→ H (LM LM)	→ H H LM
	* R→L: LM(LM LM)	→ LM(H LM)	→ (LM H) LM	→*LM H LM

Conversely, left-to-right application can yield both under-application (60a) and over-application (60b) opacity because the targeting of the left of the latter two TBUs in the tri-tonal sequence can create or destroy the environment of application for the first pair.

Thus, in (a), the two left underlying tones (**H LM LM**) do not violate the OCP, and so no sandhi occurs. The two right tones do violate the OCP (**H LM LM**) resulting in a high tone in the middle TBU, creating a violation of the OCP: /H LM LM/→H H LM. This would normally be repaired (57b) but is not as the application of sandhi rules already passed over this initial pair.

In (b), the first two tones violate the OCP (**LM LM LM**), and so sandhi targets the first, repairing the violation. Sandhi then applies to the second TBU pair (**H LM LM**), again repairing the OCP by changing the middle tone, which was the environment for the first instance of tone-sandhi: /LM LM LM/→H H LM. This latter change to the middle tone would have repaired both OCP violations on its own (**LM H LM**). Thus, the first tone change is an instance of over-application.

As stated above, these are instances of tone sandhi operating across words, or between elements of a compound. So Boshan, and the similar examples found in Hakha Lai, Tianjin and others represent cases of opacity within the post-lexical domain.

## **1.6. CONCLUSION**

This chapter highlighted a number of empirical observations concerning the interaction of tone and harmony with other phonological processes. The first concerned the definition of opacity itself. A comparison of languages like Zulu and Esimbi, which reflect the realization of tone or a harmonic feature, respectively, as defined with respect to the final surface output, and Jita and Shimakonde, where the realization of tone or features is determined relative to the input suggests that the distinction between transparent and opaque within this empirical domain is a difference between output-determined and input-determined process interaction.

The second point re-examined the generalization captured by alpha-rules and autosegmental notation for opaque interactions in light of this definition of opacity to better understand the nature of input-determined harmony and tonal interactions. Within this empirical domain, these formal mechanisms capture input-output relationships that establish a mapping between an input segment and a non-equivalent output segments.

This input-driven approach to opacity makes the prediction that certain types of interactions between other processes and harmony should not exist. In particular, if harmony is driven by underlying representations, then no phonological process should feed or bleed harmony in terms of creating or eliminating a harmony trigger. I showed that this is, indeed, the case and that for harmony and tonal interactions, opacity is the

more common process interaction, instead of feeding or bleeding interactions.

Finally, I show that there are cases of within-stratum or within-level opacity including within the post-lexical and word levels in addition to some cases of opacity being quite amenable to a stratal approach.

Ideally, a formal approach to opacity would capture these generalizations. In the next chapter, I present the details of DCT, which, I argue, does capture these generalizations whereas other approaches to opacity do not. Because DCT does not represent a theory of all cases of opacity as it focuses on a narrow empirical domain, I discuss how DCT should be seen not as a replacement for all theories of opacity, but rather as an augmentation to approaches such as Stratal OT, which captures the instance of opacity demonstrably deriving from inter-strata process interactions.

## CHAPTER 2

### DIAGONAL CORRESPONDENCE THEORY

#### 2.1. INTRODUCTION

In chapter one I highlighted a number of observations for harmony and tonal interactions that are opaque. First, I argued that opacity is better defined as input-defined output, as contrasted with transparent, output-defined output. Second, I argued that the generalization captured by ordered alpha-rules or autosegmental rules for opaque interactions is one of non-equivalent correspondence among segments or features. Third, I showed that instead of being marked, opacity is quite common when it comes to tone and harmony and that certain types of feeding or bleeding relationships are non-existent. Finally, I showed that while some cases of opacity reflect the interaction of phonological processes that are at different domains, or strata, of application, there are myriad cases of within-strata opacity. In this chapter I introduce Diagonal Correspondence Theory (DCT), which captures these observations formally through a modification of existing Optimality Theory architecture.

The basic idea behind DCT is to expand the scope of faithfulness constraints. Normal faithfulness constraints (more detail in §1.3.3 on OT) express a relationship between equivalent segments in the input and output. For example, the phonological process  $A \rightarrow B/C\_D$ , creates an input-output pair of  $/CAD/ \rightarrow CBD$ . In OT, the C on the input corresponds with the C on the output, input A corresponds with output B and input D corresponds with output D. The change of A to B violates a constraint maintaining faithfulness among corresponding segments, presumably to decrease markedness of the

string, while the input-output mapping of  $C \rightarrow C$  and  $D \rightarrow D$  does not violate any faithfulness constraints.

(1) Graphical representation of standard correspondence:

a) /CAD/  
    ↓ ↓ ↓  
    [ CBD ]

In chapter one I showed that cases of opacity involving tone shifting and harmony reflect a different type of correspondence. Two representative examples from the first chapter, Jita tone shifting, and the interaction of harmony and lowering in Shimakonde are repeated here:

(2) Opaque interactions in Shimakonde and Jita

a) Shimakonde Vowel Height Harmony and Reduction:

/ku-pet-il-a/      kú-pát-éél-a    ‘to sift for’

b) Jita tone shifting

/ku-βón-er-a/      ku-βon-ér-a    ‘to get for’

The Shimakonde example reflects a process of vowel height harmony, where the applicative suffix, *-il-* surfaces as *-el-* because of height harmony to the verb root, *pet*, and reduction, where pre-penultimate mid vowels are reduced to *a*. The Jita example reflects a single phonological process of a one-TBU tone shift.

Both examples reflect the following correspondence relationship, which I term diagonal because it combines the vertical input-output correspondence, and a horizontal,

syntagmatic relationships between segments:

(3) Graphical representation of

a) Jita tone shift

/ku-βón-er-a/



[ku-βon-ér-a]

b) Shimakonde Harmony

/ku-pet-il-a/



[ku-pat-eela]

DCT establishes this correspondence relationship among non-equivalent input-output segment pairs. As with input-output faithfulness (i.e. the vertical correspondence among equivalent segments in 1), DC faithfulness constraints incur violations when segments that are in diagonal correspondence are different. This can capture opaque generalizations as illustrated in (3), for example, where in (3a) output *ér* must agree with respect to high tone with input *βón* and in (3b) where the applicative suffix, *-el-*, must agree in height with the vowel in the input verb root, *pet*.

DCT builds on a number of existing concepts within OT, namely two-level markedness constraints (McCarthy, 1996), correspondence theory and the “full model” of reduplication (McCarthy & Prince, 1995) and harmony as correspondence (Bakovic, 2001; Hansson, 2001; Krämer, 2003; Rose & Walker, 2004). Therefore, I begin this chapter by describing these different theories in detail before providing a formal expression of DCT.

In §2.2 I explore the theoretical precursors to diagonal correspondence which include the full model of reduplication (McCarthy & Prince, 1995) and two-level constraints (McCarthy, 1996). In §2.3, I present a theory of vowel harmony based on

correspondence that can also account for blocking, a phenomenon previously thought to be outside the scope of harmony via correspondence (Hansson, 2001; cf. Hansson 2007).

Section 2.4 shows how DCT can account for opacity involving tonal interactions and harmony in a number of languages. Finally, because of the limited empirical coverage of this approach, I discuss how DCT fits within a larger theory of opacity.

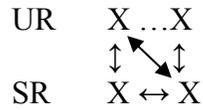
## **2.2. THEORETICAL PRECURSORS TO DIAGONAL CORRESPONDENCE**

Identity constraints establish the agreement, or identity, of features among corresponding elements, with correspondence determined with respect to input-output pairs, base-reduplicant, output-output pairs, or across string-internal segments. For example, IDENT(F) is shorthand for a constraint that requires that corresponding input-output segments agree with respect to the feature F; IDENT(F)-BR incurs violations when corresponding segment in base and reduplicant differ for feature F; IDENT(F)-OO incurs violations when the same segment in different cells of a paradigm differ with respect to feature F; IDENT(F)-CC incurs a violation for output consonants that are in correspondence that do not agree with respect to feature F.

DCT establishes a new type of correspondence relationship among segments. The diagram below sketches the new relationship proposed by DC in the context of other established correspondence relationships in OT. The up-down arrow represents input-output correspondence while the left-right arrow represents syntagmatic correspondence of the sort in BR-correspondence or string correspondence in harmony (Bakovic, 2000; Krämer, 2001; Walker, 2000; Rose & Walker, 2004; Hansson, 2001), described in further detail in §2.3. The new correspondence is the diagonal arrow, establishing a

correspondence between an output segment and a different input segment.

(4) Diagonal correspondence



Instead of seeing IO, BR, CC and OO correspondences as completely independent constraint sets, they can all be seen as subsets of a more general across-the-board correspondence. Input-output correspondence limits correspondence to one particular dimension, the input-output dimension; syntagmatic correspondence (S-IDENT, ID-CC) ignores the input-output dimension and establishes correspondence in the orthogonal output dimension; output-output correspondence holds the other dimensions constant and makes use of the paradigmatic dimension; BR correspondence is another kind of syntagmatic correspondence that holds all dimensions constant except for base-reduplicant relationship.

(5) Typology of correspondences

Correspondence	I/O	Paradigmatic	Syntagmatic	Reference
ONE-DIMENSIONAL				
Corr-IO	I~O	evaluated form	$n$	McCarthy & Prince (1995)
Corr-OO	output	eval ~ base	$n$	Benua (1996)
Corr-BR	output	evaluated form	$B_n \sim R_n$	McCarthy & Prince (1995)
Corr-CC	output	evaluated form	$C_n (V) \sim C_{n+1}$	Hansson (2001)
S-IDENT	output	evaluated form	$V_n (C_0) \sim V_{n+1}$	Krämer (2001)
TWO-DIMENSIONAL				
Corr-IR	I~O	evaluated form	$B_n \sim R_n$	McCarthy & Prince (1995)
<b>Diagonal</b>	<b>I~O</b>	<b>evaluated form</b>	<b><math>X_n \dots X_{n+1}</math></b>	

In the above table, the correspondence relationship is shown by the cell with a tilde

indicating which segments along the dimension specified are in correspondence, while the other cells indicate the variable along which the other dimensions are fixed. So, for input-output correspondence, the correspondence holds between input and output forms. Along the paradigmatic dimension, the only relevant form is the target form and in the syntagmatic dimension, the syntagmatic order of each segment is held constant, so segment 1 in the input string corresponds with segment 1 in the output string and so on. For CORR-CC, correspondence holds among each of the consonants in the evaluated output form; for output-output correspondence, the output of the evaluated form is compared to the output of the evaluated form in a segment-by-segment comparison; in CORR-BR, the first segment in the base corresponds with the first segment in the reduplicant for the output. In each of these relationships, correspondence varies only in one dimension.

If all of these dimensions of correspondence are parameters, then a potential correspondence exists between all segments in both input and output and all output forms in the same paradigm with each specific correspondence relationship identifying some subset of these correspondences. In DC the variation is along two dimensions – the input-output dimension and the syntagmatic dimension.

In this section, I discuss two precursors to this type of relationship: Input-Reduplicant correspondence and two-level markedness constraints, which establish markedness based on adjacency as determined by both input and output forms.

### **2.3.1. The full model of reduplication**

There is precedence for this sort of two-dimensional correspondence. In the model of

correspondence laid out in McCarthy and Prince (1995) there is a contrast between the basic model of reduplicative correspondence, which includes only BR and IO (or IB) correspondence and the full model, which includes the added diagonal dimension of IR correspondence, correspondence between input and reduplicant.

The basic model accounts for the relationship between base and reduplicant and input in many of the documented cases of reduplication. In base-reduplicant correspondence, agreement is established between the base and the reduplicant morpheme to copy phonological material from one to the other. In Javanese, for example, a reduplicant prefix is copied from the surface form of the base and is not a copy of the underlying form:

(6) Javanese reduplication (McCarthy & Prince, 1995)

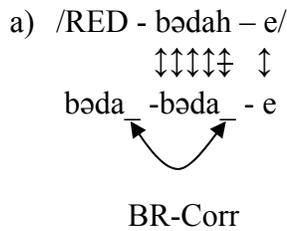
Root	Reduplicated Form	Red. + V-initial suffix	
a) bədah	bədah-bədah	bəda-bəda-e	‘broken’
b) dajoh	dajoh- dajoh	dajo-dajo-e	‘guest’

To enforce *h* deletion in the reduplicant to reflect intervocalic *h*-deletion in the base, a set of constraints establishing correspondence between the two may be used with the constraint DEP-BR establishes a correspondence relationship among elements in a syntagmatic string.

(7) Tableau for Javanese reduplication (McCarthy & Prince, 1995) showing BR-correspondence:

/RED-bədah-e/	DEP-BR	*VhV	MAX-IO
a) →bəda-bəda-e			*
b) bədah-bədah-e		*	
c) bədah-bəda-e	*!		

(8) Figure showing syntagmatic correspondence in Javanese:



The full model is required for a couple of special cases where there is greater faithfulness between the input and reduplicant than base and reduplicant or input and base. For example in Klamath (Clements & Keyser, 1983) the distributive morpheme is a reduplicant morpheme that is based on the input, rather than the base. This is evident in the examples in (9) where the first vowel of the base undergoes deletion or reduction following another syllable. The vowel in the reduplicant, instead of being based on the reduced or deleted base vowel in the output is instead faithful to the vowel of the input verb stem.

(9) Klamath RI faithfulness

a) Vowel deletion

/DIST+mbody'+dk/ mbo-mpditk 'wrinkled up (dist.)'

/DIST+poli:k'a/ po-pli:k'a 'little policemen (dist.)'

b) Vowel reduction

/DIST+dmesga/	de-dməsga	‘seize (dist.)’
/DIST+sipc+a/	si-səpca	‘put out a fire (dist.)’

This can also be understood as a type of unorthodox opacity. A rule-based approach would require that reduplication precede vowel reduction/deletion but the traditional counter-bleeding and counter-feeding ordering analyses do not apply. First, reduplication feeds reduction since it creates the non-syllable-initial environment for reduction/deletion. Second, if reduction had applied first it would not have been applicable to the form since the verb stem vowel is not preceded by a syllable and so in this sense the rules are in a counter-bleeding relationship. This is not a traditional counter-bleeding relationship, however, because at issue is not the application of reduction (which could have applied based on, for example being in penultimate position), but rather the vowel of the reduplicant.

(10) Klamath rule ordering:

a)	/DIST+sipc+a/	/DIST+sipc+a/
reduplication	si-sipca	reduction --
reduction	si-səpca	reduplication si-sipca

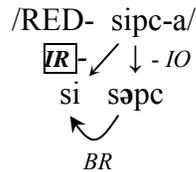
In an OT approach, the inadequacy of the surface-based approach is clear from the tableau below: neither base-reduplicant identity nor input-output identity can account for the reduplicant’s vowel. To get the correct form, IR-faithfulness must exist and must be

highly ranked so that the reduplicant's vowel is [i]. The result is that an element on the output crucially depends on a non-identical element of the input:

(11) Necessity of IR-faithfulness in Klamath

/RED-sipc-a/	REDUCE	Id(H)-BR	Id(H)-IO	Id(H)-IR
sə-səpca			*	*
→si-səpca		*	*	
si-sipc	*!			
sə-sipc	*!	*		*

(12) Visual representation of IR correspondence for Klamath



**2.3.2. Diagonal Correspondence as a Two-Level Constraint**

The idea that constraints can refer to input forms is the hallmark of faithfulness and McCarthy & Prince (1995) note that there may be more to the notion of correspondence by alluding to other (non-faithfulness) constraints that could refer to both input and output:

One topic worthy of future investigation is the potential for stating constraints other than the faithfulness variety on correspondent pairs in input and output. Developments along this line can produce the same general effect as the ‘two-level’ rules introduced by Koskeniemi (1983) and further studied by Karttunen (1993), Lakoff (1993), and Goldsmith (1993) and others.

McCarthy (1996) lays out a framework wherein a markedness constraint can refer to either the underlying or surface form for any of the relevant elements of a markedness constraint. Building on Archangeli (1994), the components of a regular surface-based

markedness constraint for harmony include a number of elements including two substantive components for context-dependent markedness constraints – the marked element and the context within which it is marked. Were harmony in Mafa (8 in §1.2.1:  $\delta\text{ək-a}\text{ʔa}$  vs.  $\text{ʃid-e}\text{ʔe}$ ) enforced using a markedness constraint, these two terms would be a back vowel following a palatal vowel. In many cases order is also crucial with respect to the two elements – because Mafa harmony targets suffixes, the order is left-to-right. Finally, further specification of the degree of adjacency may be necessary to refer to whether there is any intervening material between the two elements. For vowel harmony, ‘V-to-V’ adjacency is necessary; for local assimilation, immediate adjacency is necessary. When a constraint of this sort is ranked above the identity constraint maintaining the value for the underlying feature [BACK], this constraint (abbreviated HARMONY) selects the a surface-transparent form:

(13) Transparent Shimakonde harmony

$/\text{ʃid-a}\text{ʔa}/$	ID[BACK]/ROOT	HARMONY	ID[BACK]
(a) $\rightarrow\text{ʃid-e}\text{ʔe}$			**
(b) $\text{ʃid-a}\text{ʔa}$		*!	
(c) $\text{ʃəd-a}\text{ʔa}$	*!		

If, however, each of the substantive components of the constraint can refer to underlying forms, this constraint can be altered to account for the opaque Mafa vowel harmony with a near-identical tableau. The constraint would be as follows:

(14) IO markedness constraint for Mafa opacity

*	Condition	Level
$\alpha$	[-back]	Underlying
$\beta$	[+back]	Surface
Order	$\alpha, \beta$	Underlying
Adjacency	V-to-V	Indifferent

This markedness constraint would incur a violation whenever an input front vowel is followed by an output back vowel:

(15) Opaque Mafa harmony

/bə-j-aʔa/	*əj	HARMONY	ID[BACK]
(a) →bi-j-aʔa			*
(b) bi-j-eʔe		*!	**
(d) bə-j-aʔa	*		

The Harmony constraint is now evaluated as a two-level constraint and the  $\alpha$  now refers to whether the vowel in the underlying form – not surface form – is front.

The main criticism that has been leveled against this account of opacity is the supposed problem of intermediate forms. Oft-cited cases of this include the inability to apply syllable-based phonotactic constraints on an unsyllabified underlying form, and so a syllabified intermediate form is required. In a common example, Bedouin Hijazi Arabic (Al Mozainy, 1981; McCarthy, 1999), open-syllable vowel raising interacts opaquely with glide vocalization and epenthesis (16). The failure of raising to apply in the forms in (b) represents a case of under-application and McCarthy (1999) cites this as a problem for two-level markedness. If underlying forms are unsyllabified the open-syllable vowel raising markedness constraint, \*a]<sub>σ</sub>, would be unable to reference a syllable boundary in

the underlying form. If underlying forms are syllabified, this runs afoul of the principle of richness of the base.

(16) Opaque interaction of open-syllable raising with epenthesis and glide vocalization

a) Transparent vowel raising:

/katab/ → kitab      ‘he wrote’

b) Opaque vowel raising:

/badw/ → ba.du      ‘Bedouin’

/gabr/ → ga.bur      ‘grave’

A third alternative is possible, however, based on the idea that segmental phonotactics are best understood as string-based rather than syllable based (Steriade, 1999; Blevins, 2003). Both cite a diverse set of evidence including the lack of consistent judgments on word-medial syllabification, and the greater explanatory power provided by string-based licensing-by-cue grounding of these phonotactic constraints. Thus, the BHA constraint  $*a]_{\sigma}$  can be restated as  $*aCV$ .

There is language-internal evidence supporting this formulation of the constraint. There are no cases of mono-syllabic vowel raising and the occurrence of word-final *a* in exceptions such as *řima* ‘antelope’ (Al Mozainy, 1981), *talaba* ‘student’ (Al-Hazmy, 1972) and *ha:ða* ‘palm’ suggest that this string-based constraint is more empirically accurate than the syllable-based one. There is also another phonotactic constraint in BHA that is clearly string based and is similar to the vowel-raising constraint. Low vowels are deleted before *CaCa* sequences (*shabat* ‘she pulled’ cf. *sahab* ‘he pulled’)

motivated by a \*aCaCa (or \*aCa]<sub>σ</sub>) constraint. An \*aCV constraint would be formally similar.

(17) IO markedness constraint for BH Arabic opacity

*	Condition	Level
α	a	Surface
β	CV	Underlying
Order	α < β	Underlying
Adjacency	Strict	Indifferent

Restated thusly, (abbreviated \*a<sub>0</sub>CV<sub>I</sub>) this markedness constraints can be incorporated as a two-level constraint, selecting the correct form given an unsyllabified input for both opaque and transparent forms.

(18) Transparent BHA vowel raising

/katab/	*CC#	*a <sub>0</sub> CV <sub>I</sub>	ID[LOW]	DEP
(a) →kitab			*	
(b) katab		*		

(19) Opaque BHA vowel (non-)raising

/gabr/	*CC#	*a <sub>0</sub> CV <sub>I</sub>	ID[LOW]	DEP
(a) →gabur				*
(b) gibur			*!	*
(c) gabr	*!			

The input-output constraint would fail to apply to *gabur* because the CV-component of the constraint is stated at the underlying level, and the underlying form /gabr/ lacks a vowel.

Other instances of the effect of the intermediate form are harder to come by,

particularly within the domain of tone and harmony. Consider a hypothetical example, based on the Shimakonde data above, where harmony and reduction interact in the same way, but coalescence and harmony are in a feeding relationship:

(20) Shimakond-B

- a) /vanda-ip-a/            vandeepa
- b) /vanda-ip-il-a/        vandaapeela

The harmony in example (b), *vandaapeela*, is based on the intermediate form *vandeepeela* which would prove difficult for two-level constraints. I know of no cases like this, however, and so ideally, a formalization of opaque tonal interactions would rule out this sort of interaction.

Thus, there is evidence that two-level markedness constraints are an appropriate account for opaque interactions. DC is a two-level faithfulness constraint, however, and while the tableau in (15) showed the correct evaluation of opacity in Mafa, two-level markedness constraints are not rich enough to account for the full range of phenomena. In the next section, I argue that harmony is best accounted for through correspondence and faithfulness constraints, and so opacity involving harmony is therefore best accounted with with DC. The section after that also shows that this approach also has the benefit of unifying an analysis of opaque harmony with an analysis of opaque tonal interactions.

### **2.3. HARMONY AS CORRESPONDENCE**

There is, at this time, no consensus on how to formalize harmony within OT, yet there is

agreement that there are four descriptive elements of any harmony system that need to be accounted for, ideally with as few formal elements as possible:

(21) Harmony parameters

- a) Harmonic feature(s)
- b) Target segments
- c) Directionality
- d) Harmony-opaque and/or harmony-transparent segments

The harmonic feature is the simplest to describe and refers to the feature that the targeted segments must share in common. For example, in Yoruba, the harmonic feature is [ATR] since affixes must share the same featural specification with respect to [ATR] as the root:

(22) Yoruba [ATR] harmony

- a) [+ATR]
  - /e-we/      [ewe]      ‘lip’
  - /o-ge-de/      [ogede]      ‘incantation’
- b) [-ATR]
  - /e-gε/      [εgε]      ‘cassava’
  - /o-ge-dε/      [ɔgεdε]      ‘banana’

More complex is the challenge of defining which segments are subject to harmony and which are not. In many OT accounts of harmony (e.g. Bakovic, 2001; Hayes & Londe,

2006) it is assumed, either implicitly or explicitly, that the phonology – presumably the representation – makes available a vowel projection (Vergnaud & Halle 1979) or tier (Archangeli & Pulleyblank, 1987) which expresses just the vowels of the string so that consonants can be ignored in the structural description of constraints.

Vowel harmony also often holds across some subset of vowels with non-participating vowels being either harmony transparent or harmony-opaque<sup>1</sup>. Harmony-transparent vowels allow agreement to hold between vowels on either side of it, as if the vowel did not exist. For example, Hungarian has backness harmony (a) that is not affected by neutral vowels (b), which are demonstrably neutral by virtue of the fact that they can take either suffix (c):

(23) Hungarian back harmony with harmony-transparent vowels:

- |             |                  |           |                 |
|-------------|------------------|-----------|-----------------|
| a) toek-nek | ‘pumpkin (DAT.)’ | haz-nak   | ‘house (DAT.)’  |
| b)          |                  | radir-nak | ‘eraser (DAT.)’ |
| c) viz-nek  | ‘water (DAT.)’   | hid-nak   | ‘bridge (DAT.)’ |

Harmony-opaque vowels block agreement between vowels on either side of it. For example, in Shimakonde vowels that are [-low] agree with respect to the feature [-high] while vowels that are [+low], namely *a*, are harmony-opaque: they block harmony and are also unaffected by it:

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<sup>1</sup> The term “harmony-opaque” is used here to disambiguate from the use of the term opaque in the rest of this study.

(24) Basic Shimakonde vowel height harmony (VHH)

a) High/low vowel root

kú-pat-ííl-a ‘to get for’

kú-píkíit-ííl-a ‘to play for’

ku-put-ííl-a ‘to wash for’

b) Mid vowel root

kú-pét-éél-a ‘to sift for’

ku-tot-éél-a ‘to sew for’

c) *a*-blocking

ku-pet-an-ííla ‘to sift for each other’ (\*lek-an-ééla)

Crucially, *a* has the same feature specification as the harmonic feature, [-high], which proves challenging for many formalizations of harmony.

Thus, a theory of harmony should be able to account for both harmony-transparent and harmony-opaque vowels..

### 2.2.2. Precursors to vowel harmony as correspondence

Within the OT framework, a number of different constraints have been suggested to account for harmony that essentially capture the same idea as harmony via correspondence including AGREE (Bakovic, 2000), S(YNTAGMATIC)-IDENT (Krämer, 2001) and MATCH (McCarthy, 2003), which all essentially require that surface segments

share the same relevant feature specification.<sup>2</sup> The phonetic and cognitive underpinning of natural patterns of harmony is likely a combination of phonetic precursors such as co-articulation (Gafos, 1996; Ohala, 1994) and a cognitive bias for phonologizing relationships among like elements (Moreton, 2008). While harmony is sometimes modeled through markedness constraints (Pulleyblank, 2002), the similarity of constraints like AGREE to the identity faithfulness constraint (McCarthy & Prince, 1995) is striking and made explicit with Krämer's (2001, 2003) syntagmatic identity:

(25) Formalization of AGREE (Bakovic, 2001), S-IDENT (Krämer, 2001) and IDENT (McCarthy & Prince, 1995) constraints:

- a) IDENT(F): Let A be a segment in  $S_1$  and B be any correspondent of A in  $S_2$ . If A is  $[\alpha F]$ , then B is  $[\alpha F]$ .
- b) AGREE $[\pm hf]$ : Adjacent segments have the same value of  $[\pm hf]$ .
- c) S-IDENT[F]: Let  $x$  be an entity of type  $T = \{\text{segment, more, syllable, foot}\}$  in domain  $D = \{\text{Pwd, foot, syllable}\}$  and  $y$  be an adjacent entity of type T in domain D, if  $x$  is  $[\alpha F]$ , then  $y$  is  $[\alpha F]$

Bakovic (2001) and Krämer (2003) account for harmony-opaque segments by defining AGREE and S-IDENT as holding over adjacent vowels. A vowel that cannot accommodate the harmonic feature because of feature co-occurrence constraints (e.g.  $*[+high, +low]$  or

---

<sup>2</sup> There is also an approach to harmony based on the alignment of some harmonic feature with either the left or right edge of a domain (Archangeli & Pulleyblank, 1993; Kirchner, 1993; Cole & Kisseberth, 1995; Pulleyblank, 1996). The adoption of Correspondence Theory obviated the need for alignment constraints, however. This approach is also flawed because it stipulates directionality (ALIGN-R, ALIGN-L) whereas it is generally predictable (Hyman, 2002; Bakovic, 2000) and it also creates a too-many-repairs problem where alignment constraints could theoretically be satisfied by deletion of a vowel. Finally, an alignment approach implicitly assumes that intervening consonants are also affected by the the harmonic feature despite evidence to the contrary (Ettlinger, 2004; Kim, 2007).

\*[+high, -ATR] for Yoruba) establishes a new harmonic domain, blocking the harmonic feature from spreading further. This cannot account for the behavior of harmony in Shimakonde, however, because the featural representation of the opaque vowel, *a*, is [+low, -high] which agrees with respect to [high] with a mid [-high, -low] vowel to its left and should therefore spread [-high] to its right according to their theories. This incorrectly yields a harmony-transparent *a* where /*ku-pet-an-il-a*/ → \**kupetaneela* as opposed to the correct *kupetaniila*:

(26) Transparency of *a* using AGREE

/e C a C i/ [-h] [-h] [+h]	AGREE(Hi)	ID(Hi)
←e C a C e [-h] [-h] [-h]		*
⊗ e C a C i [-h] [-h] [+h]	* <sub>i</sub>	

Instead, agreement must be required to hold only for vowels that are [-low] in Shimakonde or, indeed, for any other languages displaying prototypical 5-vowel Bantu VHH. This can be implemented through the further use of tiers and feature geometry by positing that the [high] feature depends on the [low] feature (Clements & Hume, 1985).

Alternatively, the harmony constraint itself can be reformulated such that it holds only among vowels that are [-low]. This is the essence of the approach argued for in Archangeli and Suzuki (1997) and others where the constraint would be articulated as [LOW]/[HIGH]: segments that agree with respect to the feature [LOW] must agree with respect to [HIGH]. These constraints are ad hoc, however. The empirical pattern embodied by all of these approaches is preferably generalized such that harmony is defined as

syntagmatic identity of some harmonic feature holding among segments sharing some other feature.

### 2.2.3 Vowel Harmony as Agreement by Correspondence

The most straightforward way to formalize the agreement of certain vowels with respect to a certain feature is to use Agreement by Correspondence (ABC; Walker, 2002; Rose & Walker, 2004; Hansson, 2001), originally suggested for consonant harmony, to account for vowel harmony as well. ABC establishes correspondence amongst segments that share a particular feature or set of features and enforce agreement among corresponding segments. For example, in Aymara, homorganic consonants must agree with respect to laryngeal features:

(27) Aymara

a) Homorganic w/ laryngeal agreement

tunti	‘arid’
k’ask’a	‘acid to the taste’
k <sup>h</sup> usk <sup>h</sup> u	‘common’
*k <sup>h</sup> aka	
*kak’a	

b) Heterorganic

qotu	‘group, pile’
t’aqa	‘flock’
t’alp <sup>h</sup> a	‘wide’

To formalize this, Rose and Walker (2004) and Hansson (2001, 2004) argue that there is a fixed hierarchy of consonantal correspondence correlated with degree of similarity and that segments in correspondence must be the same with respect to the harmonic or agreeing feature. Thus, correspondence amongst the most similar consonants (i.e. identical) is ranked highest (CORR-T↔T), followed by correspondence among homorganic stops (CORR-T↔D), followed by stops with identical voicing (CORR-T↔K) followed by all oral stops (Corr-K↔D). The ranking of the relevant identity constraint with respect to this hierarchy establishes the threshold of similarity required for segment to correspond and another constraint requires that segments that correspond agree with respect to a feature. For the Aymara data, for example, highest ranked is ID-CC(sg): segments in correspondence must agree with respect to their laryngeal specification. Then, ranked below CORR-T<sup>h</sup>↔T (homorganic segments must correspond independent of laryngeal specification) but above CORR-K↔T (all voiceless consonants must be in correspondence), is the faithfulness constraint ID-IO(sg). This has the effect of requiring that homorganic consonants have the same laryngeal specification.

(28) Agreement by Correspondence

/k <sup>ʔ</sup> aska/	ID-CC(sg)	CORR-T↔T	CORR-T <sup>h</sup> ↔T	ID-IO(sg)	CORR-K↔T
→k <sub>x</sub> <sup>ʔ</sup> ask <sub>x</sub> <sup>ʔ</sup> a				*	
k <sub>x</sub> <sup>ʔ</sup> ask <sub>x</sub> a	*				
k <sub>x</sub> <sup>ʔ</sup> ask <sub>v</sub> a			*!		
/t <sup>ʔ</sup> aqɑ/					
t <sub>x</sub> <sup>ʔ</sup> aq <sub>x</sub> <sup>ʔ</sup> a				*	
→t <sub>x</sub> <sup>ʔ</sup> aq <sub>v</sub> a					*
t <sub>x</sub> <sup>ʔ</sup> aq <sub>x</sub> a	*				

The two other properties of harmony (and tone) systems that must also be specified are

locality and directionality.

Tone shifts and harmony can proceed in either an anticipatory (left) or preservative (right) manner as the above examples show: Shimakonde reflects rightward spreading, while Icelandic umlaut (§1.4.1, e.g. *kalla* ‘I call’; *kœllum* ‘we call’) proceeds leftward. There has been significant discussion as to whether the directionality of spreading is predictable from other facts in the language, or has a default. Hyman and Schuh (1974), for example, argue that tone is predominantly preservative, as the above tone examples show. On the other hand, Beckman (1997), Krämer (2001), Bakovic (2001) and others argue that directionality in vowel harmony systems is epiphenomenal of more basic principles of root or stem dominance, so constraints need not explicitly refer to directionality. Instead, directionality is driven by the fact that affixes are the target of root triggers, while cases like Icelandic are part of a different empirical domain consisting of umlaut and metaphony, which are locally bounded and are affix→stem driven. In addition to these example, there are several counterexamples to the observation (Punu: Hyman, 2003; Mafa: Ettliger, 2005) so, the convention of Rose and Walker (2004) is used by specifying directionality in correspondence as either CORR-XX<sub>R</sub> for left-to-right spreading or CORR- XX<sub>L</sub> for right-to-left spreading.

Finally, Walker (2000) and Hansson (2004) discuss the necessity of specifying the distance allowed between corresponding segments. With respect to consonant harmony, for example, many Bantu languages restrict nasal harmony to consonants separated by a single vowel (Hansson, 2004), while the tone shifts above are limited to a shift between adjacent TBUs. This can be accounted for by relativizing the correspondence constraints with respect to what may come between corresponding segments:

(29) Locality-specified correspondence constraints

a) CORR-XX, CORR-X-Y-X, CORR-X- $\sigma$ -X, CORR-X- $\infty$ -X

CORR-XX establishes correspondence among strictly adjacent segments, CORR-X-Y-X establishes correspondence between segments of class X separated maximally by a segment of another type, Y, (e.g. two vowels separated by a consonant, two consonants separated by a vowel), and so on, to CORR-X- $\infty$ -X, requiring correspondence between segments of class X at any distance.

### 2.3 FORMALIZATION OF DIAGONAL CORRESPONDENCE

In this section, I formally articulate the definition of DCT. The new set of DC constraints is essentially the same as that in ABC except that the first term refers to the input string while the second term refers to the output string. Enforcing identity of some feature F among these diagonally-corresponding segments is IDENT[F]-D, which is the analog of S-IDENT or IDENT[F]-CC. The formal statements of the new constraint is as follows:

(30) Diagonal Correspondence:

a) CORR-D-XY: Let R be an input string of segments and S be an output string of segments and let X and Y be segments that share a specified set of features. If  $X \in R$  and  $Y \in S$  and if there is no segment Z intervening between X and Y, then X is in diagonal correspondence with Y.

- b) CORR-D-X- $\tau$ -Y: Let R be an input string of segments and S be an output string of segments and let X and Y be segments that share a specified set of features and let  $\tau$  specify some metrical unit. If  $X \in R$  and  $Y \in S$  and if there is at most the metrical unit  $\tau$  intervening between X and Y, then X is in diagonal correspondence with Y.
- c) CORR-D-XY $_{\delta}$ : Let R be an input string of segments and S be an output string of segments, let X and Y be segments that share a specified set of features and let  $\delta$  specify a direction, L or R. If  $X \in R$  and  $Y \in S$  and if Y is to the direction of X specified by  $\delta$ , then X is in diagonal correspondence with Y.
- d) CORR-D-X-Z-Y $_{\delta}$ : Let R be an input string of segments and S be an output string of segments, let X and Y be segments that share a specified set of features and let  $\delta$  specify a direction, L or R and let  $\delta$  specify a direction, L or R. If  $X \in R$  and  $Y \in S$  and if there is no segment Z not sharing the specified set of features intervenes between X and Y and if Y is to the direction of X specified by  $\delta$ , and if there is at most the metrical unit  $\tau$  separating X and Y, then X is in diagonal correspondence with Y.

As shown above, the basic notion of DC may be augmented by parameters specifying directionality and locality. In the next two sections, §3.2 and §3.3, I show how this constraint can account for opaque interactions involving tone and harmony, respectively.

## 2.4 DC AND TONE SHIFTING

This section presents a DC analysis of the opaque tonal phenomena discussed above, namely tone shift. Kikuyu (Clements, 1984) reflects a tone shift similar to Jita. Underline

indicate the underlying placement of high tone:

(31) Kikuyu tone shift

- a) to rər áya ‘we look at’
- b) to tòm áya ‘we send’
- c) to m̩ r̩r̩ áya ‘we look at them’
- d) to m̩ tòm áya ‘we send them’

The examples in (c,d) show that the tonal shift is not definable with respect to a particular position (e.g. first affix) and that the tone shift occurs for adjacent underlying tones, a problem for an account based on the OCP, binary tonal domain (Cassimjee & Kisseberth, 1998), or peak delay (Myers, 1999; Kaplan, 2008).

The DC in effect here is between each input TBU and its right-adjacent output TBU, effected by a constraint CORR- $\mu$ -C- $\mu_R$ , abbreviated DC. Subscripts indicate segments that are in correspondence.

(32) Tone shift in Kikuyu using DC

/to <sub>x</sub> -tó <sub>y</sub> m-a <sub>z</sub> ʔa/	ID-DC(T)	DC	ID-IO(T)
(a) →to-to <sub>x</sub> m-á <sub>y</sub> ʔa			**
(b) to <sub>x</sub> -tó <sub>y</sub> m-a <sub>z</sub> ʔa		*!***	
(c) to-to <sub>x</sub> m-a <sub>y</sub> ʔa	*!		

For tone spreading the markedness constraint against single high tones, discussed above,

can now be evaluated based on surface forms alone with DC taking care of directionality, an element missing from the earlier account:

(33) Tone spreading in Kikewere using DC

/ku <sub>w</sub> -bó <sub>x</sub> h-e <sub>y</sub> l-a <sub>z</sub> n-a/	*MONO	ID-DC(T)	DC	ID-IO(T)
(a) ku-bó <sub>w</sub> h-e <sub>x</sub> l-a <sub>y</sub> n-a <sub>z</sub>	*	**!		
(b) →ku-bó <sub>w</sub> h-é <sub>x</sub> l-a <sub>y</sub> n-a <sub>z</sub>		*		*
(c) kú-bó <sub>w</sub> h-e <sub>x</sub> l-a <sub>y</sub> n-a <sub>z</sub>		**!		*
(d) ku-bo <sub>w</sub> h-é <sub>x</sub> l-a <sub>y</sub> n-a <sub>z</sub>	*			**

Note that these evaluations yield the correct output form without the benefit of autosegmental representation. Autosegmental notation constitutes an abstract representation of forms wherein the language learner has no way of determining the difference between, say, a doubly-linked high tone and two adjacent high tones. As such, the analysis here represents an improvement. Further discussion of the relationship between correspondence theory and autosegmental representation of tonal processes is discussed in chapter 2.

## 2.5. DC AND HARMONY

This section provides an analysis of several well-known and lesser-known cases of opacity involving vowel harmony using DC – namely Yowlumne, Mafa with Shimakonde addressed in chapter three. Particular attention is paid to the predictions the theory makes with respect to how an opaque interaction between harmony and one process dictates that harmony will interact opaquely with other processes. For example, the opaque over-application of harmony with respect to reduction in Shimakonde predicts the opaque under-application of harmony with respect to vowel coalescence, or the

opaque interaction of harmony with vowel deletion in Icelandic predicts the opaque interaction of harmony with epenthesis. Ultimately, the data suggest that opaque interactions are in fact that unmarked process interaction with harmony, a prediction made with DC, but not with any other theory of opacity.

There are a number of other issues relating to harmony and opacity that are also taken up in Chapter 3, in particular a discussion of the shortcoming and some remedies for the correspondence-theory based approach to harmony adopted here.

### **2.5.1 Yowlumne Yokuts**

A discussion of opacity, particular opacity as it relates to harmony, would not be complete without an analysis of Yowlumne Yokuts as there is a long tradition of generative studies of the language. The original source data is Newman (1944) and other treatments of the opacity in Yowlumne include Kuroda (1967), Kisseberth (1969, 1970, 1973), Kenstowicz and Kisseberth (1977, 1979), Archangeli (1984, 1991), Archangeli & Suzuki (1997; AS), McCarthy (1999) and Bye (2003; B03). Of particular interest here is the accounts in Archangeli and Suzuki which adopts two-level constraints.

The crucial data are as follows. First, long vowels lower from high to mid with vowel length determined by a morphological template (CVVC for perfective, CVC for imperfective) (34). Furthermore, there is rightward-spreading round harmony on vowels that are the same height (35).

(34) Yokuts vowel lowering (from A&S)

	CVVC-t	CVC-aaʔaa	
a)	doos-it	dus-ooʔoo	‘was reported’/‘is reporting’
b)	meekʔ-it	mikʔ-aaʔan	‘was swallowed’/‘is swallowing’
c)	ʔootʔ-ut	ʔutʔ-aaʔaan-it	‘stolen’

(35) Yokuts vowel harmony (from A&S)

a)	/xat-hin/	xathin	‘ate’
	/xat-al/	xatal	‘might eat’
b)	/dub-hin/	dubhun	‘led by the hand’
	/bokʔ-al/	bokʔol	‘might find’
c)	/hud-al/	hudal	‘might recognize’
	/bokʔ-hin/	bokhin	‘found’

The forms in (a) show the underlying or unharmonized form of two different suffixes, which are targeted by round harmony triggered by the root in (b), but only when the vowels are the same height (c).

Finally, there is a process of closed-syllable vowel shortening:

(36) Yokuts vowel harmony (Kenstowicz & Kisseberth, 1977):

a)	sa:p-al	‘burn-DUB’	sap-hin	NONFUT
	do:s-en	‘report-FUT’	dos-kʔo	IMP
b)	pana:-hin	‘arrive-NONFUT’	pana-l	DUB
	cʔuyo:-hun	‘urinate-NONFUT’	cʔuyo-l	DUB

Vowel lowering and vowel harmony interact opaquely in that roundness spreads to the suffix based on whether the suffix has the same height as the underlying form of the root vowel and not based on the height of the surface vowel. This results in both over-application (a) and under-application (b) opacities:

(37) Yokuts opacity (from A&S)

- |               |         |                 |          |
|---------------|---------|-----------------|----------|
| a) /c'uum-it/ | c'oomut | 'destroyed'     | *c'oomit |
| b) /c'uum-al  | c'oomal | 'might destroy' | *c'oomol |

In (a), the *-it* suffix is subject to round harmony despite the height disagreement in the surface because the vowel heights agree in the input, while in (b), round harmony does not spread to the suffix despite the height agreement in the surface because the heights disagree in the input.

Vowel shortening also interacts opaquely with vowel lowering, and while these data include examples also involving opacity with vowel harmony, a solution to this particular opacity framed in terms of DC is not offered since the interaction does not include the harmony process directly.

(38) Opaque interaction of vowel lowering and vowel shortening:

- a) /ʔilii+l/ʔilel

For theories of opacity that attempt to account for all data, the interaction of all three processes proves particularly difficult for a form such as:

(39) Opaque interaction of vowel lowering and vowel shortening and vowel harmony:

a) /c'uum-hin/ c'omhun 'destroy'

To account for the data in (75) and (76), a correspondence can be established between the affix vowel and root vowel based on their heights in the output and input respectively.

Thus, based on the correspondence constraints above, the DC constraint for Yowlumne is as follows:

(40) Yowlumne Correspondence

a) CORR-D-E-O<sub>R</sub>: Let R be an input string of segments and S be an output string of segments and let X and Y be vowels that are the same height [ $\alpha$ HIGH]. If  $X \in R$  and  $Y \in S$ , and if Y is to the right of X, then X is in diagonal correspondence with Y.

This constraint (abbreviate DC below), combined with an identity constraint requiring that vowels in diagonal correspondence agree with respect to rounding (ID-[RND]-DC) yields the correct forms for Yowlumne:

(41) Opaque interaction vowel harmony and vowel lowering in Yowlumne

/c'uux <sub>x</sub> m-i <sub>y</sub> t/	*Hi/ $\mu\mu$	DC	ID(RND)-DC	ID-IO(RND)
(a) $\rightarrow$ c'oomu <sub>x</sub> t				*
(b) c'oox <sub>x</sub> mi <sub>y</sub> t		*!		
(c) c'oom-i <sub>x</sub> t			*!	
(d) c'uum-u <sub>x</sub> t	*!			

This formulation of rounding harmony also yields the correct output form for transparent

cases where harmony spreads and cases where it does not, as well:

(42) Transparent vowel harmony in Yowlumne

/du <sub>x</sub> b-hi <sub>y</sub> n/	DC	ID(RND)-DC	ID-IO(RND)
(a) →dubhu <sub>x</sub> n			*
(b) du <sub>x</sub> bhu <sub>y</sub> n	*!		*
(c) dubhi <sub>x</sub> n		*!	

(43) Transparent vowel non-harmony in Yowlumne

/du <sub>x</sub> b-a <sub>y</sub> l/	DC	ID(RND)-DC	ID-IO(RND)
(a) →dubo <sub>x</sub> l	*!		*
(b) duba <sub>z</sub> l			
(c) duba <sub>x</sub> l	*!	*!	

In the transparent form, *dub-al*, the output suffix vowel is not in correspondence with the input verb root vowel because the suffix is not the same height as the root vowel, and so no identity of roundness is required.

The last crucial set of data reflects the interaction between harmony and epenthesis. Most analyses (Archangeli, 1982; McCarthy, 1999) describe epenthesis as feeding harmony:

(44) Yokuts epenthesis feeds harmony

- a) ?ugunhun      ?ugnal      ‘drank / might drink’
- b) luk’ulhun      luk’lal      ‘buries / might bury’
- cf. logiwhin      logwol      ‘pulverizes / might pulverize’

While this counts as feeding in the sense of rule-ordering, the DC approach suggests that

the relationship is not precisely feeding in that epenthesis does not either create a trigger for vowel harmony nor does it establish the conditioning environment for a target. Rather, epenthesis creates a target in a way that can still be accommodated by DC despite being transparent:

(45) Transparent interaction of epenthesis and vowel harmony in Yowlumne

/lu <sub>x</sub> kʰl-hi <sub>y</sub> n/	*CCC	DC	ID(RND)-DC	ID-IO(RND)
(a) →lukʰu <sub>x</sub> lhu <sub>x</sub> n				*
(b) lukʰlhu <sub>x</sub> n	*!			*
(c) lukʰi <sub>x</sub> lhu <sub>x</sub> n			*!	

This example does raise the question of how correspondence is assessed, particularly with respect to locality when the proximity of the segments in question is not the same in input and output forms, i.e. when there is epenthesis or deletion. For example, in the example below, the question arises whether the *i* in the suffix is adjacent to the underlying *u* in the verb stem, or the epenthetic *u*:

(46) Yowlumne correspondence

a)	l	u	kʰ		l	-	h	i	n
	↓	↓	↓	↓	↓		↓	↓	↓
	l	u	kʰ	u	l	-	h	i <sub>y</sub>	n

For cases where proximity and harmony-blocking are not applicable, this is not an issue, as in the above example, but for instances where certain vowels block the spreading of harmony, (e.g. Shimakonde, Yowlumne) this becomes a crucial issue. Because epenthesis

can counter-bleeds or bleed harmony on environment (§1.4) then adjacency must be an independently specified parameter referring to input (epenthesis counter-bleeds opacity) or output (epenthesis bleeds opacity).

(47) Harmony blocking examples:

a) Shimakonde:

/kú-pet-an-il-a/      kúpátánííla      (cf. kúpátééla)

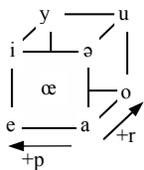
b) Yowlumne

/logw-ʔas/      logiwʔas      ‘pulverize’

### 2.5.2. Mafa

Mafa has palatal harmony that under-applies with respect to local glide assimilation. There are eight vowels in Mafa defined by three distinct features: rounding, frontness and height:

(48) Mafa vowel space



All vowels are subject to fronting (/ə/→[i], /u/→[y], /o/→[œ] and /a/→[e]), as well as the alveolar consonants ([sə]~[ʃi], [zə]~[ʒi], [tsə]~[tʃi], [dzə]~[dʒi]:

(49) Mafa front harmony affix allomorphy:

- a) ðək-aʔa      ‘He sows it’      ʃid-eʔe ‘He thanks it’  
b) pəz-aʔa      ‘He cultivates it’      piʒ-eʔe ‘Cultivate it!’

Mafa also has high-vowel palatal assimilation such that /ə/ and /u/ front to [i] and [y] respectively (50) and when the two interact, assimilation counter-feeds harmony, which under-applies (51):

(50) High vowel glide assimilation

- a) gudzə      ‘to tremble’      gudzij ‘tremble!’  
b) sə      ‘to drink’      si-j      ‘drink!’      \*ʃi-j

(51) Opaque interaction of harmony and palatal assimilation:

- a) si-j-aʔa ‘drink it!’      \*ʃij-eʔe  
b) ʒij-aʔa ‘big (DEF)’      \*ʒij-eʔe

This can be accounted for via diagonal correspondence with the constraint formulated in the following manner:

(52) Mafa Correspondence

- a) CORR-D-V-V<sub>R</sub>: Let R be an input string of segments and S be an output string of segments and let X and Y be two vowels. If X ∈ R and Y ∈ S, and if Y is to the right of X, then X is in diagonal correspondence with Y.

There are no neutral vowels in Mafa and all vowel participate in harmony, so all that is required for a front affix is a front vowel somewhere in the stem in the input. A front vowel in the output, the results of assimilation is not adequate to trigger harmony, however:

(53) Mafa under-applications

/sə <sub>x</sub> j-a <sub>y</sub> ?a <sub>z</sub> /	*əj	DC	ID(BACK)-DC	ID-IO(BACK)
(a) →sij-a <sub>x</sub> ?a <sub>y</sub>				*
(b) sij-e <sub>x</sub> ?e <sub>y</sub>			**	***
(c) səj-a <sub>x</sub> ?a <sub>y</sub>	*!		*!	
(d) sij-a <sub>y</sub> ?a <sub>z</sub>		*!		

Thus, DC can account for tone shifts and under- and over-application of harmony in Jita, Mafa and Yowlumne. Chapter three also presents a detailed case study of DCT and Shimakonde.

## 2.6. Further Implications of Diagonal Correspondence

One of the great insights of OT is that all of the myriad possible constraint rankings should yield possible languages. If some phenomenon in a language is found that can not be accounted for with a certain constraint ranking, this suggests the universal constraint set has been incorrectly specified; similarly, if a constraint ranking yields a language that seems impossible, then a pathology is said to exist. This pathology suggests a grammar that it too permissible and the constraint set must be modified to rule out this impossible language.

For example, given two constraints, a \*VOICEDCODA markedness constraint and

an ID[VOICE] faithfulness constraint, two types of languages are possible: M»F languages where there is coda devoicing and F»M languages where voicing is retained and both voiced and voiceless consonants are possible in syllable codas. Absent from this typology are coda voicing languages, which are argued to not exist (Kiparsky, 2004; but see Yu, 2004 and Blevins, 2004). This is therefore considered an appropriate statement of UG constraints, with \*VOICELESSCODA correctly absent from the inventory of constraints.

Using the constraints argued for above, we can establish a typology of languages with respect to opacity and harmony by permuting the rankings of these constraint. If examples of each exist and no languages are unaccounted for, then the constraint set can be said to be both adequately restrictive and descriptive. If we start with the /eCi/ input, the three faithfulness constraint – input-output faithfulness, syntagmatic output faithfulness, and diagonal faithfulness – can be permuted with a markedness constraint targeting the initial, or unstressed syllable. The following language types are possible:

(54) Factorial typology

- a) Fully faithful: ID-IO » M, ID-D, ID-S

A language without harmony or reduction: /eCi/ → [eCi] (55a)

e.g. Punu: [-ded-il-a]

- b) Transparent harmony: ID-S » ID-IO » M, (ID-D)

A language with transparent VH: /eCi/ → [eCe] (55b)

e.g. Kisa (Sample, 1976): /rek-il/ → [rekel]

c) Opaque harmony: M, ID-D » ID-IO, ID-S

Harmony rendered opaque by a markedness process: /eCi/→[aCe] (55c)

e.g Shimakonde: /pet-il/→[-patel-]

d) Reducing language: M » ID-IO » ID-D, ID-S

A language with just reduction: /eCi/→[aCi] (55d)

e.g. Belorussian (Crosswhite, 2001): /p<sup>h</sup>okú/→[p<sup>h</sup>akú]<sup>3</sup>

e) Triggered-harmony language: M, ID-S » ID-IO, ID-D

A markedness-indices alternation triggers harmony: /eCi/→[aCa] (55e)

N/A

(55) Incompatibility of a level-based approach with

/e C i/	REDUCE	ID-D	ID-IO	ID-S
a) e C i	*	*		*
b) e C e	*		*	
c) a C e			**	*
d) a C i		*	*	*
e) a C a		*	**	

The one problematic ranking is (64e), where some markedness constraint motivates an alternation in a vowel that in turn triggers harmony among other vowels. I am not aware of any language that has this sort of relationship and indeed, this is problematic for any theory of harmony.

The reason for this typological is likely as follows: Markedness violations, by definition, are repaired by resorting to some less marked segment or feature. Harmony, on the other hand, as articulated by Beckman (1997) and others, involves the licensing of

<sup>3</sup> No Bantu language was found though Ruwund (Nash, 1991) reflects a historic change of \*o>a and \*e>i.

some marked structure by some other marked structure in the output. Thus if markedness is eliminated to satisfy a constraint, the resulting segment, being unmarked, should not be able to trigger harmony. The discrepancy between this observation and the constraints in (63) is based on the conflation of multiple input-output faithfulness constraint into one ID-IO constraint. In reality, there should be two – one for preserving a marked feature for the prominent (here, second) vowel, which is ranked higher than a second for the initial vowel. The markedness constraint should only be able to be ranked below highly ranked prominent-syllable faithfulness constraint if it triggers an alternation in the language.

Interestingly, this possibility can also be ruled out by always ranking ID-D over ID-S. This fixed ranking does not limit the ability to produce any of the other attested language patterns and captures this same generalization in a slightly different way. This essentially amounts to saying that no harmony pattern can be triggered by something that is not in the input – a generalization that seems well supported by typological evidence and agrees with the general spirit of an input-based approach to phonology.

This modification still manages to be restrictive in terms of the type of rule interaction that is allowed in that it does not admit a counter-feeding or counter-bleeding process to be counter-bled or –fed by another process.

## **2.7 CONCLUSION**

In this chapter, I showed that Diagonal Correspondence Theory is able to account for the opaque interactions found in a number of languages as well as account for the other observations in chapter one.

Thus, DCT can account for the input form having a greater role by expanding the

role of faithfulness to include opaque harmony and tonal interactions. This formal approach makes the correct prediction that certain forms of opacity involving tone shifts and harmony are not found.

This chapter also provided a theoretical justification for DCT by showing its relationship to a number of other accepted theories within OT including the full model of reduplication and two-level markedness constraints.

If DCT is, indeed, appropriate for certain kinds of opacity – namely the empirical domain that is amenable to insights through Autosegmental Phonology - the question then becomes what to do with other instances of opacity.

Some instances of opacity clearly reflect the interaction of different phonological at different levels, or strata, and so there is certainly a justification for stratal OT. As I showed, however, this is inadequate by itself to account for all instances of opacity. Thus a combination of a number of solutions may be warranted, dependent on the particular empirical domain. DCT therefore is a piece in the larger puzzle of the myriad sources of opacity and suggests that all opaque data should not be treated the same.

## CHAPTER 3

### CASE STUDY ON SHIMAKONDE

#### 3.1. BACKGROUND

This chapter will focus on the three opaque phonological interactions found in Makonde, a Bantu language of the P.23 sub-grouping. The most closely related languages are Mwera, Yao, Mkhwa and Maatumbi (Guthrie, 1948; Manus 2003) and it is spoken by approximately 1.2 million people in northeast Mozambique and southwest Tanzania (Manus, 2003). Two varieties of Makonde are of particular interest: *Shímákoonde*, documented in Liphola (2001), primarily spoken in south east Mozambique, and *Símákoonde*, documented in Manus (2003), spoken on the island of Unguja, Zanzibar and the main port city of Tanga. Differences between the two varieties are minimal with respect to the phonological processes discussed below and are noted when relevant. Additional data from other varieties of Makonde, Chimaraba and Chimahuta (Odden, 1990), are used when appropriate.

Briefly, there are three processes – vowel reduction, vowel coalescence and vowel harmony – that all interact opaquely with each other. Vowel harmony over-applies with respect to vowel reduction; vowel reduction under-applies with respect to vowel coalescence; and vowel harmony also under-applies with respect to vowel coalescence. I argue that the overarching generalization that these distinct cases of opacity embody is that Shimakonde reflects an input-output mapping that can be accounted for with Diagonal Correspondence Theory (DCT; chapter 2).

The organization of this chapter is as follows: §3.2 details vowel reduction in

Shimakonde referencing its stress system and vowel inventory while §3.3 and §3.4 discuss the harmony and coalescence processes respectively. §3.5 shows how these three processes interacting opaquely and §3.6 shows why the Shimakonde data are problematic for surface-based approaches to phonology, particularly OT. Finally, in §3.7 I show how the opaque relationships can be accounted for with DCT.

### **3.2. VOWEL REDUCTION**

Discussing the details of vowel reduction in Shimakonde requires an understanding of the vowel inventory and stress system.

#### **3.2.1. Stress**

Shimakonde words have penultimate stress realized as vowel lengthening in citations forms. The vowel of the root is long when it is in the penult (1a), but short when unstressed (1b,c). Suffix vowels that are otherwise short are also lengthened in the penultimate syllable (1b,c).

##### (1) Vowel lengthening

- a) kú-píínd-a            ‘to bend’
- b) kú-pínd-íika            ‘to be bent’
- c) kú-pínd-ík-íil-a        ‘to be bent for’

Long vowels can also result from adjacent hetero-morphemic short vowels. When the vowels differ coalescence or glide-formation occurs (§3.4) but when the two vowels are

the same, the result is simply a long vowel. The existence of unstressed long vowels suggests that the process in (1) is stressed syllable lengthening as opposed to pre-tonic shortening.

(2) Shimakonde vowel fusion yielding non-penultimate long vowels

- a) /tu-nda-akaáta/      tunda**aa**kaáta    ‘we will take a bit’ (cf. akaáta ‘take a bit!’)
- b) /va-nda-alal-a/      vanda**áa**laála    ‘they will be beautiful’ (cf. alaala ‘be beautiful!’)
- c) /va-nda-amat-a/      vánda**áa**maáta    ‘they filter’ (L. p.193)

Finally, lengthening is a post-lexical process as evidenced by the fact that when two or more words are combined into an (intonational) phrase, only the penultimate syllable of the whole phrase is lengthened (3):

(3) Post-lexical application (from Chimaraba and Chimahuta dialects)

- a) /kú-pínd-a málombe/      kúpí**nda** máloombe    ‘to bend maize’      (Odden, 1990)
- \*kúpí**inda** máloombe    (only as citation forms)
- b) /kú-kolom-a li-kolomódi/      kúkoloma likolomoódi ‘to cough (a cough)’ (Odden, 1990)

**3.2.2. Vowel system**

In the stressed penultimate syllable, all five of Shimakonde’s vowels can be realized:

(4) Minimal pairs for Shimakonde vowels

- a) kúpááta                    ‘to get’
- b) kúpééeta                  ‘to sift’
- c) kúpííta                    ‘to pass’
- d) kúpóóta                  ‘to twist’
- e) kúpúúta                  ‘to wash’

Length is not contrastive within a morpheme, so Shimakonde has a five-vowel system characteristic of many other Bantu languages such as Punu (Blanchon, 1995), Yaka (Ruttenberg, 1971; Hyman 1998), Kongo (Hyman, 1999), Luganda (Katamba, 1993), Zulu (Downing, 1990), and Pende (Niyonkuru, 1978):

(5) Shimakonde’s 5 vowels

i        u  
e        o  
a

**3.2.3 The process of reduction**

Limiting the quality of vowels that can appear in pre-tonic syllables is a process of vowel reduction where mid vowels (*e*, *o*) are optionally reduced to *a* (e.g. the mid vowel *e* of the root *pet* is preserved in tonic position, but is reduced to *a* in pre-tonic position (6b)). When reduction applies, only the peripheral vowels – *i*, *u* and *a* – can be realized in pre-tonic syllables.

(6) Vowel reduction

- a) kú-piit-a      kú-pítáána ‘to pass (each other)’
- b) kú-puút-a      kú-pútáána ‘to wash (each other)’
- c) ku-péét-a      kú-pátáána ‘to sift (each other)’
- d) ku-poót-a      kú-pátáána ‘to twist (each other)’
- e) kú-páát-a      kú-pátáána ‘to get (each other)’

Contrasting *kú-pátáána* ‘to sift each other’ (6b) and *kú-pátáána* ‘to get each other’, for example, exhibits the neutralizing nature of reduction.

### 3.2.4 Reduction as complete neutralization

Supporting the idea that Shimakonde reduction is not simply the result of phonetic implementation or articulatory ease is the fact that the neutralization in Shimakonde is complete, even in citation form. Production data provided by Liphola (2001) shows that reduced mid vowels are acoustically indistinguishable from underlying /a/ in duration and formant frequency (7). Data from perception experiments similarly show that the reduced mid vowels are auditorily indistinguishable from underlying /a/ as well.

(7) Acoustic data from Liphola (2001)

	Duration (ms)	F1	F2
/a/ [a]	125	<b>741</b>	<b>1558</b>
/e/ [a]		<b>761</b>	<b>1542</b>
/o/ [a]		<b>814</b>	<b>1575</b>
/e/ [e]	129	749	1703
/o/ [o]	120	777	1380

While Liphola's measurements of elicited speech suggests that there is phonetic identity between reduced /e/→[a] and underlying /a/→[a], it would be surprising if all of the reduced vowels in (9) – particularly the vowel between reduced and unreduced pre-tonic vowels (e.g. the 2<sup>nd</sup> *a* in kú-pálávélélééla) – showed no phonetic trace of having been an underlying mid-vowel. Unfortunately, the phonetic measurements were only done on simple examples such as those in (6). Furthermore, no sociolinguistic, dialectal or discourse factors have been reported as the source for this variation. So, it is not clear whether the alternants (e.g. those in 9) are in free variation or whether the reduced or partially reduced forms are used in fast-speech, for example. As noted above, citation production in the elicitation experiment can yield a reduced form, so even a speech-style account would be incomplete

### 3.2.5. Variability and CORE

Despite the phonetic completeness of the neutralization, reduction is variable. Mid vowels reduced to *a* and unreduced mid vowels are in variation in pre-penultimate position:

#### (8) Vowel reduction<sup>1</sup>

	<u>Reduced</u>	<u>Unreduced</u>	
a)	kúpátáána	~ kúpétáána	'to sift each other'
b)	kú-pátáána	~ kú-pótáána	'to twist each other'

---

<sup>1</sup> The reduction documented for Simakonde (Manus, 2003) is slightly different and the rest of this section reflects the Shimakonde variety. In Simakonde reduction is obligatory for pre-tonic *e* while it does not apply to pre-tonic *o* (e.g. /-tend-/ kútándééla 'do something to someone' vs. /-tot-/ kútóteedya 'faire coudre' p.143). It is not clear that this generalization always holds, however: /-bom-/ kúbámóóka 'to be destroyed' (p. 168). Indeed, the reported data seems to reflect some freedom and variation similar to that reported in Shimakonde, though there is not enough data to assess the actual behavior.

Variation is neither all-or-nothing nor locally optional (e.g. Wilson & Riggle, 2004) in that it does not apply to either all or none of the reducible vowels (all-or-nothing) nor to each individual vowel independently (locally optional). Instead, reduction is governed by what Liphola (2001) refers to as ‘contiguity of reduction (CORE)’ which states that reduction begins at the left edge and proceeds rightward any number of vowels, so long as there are no gaps. For example, in the verb in (9), either none of the pre-penultimate mid vowels can be reduced (9a), all of the mid vowels may be reduced (9b) or one, two or three contiguous mid vowel may be reduced (9c), while unreduced mid vowels intervening between reduced vowels yields ungrammatical forms (9d).

(9) Contiguity of Reduction, in more detail

- a) /kú-pélévélél-íl-a/      kú-pélévéléleéla ~ (unreduced) ‘to not reach a full size for’
- b)                                      kú-páláváláleéla ~ (fully reduced)
- c)                                      kú-páláváléleéla ~ (partial reduction)
- kú-pálávéléleéla ~
- kú-pálévéléleéla
- d)                                      \*kú-péláváláleéla ~
- \*kú-páléváléleéla ~
- \*kú-péléváléleéla

**3.2.6. Reduction as post-lexical**

Evidence that reduction is post-lexical comes from a number of sources. First, reduction

applies across the board and is variable, qualities of traits of post-lexical phonology. Second, the process that defines the domain for reduction, penultimate syllable lengthening, is post-lexical (3). Thus, to assess what may be targeted by reduction, one must first determine the penultimate syllable of the whole intonational phrase, and not just the word. Finally, the minimal amount of data for the reduction of multi-word phrases bears this out:

(10) Post-lexical reduction:

a) /ku-telek-al-a malombe/      kutálákálá máloombe      ‘to cook maize for’

Additional data is needed including further examples similar to (10) as well as data on the reduction of coalesced mid vowels resulting from post-lexical coalescence.

### 3.2.7. Reduction: Positional Neutralization or Positional Licensing?

To this point, I have been informally referring to reduction as pre-tonic neutralization starting at the left edge, proceeding rightward. An alternate characterization of the data in (9) instead posits that mid vowels are licensed by the penultimate syllable and are optionally licensed in contiguous syllables leftward (Downing, 2006 following Walker, 2005). Thus, instead of Contiguity of Reduction, the principle at play could instead conceivably be Contiguity of Licensing (COOL). Thus, in the grammatical form *kúpá[lévéléleél]a*, (9b), the tonic has a mid vowel, as do the three contiguous syllable to its left. Mid vowels outside of this domain are not licensed, and are thus reduced to *a*. By this reasoning, *\*kúpálévá[léleé]la* is correctly ungrammatical: the domain licensed by the



Further counter-evidence comes from the irreducible nature of the final vowel (12). While these data fall out directly from describing reduction as applying contiguously from the left, stopped by the tonic syllable, a positional licensing account would have to stipulate a completely independent licensing domain for the final vowel (c). Therefore, the data in Shimakonde suggest that positional neutralization (Beckman, 1998) is the more appropriate description.

### **3.3. HARMONY**

Whereas the reduction process discussed above is rare, if not unique, among Bantu languages, Shimakonde exhibits what Hyman (1999) refers to as canonical Bantu vowel height harmony (VHH) which has the following characteristics:

#### (13) Canonical Bantu VHH

- a) Morphological:
  - i) Root controlled
  - ii) Targets derivational suffixes
  - iii) Does not affect prefixes
  - iv) Does not effect the final vowel
- b) Phonological
  - i) Mid-vowels (e, o) trigger harmony
  - ii) Closed vowels (i, u) subject to harmony
  - iii) Low vowel (a) opaque with respect to harmony
  - iv) Asymmetric wrt to front/round trigger (e does not trigger u→o).

In Shimakonde, when the last vowel in the verb stem is *i*, *u* or *a*, the suffixes' vowels surface as *i* but harmonizes to *e* when following a stem-final mid vowel:

(14) Basic Shimakonde vowel height harmony (VHH)

Applicative    Causative    Passive

a) High/low vowel root

kú-páát-a	kú-pat-ííl-a	ku-pat-iyy-a	ku-pat-igw-a	‘to get’
kú-píkíít-a	kú-píkíít-ííl-a	ku-pikit-iyy-a	ku-pikit-iyy-a	‘to play’
kú-púút-a	ku-put-ííl-a	ku-put-iyy-a	ku-put-iyy-a	‘to wash’

b) Mid vowel root

kú-téléék-a	kú-télék-éél-a	ku-telek-eeey-a	ku-telek-eeegw-a	‘to cook’
ku-tóót-a	ku-tot-éél-a	ku-tot-eeey-a	ku-tot-eeegw-a	‘to sew’

Also, VHH is iterative in that it doesn't simply apply to suffixes adjacent to the root, but spreads rightward until the final vowel:

(15) VHH iterative (unreduced forms):

- a) ku-peleveel-a            ‘to lose balance’
- b) ku-pelevel-eel-a        ‘to lose balance for’
- c) ku-pelevel-el-eel-a    ‘to well lose balance for’
- d) ku-pelevel-el-el-eeek-a ‘to cause to well lose balance for’

VHH is blocked from spreading to the right of a suffix with an *a* (16a) and when the mid-

vowel is not the final vowel of the stem (16b). There is also a single suffix – the perfective - that is immune to harmony (16c). Historically, the vowel in this suffix is derived from the Proto-Bantu degree on *\*j* which has since merged with degree two *\*i*. This particular suffix is immune to VHH in many other Bantu languages as well (e.g. Runyankore; Poletto, 1998: *a-rééb-ire*).

(16) Exceptions to VHH

- |    |               |                  |                         |
|----|---------------|------------------|-------------------------|
| a) | lek-an-ííla   | (*lek-an-ééla)   | ‘leave for each other’  |
| b) | kú-ténúk-ííla | (*kú-ténúk-ééla) | ‘to imbalance for’      |
| c) | va-pet-iil-e  | (*va-pet-eel-e)  | ‘when they have sifted’ |
|    | va-pínd-ííl-e |                  | ‘when they have bent’   |

Finally, Shimakonde also exhibits asymmetric harmony with respect to front and round mid vowels.

(17) Shimakonde front/round asymmetry:

- |    |               |                   |                      |
|----|---------------|-------------------|----------------------|
| a) | ku-shim-uuk-a | ‘to be closed’    |                      |
|    | ku-bom-ook-a  | ‘to be destroyed’ | (Manus, 2003 p. 168) |
|    | ku-pet-uuk-a  | *petooka          | ‘to be sifted’       |
| b) | ku-shim-iila  | ‘to close for’    |                      |
|    | ku-tot-eela   | ‘to sew for’      |                      |
|    | ku-pet-eela   | ‘to sift for’     |                      |

### 3.4. Vowel Coalescence

When two vowels come together without an intervening consonant, Shimakonde exhibits vowel fusion that is also found in most Bantu languages (e.g. Haya, Bemba, Punu, Runyankore; Downing, 1995; Casali, 1998; Poletto, 1998; Hyman, 2003). A number of different vowel combinations fuse to long vowels as shown in (20).

#### (18) Vowel Coalescence

- a) Low+Low → Low (repeated from (2))

/a+a/ → aa

akáát-a ‘move!’                      vandaákaata /va-nda-ákat-a/ ‘we will move’

- b) Low + mid → mid

/a+e/ → ee

eéka ‘laugh!’                      tundeéka /tu-nda-éka/ ‘we will laugh’

/a+o/ → oo

oóma ‘pierce!’                      tundoóma /tu-nda-óma/ ‘we will pierce’

- c) High + mid → mid

/a+i/ → ee

íípm ‘deny!’                      tundeéma /tu-nda-ím-a/ ‘we will deny’

/a+u/ → oo

uúnga ‘tie!’                      tundoónga /tu-nda-ung-a/ ‘we will tie’

The data in (b) show that *a* plus a mid vowel coalesce into a long mid vowel, while (c) show that *a* plus a high vowel similarly coalesce to a long mid-vowel. Liphola (2001)

demonstrates the phonetic identity of the examples in (b) and (c) with acoustic data and so this process is neutralizing in the sense that underlying contrasts are lost in the surface.

Finally, coalescence does not occur across word boundaries and is therefore not post-lexical; it does occur between prefix and verb-stem and is therefore word-level:

(19) Fusion as word-level

- |                       |  |                                    |
|-----------------------|--|------------------------------------|
| a) /kaleka u-lot-ile/ | kaléká <ul style="list-style-type: none">ulotiile</ul> | ‘If you want to...’ (Manus, p.202) |
|                       | * kalékoolotiile                                       |                                    |
| b) /ma-ina/           | méena  | ‘Names’                            |

When the initial vowel is high and the second vowel is low, fusion results in a glide+long vowel for both nouns (20a) and verbs (20b):

(20) Vowel fusion leading to glide formation:

- |               |          |            |
|---------------|----------|------------|
| a) /sagu-elo/ | ságwéelo | ‘bathroom’ |
| b) /ku-ak-a/  | kwááka   | ‘catch’    |
| /ku-imb-a/    | kwíimba  | ‘sing’     |

### 3.5. OPACITY

All three processes described above interact opaquely with each other. To summarize the interaction before going into detail: Reduction counter-bleeds VHH resulting in over-application of VHH, vowel coalescence counter-feeds VHH producing under-application of VHH and coalescence counter-feeds reduction producing under-application of

reduction.

### 3.5.1. VHH and Reduction: over-application

The opaque interaction of VHH and reduction is shown in (21). The vowel in the suffix harmonizes to *e* because of the mid vowel in the UR of the root, which is reduced to *a* in the SR.

(21) Opaque interaction

- a) /va-nda-tot-íl-a/      va-nda-tát-ééla      ‘they will sow for’  
b) /va-nda-šém-íla/      va-nda-šám-ééla      ‘they will call for’

In a rule-based approach, the two rules are in a counter-bleeding relationship:

(22) VHH-Reduction opacity as counter-bleeding

	/va-nda-šém-íl-a/		/va-nda-šém-íl-a/
Harmony	va-nda-šém-ééla	Reduction	va-nda-šám-ííl-a
Reduction	va-nda-šám-ééla	Harmony	n/a
	[va-nda-šám-ééla]		*[va-nda-šám-ííla]

Further evidence that harmony interacts with reduction comes from the feeding relationship between the two for different underlying representations where the high vowel of the causative suffix /idy/ surfaces with a reduced vowel.

(23) Examples of harmony feeding reduction

a) /kú-tót-ídy-an-a/ → kútótódyana → kútátádyana  
‘they cause each other to sew’

Reduction only applies to mid-vowels whereas in (23) it applies to what underlyingly is a high vowel. The high vowel suffix must therefore also be subject to the VHH triggered by the mid-vowel in the root.

The examples in (22) are cases of over-application opacity in that the VHH over-applies in the surface form because the trigger of harmony – the root’s mid-vowel – does not appear. Thus change of the suffix vowel from /i/ to [e] is an over-application of the process in question.

### 3.5.2. Reduction and Coalescence

As shown above, two different combinations of vowels coalesce into a long mid vowel and though the phonetic realization is the same, the two combinations interact differently with respect to reduction (and harmony; §3.5.3). Reduction can apply to a mid vowel that results from the coalescence of a low and mid-vowel:

(24) Transparent interaction of coalescence and reduction.

a) /va-nda-ék-an-a/      vandáákáána    ‘they will laugh each other’  
    /va-nda-ép-an-a/      vandáápaána    ‘they will harvest each other’  
b) /va-nda-ód-an-a/      vandaádaána    ‘they will follow each other’

Reduction of this sort and vowel coalescence are in a transparent mutually feeding relationship since *a+a* also fuses to long *a*. Mutually-feeding relationships can also be understood as a rule relationship where ordering doesn't matter:

(25) Rule ordering of coalescence and reduction:

	/va-nda-ek-an-a/		/va-nda-ek-an-a/
Coalescence	vandeekana	Reduction	va-nda-ak-an-a
Reduction	vandaakana	Coalescence	vandaakana
	[vandaákaána]		[vandaákaána]

The other interaction – of low+high vowel coalescence and reduction – is opaque, however, as mid vowels formed by the coalescence of a high and low vowel are resistant to reduction and stay mid:

(26) Non-reduction of mid vowels resulting from low+high vowels

a)	/va-nda-ím-an-a/	vandeémaána	*vandaámaána	‘they will deny each other’
	/va-nda-itík-a/	vandeétiika	*vandaátiika	‘they will respond’
b)	/va-nda-úkand-a/	vandoókaanda		‘the will wash’
	/va-nda-úkul-a/	vandoókuúla		‘they will dig’

Despite being in pre-tonic position where mid vowels are usually reduced to *a*, as in (6), the mid vowels formed by the fusion of *a* and *i/u* always surface as *ee/oo*. Coalescence

counter-feeds reduction since reduction does not affect high vowels (cf. *kúpítáána* ‘to pass each other’):

(27) Non-reduction of mid vowels resulting from low+high vowels

	/va-nda-ím-an-a/		/va-nda-ím-an-a/
Reduction	--	Coalescence	vandeémaána
Coalescence	vandeémaána	Reduction	vandaámaána
	[vandeémaána]		[*vandaámaána]

The surface forms, e.g. *vandeémaána*, exhibit under-application of reduction and the relationship can be construed as an opaque chain shift (§1.4). This chain shift presents a well-known problem for OT as shown below (§3.7; see also Kirchner, 1996).

(28) Reduction/coalescence opacity as chain shift

a) a+i → ee	b) ee → aa	c) a+i ↗ aa
A → B	B → C	A ↗ C

### 3.5.3. Coalescence and VHH

The final case of opacity results from the interaction of coalescence and VHH. As with the interaction of coalescence and reduction, the coalescence of low and mid vowels interacts transparently with VHH while the coalescence of low and high vowels yields an opaque relationship.

In the interaction of the coalescence of low+mid and VHH the resulting mid

vowel triggers VHH in the suffix: The coalesced mid vowel surfaces as *a* in (29a) because reduction also applies, while the mid vowel that results from the VHH can surface as mid because it is in tonic position. However, as noted above, reduction is variable and the unreduced form more clearly shows the VHH (29b).

(29) Interaction of low+mid coalescence and VHH:

- a) /vanda-ep-íla/            vandaápeéla ~ (reduced) ‘they will harvest for’
- b)                                vandeépeéla    (unreduced)

As rules, the two can apply simultaneously – there is no crucial rule ordering – feeding or otherwise – because of the VHH-triggering *e* in the UR stem:

(30) Transparent rule ordering of coalescence and VHH:

	/vanda-ep-íla/		/vanda-ep-íla/
a) Coalescence	vandeepila	b) VHH	vandaepela
VHH	vandeepela	Coalescence	vandeepela
(Reduction	vandaapela)	(Reduction	vandaapela)
	[vandaápeéla]		[vandaápeéla]

In direct contrast with the transparent interaction of low+mid vowel coalescence and VHH, the mid vowel that results from the coalescence of a low+high vowel does not trigger harmony as the suffix, normally susceptible to harmony, surfaces as high:

(31) Interaction of low+high coalescence and VHH:

- |                    |             |                     |
|--------------------|-------------|---------------------|
| a) /vandá-im-il-a/ | vandeemíila | ‘they will dig’     |
| /vandá-itík-a/     | vandeétiika | ‘they will respond’ |

(32) Opaque rule ordering of coalescence and VHH:

	/vandá-îm-íla/		/vandá-im-íla/
a) VHH	--	b) Coalescence	vandeepiila
Coalescence	vandeeiila	VHH	vandeepeela
	[vandeémíila]		[*vandéémeéla]

The contrast between the two types of opacity (also discussed in chapter one) involving reduction is particularly interesting because one is over-application opacity and the other is under-application. Also, the two cases of under-application opacity involving coalescence have perhaps a bit of counter-intuitive ramification: Long mid vowels that never reduce do **not** trigger harmony, while those that can reduce to *a* **always** trigger harmony.

### 3.5.4 Interim Summary

Examples of the opaque interactions are as follows:

(33) Opaque interaction in Shimakonde:

- |                       |                   |                       |                   |
|-----------------------|-------------------|-----------------------|-------------------|
| a) VHH + reduction:   | /va-nda-ŷem-il-a/ | vandaŷameela          | Over-application  |
| b) VHH + coal.:       | /va-nda-im-il-a/  | vandee <i>i</i> ila   | Under-application |
| c) coal. + reduction: | /va-nda-im-an-a/  | vandee <i>e</i> maana | Under-application |

The interactions are summarized in table 1 in terms of their extrinsic rule ordering:

Rule 1	Rule 2	Surface result	Rule interaction
<b>Opaque</b>			
VHH	Reduction	over	Counter-bleeding & Feeding
VHH	a+i coalescence	under	Counter-feeding
Reduction	a+i coalescence	under	Counter-feeding
<b>Transparent</b>			
VHH	a+e coalescence		Mutually-feeding
Reduction	a+e coalescence		Mutually-feeding

A common observation underlies all three opaque relationships, independent of the actual type of opacity involved. The observation is that whether a process applies or not is dictated by the UR, rather than the SR. Thus in (a), the realization of the affix as mid is dictated by the mid vowel in the UR of the stem. Similarly in (b), the realization of the affix as high is also dictated by the lack of a mid vowel in the UR of the stem. Finally, whether a vowel can reduce or not in (c) is also based on whether the vowel is mid in the input. A characterization of opacity in Shimakonde would capture ideally all three generalizations with the same formal mechanism.

### 3.5.6 The Inadequacy of Surface-based Approaches

The forms in (33) are problematic for any surface based approach to phonology because while the opaque forms motivate rejecting the generalization in question (the first of the two generalization listed in each pair), the transparent forms show that the generalization does hold and does reflect productive phonological knowledge.

The form in (33a) is problematic for any surface based approach because the mid vowel trigger of VHH is no longer present in the surface representation. So, while roots with an underlying and surface vowel of /a/~[a] transparently receive the *-il-* form of the

applicative suffix, the opaque form in (33a) with underlying /e/ and surface [a] takes the *el* form. Thus, contra OT, it is not the surface form of the verb that determines the realization of the suffixes, which are identical for (33a), rather it is the underlying form.

The OT formalism appropriately captures the difficulty that surface based approaches have with over-application through a constraint-ranking problem for the opaque surface form in (33a). As with all cases of over-application, the problem is one of harmonic bounding of the actual form by an ungrammatical transparent form. The constraint ranking for VHH requires HARMONY » FAITH and REDUCE » FAITH<sup>2</sup>, but the actual ranking is immaterial for this opacity because the SR *vandaǰámééla* incurs more faithfulness violations than the transparent, but ungrammatical, form *vandaǰámiíla* without improving the overall harmony<sup>3</sup> of the SR in any way. No conceivable ranking of constraints will result in *vandaǰámééla* being a better candidate than *vandaǰámiíla*. This constraint violation pattern does communicate the basic problem: In the surface form, with the VHH trigger reduced to *a*, there is no reason for the suffix to incur a faithfulness violation and surface with a mid-vowel:

(34) Opaque interaction in OT

/va-nda-shém-íla/	ID(HEIGHT) <sub>PENULT</sub>	HARMONY	REDUCE	ID(HEIGHT)
(a) ← va-nda-shám-eéla	* <sub>i</sub>			*
(b) ⊕ va-nda-shám-ííla				*
(c) va-nda-shém-eéla			*	

The transparent feeding interaction in (25a) proves to not be a problem for standard OT:

<sup>2</sup> The constraints HARMONY and REDUCE are used here temporarily, and are formalized in more detail below when an account of Shimakonde is presented.

<sup>3</sup> Harmony in the general OT sense, not in the VHH sense.

## (35) Transparent interaction in OT

/kú-tót-ídy-an-a/	REDUCE	HARMONY	ID(HEIGHT)
(a) →kútótádyana			*
(b) kútótídyana	*	*	
(c) kútótédyaana	*		*

The two other opaque relationships are instances of under-application and result in a ranking paradox only when juxtaposing the opaque and transparent forms. Reduction and harmony require some sort of rule or constraint ranking to drive the process. The transparent forms appropriately reflect the application of these processes in the surface form while cases of under-application violate the rule or constraint ranking and the process under-applies.

For example, all the transparent cases of reduction motivate a REDUCE » IDENT(HEIGHT) ranking – otherwise, reduction would never apply. In the opaque forms, however, the same constraint ranking would select the incorrect form:

## (36) OT:

/va-nda-ím-an-a/	ID(HEIGHT) <sub>STRESS</sub>	ONSET	REDUCE	ID(HEIGHT)
(a) vandaímaana		*!		
(b) ⊖vandeémaána			**	
(c) ←vandaámaána				*

So, in contrast with the previous instance of opacity where no constraint ranking possible could generate the correct output, it is only by comparison with existing transparent forms do the forms become opaque since the reverse ranking (of ID(HEIGHT) and REDUCE) would produce the correct opaque form, but the incorrect transparent form:

(37) Constraint ranking to yield opaque form w/ incorrect transparent form

Opaque a) /va-nda-ím-an-a/	FAITH <sub>STRESS</sub>	ONSET	ID(HEIGHT)	REDUCE
vandaímaana		*!		
→vandeémaána				**
vandaámaána			*	
Transparent b) /va-nda-ek-an-a/				
vandaekana		*!		
vandaakana			*!	
←vandeekana				**

Finally, the other case of under-application – coalescence and harmony – similarly reflects a ranking paradox between transparent and opaque forms. The unreduced forms are shown to facilitate exposition.

(38) Opaque constraint ranking

a)/va-nda-ím-il-a/	ONSET	HARMONY	ID(HEIGHT)
vandaímiila	*		
←vandeémiila		*	**
⊖ vandeemeela			***
b)/va-nda-ek-il-a/			
vandaেকেলা	*!		
vandeekaala		*!	**
→vandeেকেলা			**
c)/va-nda-pet-il-a			
→vandapeteela			*
vandapetiila		*	

Because of examples like (33a) where harmony is not true of surface forms, basic OT would be required to posit that the harmony process is not a productive generalization of the language. However, the example in (33c) and the productivity of the harmony process suggest otherwise.

### **3.6 SHIMAKONDE OPACITY AS DC**

In this section, I show that the above opaque relationships may be accounted for through the use of diagonal correspondence. The first two sub-sections articulate a formalization of DC harmony and reduction, while the last three account for each of the opaque relationships.

#### **3.6.1 Blocking with Agreement By Correspondence**

As discussed above, a crucial problem with previous approaches to harmony via agreement is the inability to account for harmony blocking in a language like Shimakonde, where a vowel sharing the same feature as the harmonic feature acts as a blocker of harmony. While ABC was originally described as being unable to support the blocking of agreement for any situation, this section shows that ABC can, in fact, account for blocking, including of the type found in Shimakonde (Inkelas, 2008; Rhodes, 2008).

The property of non-blocking for the ABC formalization of harmony is based on a global evaluation of correspondence and agreement: Nowhere in (10) is any sort of adjacency required and every segment in the string is evaluated with respect to every other. This leads to some curious pathologies which motivated Hansson (2006, 2007) to argue for globality of correspondence, but locality of agreement where agreement is evaluated only for adjacent corresponding segments. This reformulation can yield blocking.

The pathology he observes is similar to the one raised by Wilson (2003) and McCarthy (2005) of a majority rule effect wherein the number of segments changing dictates what type of harmony is found. For example, in a hypothetical language that has

left-to-right [anterior] agreement among all sibilants, agreement would be enforced by a ranking of CORR- $\check{C} \leftrightarrow Z$ , correspondence amongst all stridents, and ID[ANT]-C<sub>L</sub>C<sub>R</sub> above ID[ANT]-IO:

(39) Hypothetical sibilant agreement

/tʃ...s/	CORR- $\check{C} \leftrightarrow Z$	ID[ANT]-C <sub>L</sub> C <sub>R</sub>	ID[ANT]-IO
→ tʃ <sub>x</sub> ...ʃ <sub>x</sub>			*
tʃ <sub>x</sub> ...s <sub>y</sub>	*!		
tʃ <sub>x</sub> ...s <sub>x</sub>		*!	

If the language has a constraint against  $\mathfrak{z}$ , \* $\mathfrak{z}$ , then the behavior of a neutral  $z$  as either harmony-transparent or harmony-opaque is dependent on the number of faithfulness violations for sibilants to its right, which is based on their underlying form:

(40) Hypothetical sibilant agreement

/ʃ...z...S...S...S/	* $\mathfrak{z}$	CORR- $\check{C} \leftrightarrow Z$	ID[ANT]-C <sub>L</sub> C <sub>R</sub>	ID[ANT]-IO
ʃ <sub>x</sub> ...z <sub>y</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub>		*!***		
ʃ <sub>x</sub> ... $\mathfrak{z}$ <sub>x</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub>	*!			
→ʃ <sub>x</sub> ...z <sub>x</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub> ...ʃ <sub>x</sub>			****	?
→ʃ <sub>x</sub> ...z <sub>x</sub> ...s <sub>x</sub> ...s <sub>x</sub> ...s <sub>x</sub>			****	?

Compare, for example, the different surface forms that arise based on the underlying form of the rightmost sibilant. In this first case,  $z$  is harmony-opaque and blocks rightward spreading (the final sibilant is that target of [+anterior] spreading from the preceding  $s$ ), while in the second case, having a different number of underlying [-anterior] segments renders the  $z$  harmony-transparent:

(41) Hypothetical sibilant agreement

/ʃ...z...s...s...ʃ/	* <sub>3</sub>	CORR-Č↔Z	ID[ANT]-C <sub>L</sub> C <sub>R</sub>	ID[ANT]-IO
ʃ...z <sub>y</sub> ...ʃ...ʃ...ʃ		*!***		*
ʃ...z <sub>x</sub> ...ʃ...ʃ...ʃ	*!			
ʃ...z <sub>x</sub> ...ʃ...ʃ...ʃ			****	**!
→ʃ...z <sub>x</sub> ...s <sub>x</sub> ...s <sub>x</sub> ...ʃ			****	*

(42) Hypothetical sibilant agreement

/ʃ...z...s...ʃ...ʃ/	* <sub>3</sub>	CORR-Č↔Z	ID[ANT]-C <sub>L</sub> C <sub>R</sub>	ID[ANT]-IO
ʃ...z <sub>y</sub> ...ʃ...ʃ...ʃ		*!***		*
ʃ...z <sub>x</sub> ...ʃ...ʃ...ʃ	*!			
→ʃ...z <sub>x</sub> ...ʃ...ʃ...ʃ			****	*
ʃ...z <sub>x</sub> ...s <sub>x</sub> ...s <sub>x</sub> ...ʃ			****	**!

To remedy this, Hansson argues that Identity should be evaluated locally, with violations based only on adjacent corresponding segments. While this solves the above pathology by selecting (d), the *z*-blocking candidate, in both of the above cases, another curious blocking phenomenon, mentioned but not fully examined in Hansson (2007) is still possible with this formalization of harmony.

As Hansson (2007) points out, if another segments is more similar to the target than the trigger, then it can also block agreement. While the below example presents this type of blocking as being dependent on the sequence of segments, with [z] blocking the spreading of [anterior] rightward, no such linear relationship is required as shown in the second tableau:

(43) Hypothetical sibilant agreement

/tʃ...z...s/	* <sub>3</sub>	CORR-Š↔Z	CORR-Č↔Z	ID[ANT]-CC	ID[ANT]-IO
→tʃ <sub>x</sub> ...z <sub>y</sub> ...s <sub>y</sub>			**		
tʃ <sub>x</sub> ...z <sub>y</sub> ...ʃ <sub>x</sub>		*!	*		
tʃ <sub>x</sub> ...ʒ <sub>x</sub> ...ʃ <sub>x</sub>	*!			*	**
→tʃ <sub>x</sub> ...z <sub>y</sub> ...s <sub>x</sub>				*	

(44) Blocking sibilant agreement

/tʃ...s...z/	* <sub>3</sub>	CORR-Š↔Z	CORR-Č↔Z	ID[ANT]-CC	ID[ANT]-IO
→tʃ <sub>x</sub> ...s <sub>y</sub> ...z <sub>y</sub>			**		
tʃ <sub>x</sub> ...ʃ <sub>x</sub> ...z <sub>y</sub>		*!	*		
tʃ <sub>x</sub> ...ʃ <sub>x</sub> ...ʒ <sub>x</sub>	*!			*	**
→tʃ <sub>x</sub> ...s <sub>x</sub> ...z <sub>y</sub>				*	

If /z/ were not in the input, then the output would be [tʃ...ʃ] and so ABC, even as reformulated, makes the odd prediction that a non-intervening segment can block the agreement of adjacent segments. Local agreement does not ameliorate the problem; instead, local correspondence is required, which would fix both (84) and (82). Local correspondence establishes correspondence relationships among adjacent participating segments only, instead of agreement holding across all segments.

(45) Blocking via phonotactic constraint of sibilant agreement

/tʃ...z...s/	* <sub>3</sub>	CORR-Š↔Z	CORR-Č↔Z	ID[ANT]-CC	ID[ANT]-IO
tʃ <sub>x</sub> ...z <sub>y</sub> ...s <sub>y</sub>			*		
tʃ <sub>x</sub> ...z <sub>y</sub> ...ʃ <sub>x</sub>		*!	*		
tʃ <sub>x</sub> ...ʒ <sub>x</sub> ...ʃ <sub>x</sub>	*!			*	**
tʃ <sub>x</sub> ...z <sub>y</sub> ...s <sub>x</sub>		*!	*		
→tʃ <sub>x</sub> ...z <sub>x</sub> ...s <sub>x</sub>				**	

(46) Non-blocking of sibilant agreement by non-intervening phonotactic constraint

/tʃ...s...z/	* <sub>3</sub>	CORR-Š↔Z	CORR-Č↔Z	ID[ANT]-CC	ID[ANT]-IO
tʃ <sub>x</sub> ...s <sub>y</sub> ...z <sub>y</sub>			*!		
→tʃ <sub>x</sub> ...ʃ <sub>x</sub> ...z <sub>x</sub>				*	*
tʃ <sub>x</sub> ...ʃ <sub>x</sub> ...z <sub>x</sub>	*!				**
tʃ <sub>x</sub> ...s <sub>x</sub> ...z <sub>y</sub>		*!		*	
tʃ <sub>x</sub> ...ʃ <sub>x</sub> ...z <sub>y</sub>					

**3.6.2. Bantu harmony via correspondence theory**

So, we can now account for harmony-opaque *a* in languages like Shimakonde (when there is no reduction rendering harmony opaque). Establishing harmony among vowels requires a set of correspondence constraints based on similarity. Since Bantu VHH for 5-vowel systems is among [-low] vowels, the constraint enforcing correspondence among [-low] vowels, CORR-E↔I is ranked highest. Since [high] agreement holds among [-low] consonants, ID-VV[Hi] is ranked next, and since *a* blocks harmony, ID-IO is ranked after that (compare (g) to harmony-transparent (h)). Ranked below these are the remaining correspondence constraints in the family which establish correspondence among [-high] vowels (CORR-A↔E) and all vowels (CORR-A↔I) which are inactive in Shimakonde.

(47) Bantu 5-vowel harmony using Correspondence Theory

/pet-il/	CORR-E↔I	ID-D[Hi]	ID-IO[Hi]	CORR-A↔E	CORR-A↔I
a) →pe <sub>x</sub> t-e <sub>x</sub> l			*		
b) pe <sub>x</sub> t-i <sub>x</sub> l		*			
c) pe <sub>x</sub> t-i <sub>v</sub> l	*				

/pet-an-il/					
d) pe <sub>x</sub> t-a <sub>y</sub> n-i <sub>x</sub> l		*		*	*
e) pe <sub>x</sub> t-a <sub>y</sub> n-i <sub>y</sub> l		*		*	
f) pe <sub>x</sub> t-a <sub>x</sub> n-i <sub>x</sub> l		*			
g) →pe <sub>x</sub> t-a <sub>x</sub> n-i <sub>y</sub> l					*
h) pe <sub>x</sub> t-a <sub>x</sub> n-e <sub>x</sub> l			*		
i) pe <sub>x</sub> t-a <sub>y</sub> n-e <sub>x</sub> l			*	**	
j) pe <sub>x</sub> t-a <sub>y</sub> n-e <sub>y</sub> l				*	
k) pe <sub>x</sub> t-a <sub>x</sub> n-e <sub>y</sub> l				*	

Harmony in Shimakonde, in particular, the harmony-opaque *a*, can be thus accommodated by establishing a correspondence between adjacent [-low] vowels and requiring [high] identity among corresponding segments. This also formally realizes the striking similarity between AGREE and IDENT noted above without resorting to the complicated theoretical machinery needed by Krämer (2001) to get blocking and transparency including constraint conjunction and ad-hoc constraints like BALANCE. In both cases, though, in addition to correspondences among identical input and output elements, the two approaches add a syntagmatic correspondence relationship among segments in the same output string.

### 3.6.3. DC Harmony

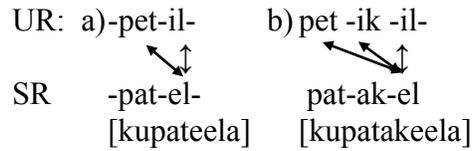
To account for opaque harmony with DC, the following DC constraint is necessary:

#### (48) Shimakonde Correspondence

- a) CORR-D-E<sub>STEM</sub>-I<sub>R</sub>: Let R be an input string of segments and S be an output string of segments and let X and Y be segments that are [+syllabic, -low] . If X ∈ R and Y ∈ S and both are members of the stem, then X is in diagonal correspondence with Y.

This constraint establishes the following correspondence relationships:

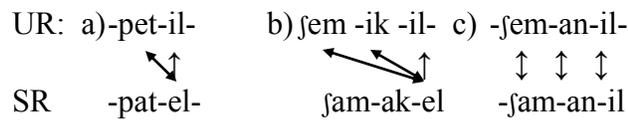
(49) Expanded correspondence in Shimakonde



Here, all of the [-low] vowels in the input and output macrostem are in correspondence with each other (diagonal correspondence also holds for the /-ik-/ suffix, but is not illustrated), so to account for harmony, all of the segments in correspondence can be made to agree with respect to the feature [-high].

These new correspondences are shown for the three crucial harmonic forms, which includes blocking (§2.2,5):

(50) Expanded correspondence in Shimakonde



In (a) and (b), all the [-low] vowels are in correspondence with each other, while in (c), the harmony-opaque low vowel is not in correspondence with the others because they don't share the low feature specification, and the [-low] vowels are not in correspondence because they are too far apart – they are not separated by just consonants.

Shimakonde harmony, and Bantu harmony in general, exhibits a number of asymmetries with respect to harmony that are all related to each other. First, [+high] does not spread, whereas [-high] does; second, spreading is left-to-right; third, affixes

harmonize to the root, but not vice-versa (i.e. the root doesn't harmonize to a prefix). These observations are all essentially the same one and cover the same empirical phenomenon. Expressing this asymmetry by positing [-high] spreads while [+high] does not would be stipulative and beg the question of why [-high] spreads given that for other features, the positive value spreads (e.g. nasalization; Walker, 2000). Expressing this asymmetry as being root-controlled (Clements, 1981), as argued in Bakovic (2000), accounts for all of the asymmetries as well as why only roots can be underlying mid but requires positing two separate domains, a stem including the root + suffixes, and a word consisting of prefixes + stem. With this assumption, [-low] vowels can then be made to agree with respect to [high].

#### **3.6.4. Reduction**

In this section I present an account for mid vowel reduction in Shimakonde. Reduction to the low vowel *a*, in lieu of a high or mid vowel may seem odd at first blush. Indeed, Lindblom (1990) argued that reduction was motivated phonetically by the minimization of articulatory effort or not being able to reach extreme articulatory targets during the short duration of a shortened vowel. So, many cases of vowel reduction change vowels to a high, mid or central vowel (e.g. Russian, Kenman 1975; Catalan, Mascaró 1978; Italian; English). However, Crosswhite (2003) highlights an entirely different type of vowel reduction that serves to enhance contrast, limiting perceptually challenging vowels to prominent positions. Whereas the former is typical of languages that shorten unstressed syllables, like English, the latter is typical of languages with length-based correlates of stress that do not shorten unstressed syllables, a typological category in which

Shimakonde squarely falls. Languages of this type favor corner vowels – *i*, *u*, and *a* – in unstressed position. In these systems, non-peripheral vowels typically neutralize to the most perceptually salient, sonorous vowel, *a*, which increases articulatory effort and presents a more extreme articulatory target in direct contrast with the other type of reduction. Shimakonde exhibits precisely this perceptual salience-based pattern of reduction with mid vowels neutralizing to the more perceptually salient *a*.

Another analysis (Barnes, 2002; Downing, 2006), presented in further detail in §3.8 as it has a bearing on the analysis of opacity, is based on an element-theory of the vowel system wherein *e* and *o* are complex vowels combining two elements (*a+i* and *a+u*, respectively) and reduction involves simplifying vowels to a single element. The *a* element represents the aperture node and *i* and *u* represent vowel place and so there are only two heights and reduction represents a loss of color for the open vowels *e*, *a*, *o* (i.e. those that include the *a* element).

In either case, the data for Shimakonde variation, in particular CORE, prove challenging for current OT accounts of variation and optionality. Anttila (1997), Kiparsky (1993), Boersma & Hayes (2001) and Cotzee (2008) all argue that phonological variation is best accounted for with variable constraint ranking. For example, for English *t/d* deletion (Guy, 1994), *cost* may be the most optimal output with MAX » \*CMPLXCODA while its variant, *cos* reflects \*CMPLXCODA » MAX. In Shimakonde this approach does not work.

For Shimakonde, suppose there is some markedness constraint banning mid vowels in penultimate position. The variable constraint ranking approach would posit that this is variably ranked with respect to a faithfulness constraint maintaining the quality of mid

vowels (ID[LOW]). While this variable alternation between M»F and F»M could account for the variation between full and no reduction (e.g. *kútálákaána* ~ *kútélékaána*) there is no reasonable constraint re-ranking that could generate the partially reduced forms (e.g. *kútélékaána*) (see tableau in 42). This is because each faithfulness violation – each reduction of a pre-tonic mid vowel to *a* - incurs an identical violation of ID(LOW). This is a problem for any type of variation involving more than two variants with a different number of identical faithfulness violations.<sup>4</sup>

(51) Correct evaluation of the opaque form

/ku-telek-an-a/	*[-LOW]/PRE-PENULT	ID(LOW)
(a)→kutelékaána	**	
(b)→kotalákaána		**
(c) ? kotalékaána	*	*

To account for reduction, recall that the generalization for reduction is that it neutralizes mid and low vowels to low in contiguous syllables starting at the left word edge up until the tonic. The difference between mid and low vowels is the specification of [low], and so reduction involves the substitution of [-LOW] with [+LOW] in the relevant domain. The domain of reduction, abbreviated here as  $\delta$ , is anchored at the left edge using an undominated alignment constraints, Align (Reduction Domain, edge-L, Wd, edge-L) or ALIGN-L(RED, WD). If the alignment of the right edge of the reduction domain with the tonic were ranked above or below only ID(LOW), then the only variants would be

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<sup>4</sup> A solution using Harmonic Grammar (Smolensky & Legendre, 2006) may also be possible with cumulative violations of a weighted faithfulness constraint outranking markedness when enough violations accrue.

complete or no reduction. However, if there are multiple faithfulness constraints for each syllable in a fixed ranking based on its distance from the penult, then, the ranking of ALIGN-R(RED) with respect to this hierarchy would specify which syllables are in the domain of reduction and those that are outside the domain of reduction, abbreviated here as  $\bar{\sigma}$ .

(52) Family of faithfulness constraints to account for CORE:

- a)  $ID(LOW)/\sigma_{penult} \gg ID(LOW)/\sigma_{penult-1} \gg ID(LOW)/\sigma_{penult-2} \text{ etc...}$

I use  $*[-LOW]/\bar{\sigma}$  and  $ID(LO)/\bar{\sigma}$  as shorthand for this approach to reduction.

### 3.6.5. Harmony & Reduction Opacity

Having established the constraint for reduction and opaque harmony, the evaluation tableaux for the three forms in (33) are shown in (44)-(46).

First, all *e*'s and *i*'s on the input and output are in correspondence and the [high] specification is shared by all segment in correspondence:

(53) Correct evaluation of the opaque form

$pe_x t-i_x l-$	$ID(LO)/\bar{\sigma}$	$*[-LOW]/\bar{\sigma}$	$CORRD-E \leftrightarrow I$	$ID(HI)-D$	$ID-IO(HI)$
$\rightarrow patee_x l$					*
$pe_x tee_x l$		*!			
$pa_x tii_x l$				*!	
$pa_x taa_x l$	*!				
$pa_x tii_y l$			*!		

Regardless of the number of affixes, the correspondence relationship holds for vowels

outside of the domain of reduction producing the mid vowel allomorph. This also accommodates the feeding relationship between VHH and reduction: underlying *-ik-* surfaces as *-ak-* when it is preceded by a root mid vowel and in the domain of reduction (e.g. ex. 23).

This is a crucial example for an input-based approach because of the existence of the intermediate form *-ek-* in the rule-based derivation of this form. Input-output constraints have problems with intermediate forms which lead to the rejection of two-level constraint (McCarthy, 1996). The difference here is that the input-output constraint is a faithfulness constraint so that it can still be dominated by a markedness constraint (here  $*[-LOW]/\text{ø}$ ) yielding a feeding relationship and the intermediary form. Further discussion of input-output constraints, is in chapter two.

(54) Correct evaluation of the opaque form with harmony-transparent vowels

$-\text{she}_x\text{m}-\text{i}_x\text{k}-\text{i}_x\text{l}-$	ID(LO)/ $\bar{\text{o}}$	$*[-LOW]/\text{ø}$	CORRD-E $\leftrightarrow$ I	ID-D(HI)	ID-IO(HI)
$\rightarrow\text{shamakee}_x\text{l}$					*
$\text{she}_x\text{mi}_x\text{ki}_x\text{l}$		*!			
$\text{she}_x\text{mi}_x\text{ki}_x\text{l}$				*!	
$\text{she}_x\text{mi}_x\text{ki}_x\text{l}$	*!				
$\text{shame}_x\text{kee}_x\text{l}$		*!			

This also selects the correct candidate for the form that is problematic for the positional licensing account, where an *a* is in tonic position:

(55) Correct evaluation of the opaque form with harmony-transparent vowels

-she <sub>x</sub> m-i <sub>x</sub> k-a <sub>x</sub> n-	ID(LO)/σ	*[-LOW]/σ	CORRD-E↔I	ID-D(Hi)	ID-IO(Hi)
→[sha] <sub>σ</sub> [me <sub>x</sub> kaa <sub>x</sub> l] <sub>σ</sub>					*
shami <sub>x</sub> kaa <sub>x</sub> l		*!		*	
shame <sub>x</sub> kee <sub>x</sub> l	*!			*!	

Finally, *a* blocks correspondence among vowels to its right yielding the correct candidate with blocking:

(56) Correct evaluation of the opaque form with harmony-opaque vowels

/pe <sub>x</sub> t-a <sub>x</sub> n-i <sub>v</sub> l/	CORRD-E↔I	ID-D(Hi)	ID-IO(Hi)	CORR-A↔E	CORR-A↔I
→pa <sub>x</sub> ta <sub>x</sub> nii <sub>v</sub> la					*
pa <sub>x</sub> ta <sub>x</sub> nee <sub>x</sub> la			*!		
pa <sub>x</sub> ta <sub>x</sub> naa <sub>v</sub> la			*!		
pa <sub>x</sub> ta <sub>x</sub> nii <sub>v</sub> la					
pa <sub>x</sub> ta <sub>x</sub> nii <sub>v</sub> la	*!				

### 3.6.6. Coalescence & Harmony

The same idea applies to the opaque interaction of coalescence and harmony: The surface suffix vowels are in correspondence with the underlying root vowel. In the case of *a + e* coalescence, the suffix vowels, which are in correspondence with the underlying *e* must agree with it with respect to the feature [high] and so they surface as *e*. With *a + i* coalescence, the suffix vowels agree with the underlying *i* with respect to the feature [high] and so they surface as *i*. Crucially, the constraint enforcing identity between vowels that are in syntagmatic correspondence (S-IDENT in Krämer 2001; AGREE in Bakovic, 2001; ID-CC in Rose & Walker, 2004; ID-S here to maintain symmetry with ID-IO and ID-D), as opposed to diagonal correspondence, is low ranked. Therefore, VHH is not surface true. This is shown in the following tableaux:

(57) Transparent interaction of  $a+e$  coalescence as input-driven

/-nda-e <sub>x</sub> p-i <sub>x</sub> l-/	CORRD-E $\leftrightarrow$ I	ID(HI)-D	ID-IO(HI)	ID-S(HI)
$\rightarrow$ ndee <sub>x</sub> pee <sub>x</sub> l			*	
ndee <sub>x</sub> p <i>ii</i> <sub>x</sub> l		*!		
ndee <sub>x</sub> p <i>ii</i> <sub>y</sub> l	*	*!		

(58) Opaque interaction of  $a+i$  coalescence using Diagonal Correspondence

/-nda-i <sub>x</sub> m-i <sub>x</sub> l-/	CORRD-E $\leftrightarrow$ I	ID(HI)-D	ID-IO(HI)	ID-S(HI)
$\rightarrow$ ndee <sub>x</sub> m <i>ii</i> <sub>x</sub> l				*
ndee <sub>x</sub> m <i>ee</i> <sub>x</sub> l		*	*	
ndee <sub>x</sub> p <i>ii</i> <sub>y</sub> l	*			

### 3.6.7. Coalescence and Reduction

The opaque interaction of coalescence and reduction does not involve harmony and as such is not directly related to the discussion above with respect to diagonal correspondence. A number of solutions are possible, however – the solution presented here is to have two different types of mid vowels based on the fusion of the different input vowel features.

When  $a+i$  fuse, the resulting feature set is [+low & +high, -low] and reduction deletes the [-low], which normally results in a reduced [+low] vowel. However, the remaining [+high] (recall that  $i$  and  $u$  do not reduce) yields an invalid combination of features [+high, +low]. Despite the illegality of this feature combination, it can be said to be resolved or articulated as an aggregate of the two features; as an  $e$  (Gnanadesikan, 1997). This approach captures the essence of the element based approach since it posits two different  $e$ 's, a normal [-high, -low] which is the result of  $a+e$  fusion, and a [+high, +low]  $e$ , which is the result of  $a+i$  fusion and is irreducible since it is already [+low] and

reduction has no impact on [+high] vowels.

On the other hand, for *a+e* coalescence, the deletion of [-low] leaves [-high, +low], or *a*.

(59) Feature resolution yielding different results with respect to reduction

	<u>Fusion</u>		<u>Reduction</u>		<u>Result</u>
a)	a+i	+low / +high, -low	➔	*-low	➔ +high, +low
b)	a+e	+low / -high, -low	➔	*-low	➔ -high, +low

### 3.7. ALTERNATE APPROACHES

In this section, I briefly discuss a number of alternate approaches to Shimakonde opacity.

#### 3.7.1. Morpheme selection

Some recent approaches to opacity suggest that opaque relationships are not productive as phonological processes and are only the result of allomorph selection (Sanders, 2003; Yip, 2003; Lee, 2004). This would suggest that the underlying form of the root selects the appropriate allomorph; in a form like *ku-fam-eela*, *-el-* is the applicative allomorph selected by the root *fem* while harmony would not be a productive phonological process in the language per se as it is violated in surface forms.

This has the unfortunately consequence of losing a generalization of the language from the main locus of phonological generalizations in the grammar (the constraint ranking in OT) and placing it into a different component – allomorph selection. Whereas some cases of allomorphy, in particular suppletive allomorphy, warrant an independent

allomorph selection process (Paster, 2006) doing so for all cases of allomorphy would miss the powerfully productive generalization that allomorphy is often driven by the phonotactics of a language. If one were to split the difference and argue that some cases of allomorphy are phonotactically driven and therefore part of the phonological grammar, while others are phonotactically arbitrary, the question becomes which type of allomorphy is exhibited by Shimakonde. Because the allomorphy in Shimakonde is ultimately a cross-linguistically common alternation and phonetically natural, ideally it should be captured in a phonological grammar.

Second, while this approach works for the selection of a single allomorph, it is problematic for cases like Shimakonde that exhibit feature spreading across a number of suffixes, which can also be blocked. Given the forms in (50), allomorph selection can logically proceed one of two ways for selecting the appropriate allomorph for the final applicative suffix.

(60) Allomorph selection:

- a) /va-nda-shem-ik-il-a/ vandashamakeela
- b) /va-nda-shem-an-il-a/ vandashamaniila

One option is that it can be selected by the verb root /-*fem*-/ which would produce the incorrect form for (50b) since /-*fem*-/ would select the *el* allomorph because of the mid vowel in the stem. This would be incorrect because the *-an-* suffix should block VHH. Alternatively, the adjacent morpheme can choose the appropriate allomorph so the realization of the applicative in (50b) would correctly be *il* because of the adjacent, non-

mid *an* suffix. This ends up being problematic for (50a) however, since the adjacent suffix to the applicative is *ik*, a non mid, which should select the *il* as the allomorph for the applicative.

This empirical shortcoming highlights the more general problem with this approach. It eschews using the phonological grammar for a lexically-driven sub-categorization approach. Doing so prevents the grammar from taking advantage of the representations and constraints that are part of the Phonology and necessary to account for a complex process like harmony that has harmony-transparent and harmony-opaque segments.

Finally, accounting for the opacity involving coalescence and reduction using morpheme selection would involve the counter-intuitive ungrounded requirement that *e*-initial verbs would select the reduced *a*-final allomorph for a prefix like *nda* over the *e* final variant that *i* selects (/ -nda-ep- / → [-nda-ap-] vs. / -nda-im- / → [-nde-em-]).

### 3.7.2. Strata

An alternate approach involves the use of strata, or levels. This could work for reduction and harmony as harmony applies at the stem level, and reduction at the post-lexical level. Crucially, this level-based approach cannot deal with the coalescence/harmony opacity and the harmony/reduction opacity that serve as the primary motivation for Diagonal Correspondence. If, reduction applies at the stem level, then this should bleed harmony if the interaction is evaluated transparently. This is not the case, however, as seen in a surface form like *ku-pat-eela*; instead, harmony counter-bleeds reduction at the stem level – an opaque relationship that requires an input-based solution.

(61) Incompatibility of a level-based approach with

a)	/vanda-ep-il-a/	b)	/ku-pet-il-a/
Stem:	ep-il-a		pet-il-a
Reduction	ap-il-a		pat-il-a
Harmony	--		--
Word:	vanda-ap-il-a		ku-pat-il-a
[...]			
Output:	*[vandaapiila]		*[kupatiila]

### 3.7.2 Element-based approach

The facts of Bantu VHH, coalescence, and reduction potentially possibly motivate an alternate representation to the traditional high/low feature proposal to better account for the patterning of the data. The problems with the featural account, summarized in Downing (2006), and noted independently elsewhere (Goldsmith, 1985; Harris, 1994, 1997; Hyman, 1999; Steriade, 1995; Cassali, 1998) are three-fold.

First, the vowel system reflects an opposition between mid vowels (*e, o*) and peripheral vowels (*i, u, a*) with the mid vowels being marked and the peripheral vowels unmarked. However, this does not correspond to a featural distinction in the traditional high/low system which suggests that *i, u* [+high], *a, e, o* [-high], *a* [+low] and *i, u, e, o* [-low] are natural classes. Instead, the peripheral vowels *a, i* and *u* that behave the same with respect to being immune to harmony share no common feature in opposition to the undergoer of harmony, mid [-low, -high] vowels. This problem is manifested in attempting to formalize harmony as the agreement or spreading of [-high] since *a*, which is harmony-opaque, is also [-high].

Second, coalescence is problematic for a traditional vowel representation. Liphola (2001) accounts for the resolution of features in both cases of coalescence by assuming that the mid vowels *e/o* are [-high, -low], high vowels *i/u* are [+high, -low] and the low

vowel *a* is [-high, +low]. Therefore, *a* and *i/u* coalesce into a mid vowel by contributing [-high] and [-low], respectively, while *a* and *e/o* coalesce into a mid-vowel by contributing [-low] and [-high], respectively. This begs the question of why *a* never contributes [+back] in its coalescence with *e* yielding [+back, -high, -low] in any languages and why *a* contributes a different feature to the coalesced vowel for each case.

Finally, the traditional feature system does not explain why reduction results in an [a] rather than an [i]. As discussed above, Shimakonde represents a type of reduction that eliminates complex or perceptually difficult vowels in non-prominent position. A constraint against mid vowels would be equally well accommodated by reducing them to [i], (which also reduces articulatory effort) as by the observed pattern of reducing to [a], yet this is never the case.

Harris and Lindsey (1995, 2000) propose an alternate element-based theory of vowels, which is rooted in the idea that vowels are made of combinations of privative elements, one of which is a head (heads are necessary for Shimakonde). For the five-vowel Bantu system, the elements are A, I and U which combine in the following way (with heads underlined). This representation better captures Crosswhite's generalization that mid vowels reduce because they are perceptibly more complex: mid vowels are representationally more complex (made up of two elements) and are therefore reduced, while the peripheral vowels form a natural class with respect to harmony and share the property of being simplex and having no dependents.

(62) Bantu five-vowel system – element theory

- a = [A]
- i = [I]
- u = [U]
- e = [A, I]
- o = [A, U]

Harmony, then, is the result of dependent elements spreading producing the mid vowel harmony (and never high or low) found in Bantu (54).

(63) Bantu harmony using the element theory of vowels

A /-e...i-/ I I	MAX(A)	SPREAD	ID(A)
(a) A   \\ →-e...e- I I			*
(b) -i...i-	*		
(c) -e...i-		*	

Downing (2006) also argues that using this representation for vowels can explain the opacity involving coalescence and harmony. Coalescence yields the surface representations in (55) and ranking the faithfulness of dependent elements above the faithfulness of heads deletes the redundant A-head.

(64) Coalescence using element theory

a) a+i:  $/[\underline{A}] + [\underline{I}]/ \rightarrow [\underline{A}, \underline{I}]$

b) a+e:  $/[\underline{A}] + [A, \underline{I}]/ \rightarrow [A, \underline{I}]$

The opposite ranking, with A as a head, proves problematic for vowel harmony, below.

This ranking of dependent faithfulness over head faithfulness accounts for why vowels are reduced to [a]. If, following Crosswhite, complex vowels are only licensed in prominent position, with complex vowels eliminated in pre-tonic position, then the ranking of dependent faith over head faith results in reduction as being the deletion of heads. So underlying *e* [A, I] and *o* [A, U] reduce to [A] yielding *a*.

This nicely accounts for the opaque interaction of coalescence with harmony. The opacity is due to the fact that (55a) has no dependent element to spread whereas (55b) does because the head-A deletes when in the same vowel as a dependent A:

(65) VHH with a+e coalescence, but not a+i

a)  $\begin{array}{ccc} \underline{A} & \underline{I} & \underline{I} \\ | & | & | \\ \text{nda-im-il-a} & \rightarrow & \text{ndeemiila} \end{array}$

b)  $\begin{array}{ccc} \underline{A} & \underline{I} & \underline{I} \\ | & | & | \\ \text{nda-em-il-a} & \rightarrow & \text{ndeemeela} \\ | & & \backslash / \\ \text{A} & & \text{A} \end{array}$

This does not account for the opaque interaction between coalescence and reduction, however. As shown above, the coalescence of *a + i* is not subject to reduction. However, the deletion of heads should allow (37a) to reduce to either simplex [A] or simplex [I]

yielding *a* or *i* as the reduced surface form of *a + i* coalescence. Furthermore, Downing (2006) suggests that the opaque interaction between reduction and harmony be accounted for with constraint conjunction – essentially claiming the element-based account is insufficient alone.

Finally, whereas the element theory posits that underlying vowels – both simplex and complex - have heads, the account here results in headless surface vowels. It is not clear whether this asymmetric constraint on underlying vs. surface vowel representation represents a fundamental flaw in the approach or whether the violability of constraints would accommodate this representation. This seems unlikely because if having a head is based on the ranking of a constraint, then richness of the base dictates that un-headed vowels should be included in the candidate set.

So, while changing representations can account for one of the opaque interactions in Shimakonde, it incorrectly predicts the behavior of the other, and resorts to an external theoretical enhancement for the third.

Before concluding the discussion of an element-based account of Shimakonde opacity, it is worth reflecting on what broader generalization is captured by accounting for one of the opaque relationships with this alternate vowel representation. Using the representations in (55) endeavors to explain the disparate VHH behavior of coalesced vowels by positing two different representations for vowels that have the same surface realization – one has two heads, while the other has one.

This essentially accounts for opacity using abstract underlying representations, as done in Dresher (1981) for Latin American Spanish, or Archangeli & Pulleyblank (1994) for Barrow Inupiaq. However, instead of appealing to diachrony to motivate different

underlying forms that neutralize in their surface realization as Drescher does, the two different representations are based on their synchronic source. In other words, this approach says that there are two kinds of surface *ee* vowels, one derived from underlying *i + a* and another derived from *i + e*, which is encoded in their abstract representations by one having two heads and the other having one. This property, which has no phonetic correlate, determines the coalesced vowel's ultimate behavior with respect to harmony (but incorrectly for reduction). That the same surface representation behaves differently depending on the underlying form it was derived from is one of the basic ideas in the solution proposed below. However, instead of adding an abstract, phonetically unrealized component to the representation, this effect is accomplished more directly and in the grammar itself through constraints that make direct reference to the underlying form.

Ultimately, there are compelling reasons to use an element-based approach for Bantu vowel systems. It better captures the natural classes of the vowels with respect to harmony and more closely corresponds to Crosswhite's generalization with respect to reduction. However, there is enough counter-evidence to suggest that this approach is neutral or even less adequate than the traditional feature-based approach. The theory of Shimakonde opacity I advance above in some ways operates independently of the representation chosen; as such, the feature-based approach is used throughout. An element-based representation can be substituted without impacting the general insight.

### **3.8. CONCLUSION**

In this chapter, I showed how the three opaque relationships in Shimakonde – in particular, those involving harmony – were amenable to a solution via DCT. Delving into

detail also highlighted a number of other interesting phenomena.

Reduction in Shimakonde presents a challenge for current theories of variation and requires aligning a domain of reduction with a gradient faithfulness domains emanating from the penultimate syllable. This is in lieu of establishing a licensing domain.

Also, DCT generates the appropriate forms for Shimakonde despite the existence of a feeding relationship and an intermediate form. This is due to the fact the harmony is established with faithfulness constraints, rather than markedness constraints, which would not be able to accommodate the counter-bleeding/feeding relationship in Shimakonde.

Not only does this approach intuitively capture the linguistic generalization involved in Shimakonde, it also avoids the problems the data present for other approaches to opacity. First, the process of vowel reduction is subject to variation – variation between opaque and transparent forms – and applies across the board. The variable nature of this process suggests that it is post-lexical, or late, (Kiparsky, 1985; cf. Guy, 1991) as does its application across multiple words. This presents a challenge for any account of opacity based on multiple tiers of evaluation corresponding to particular domains of process application (Bermudez-Ortero, 1998; Kiparsky, 2000). Since one of the cases of opacity requires that reduction happen “before” coalescence, this necessitates multiple tiers for one single domain – the post-lexical domain – contra a fundamental assumption of stratal OT.

Second, vowel harmony is fully productive and can extend to any number of affixes, as is typical of harmony. This fact is problematic for accounts that suggest that

opaque generalizations are not productive and are only found in stored lexical representations. The fact that harmony targets any number of suffixes is also problematic for approaches of opacity based on morpheme-selection (Sanders, 2003; Lee, 2004). Any account of this sort would require an iterative, or cyclic, process of morpheme selection interleaved with processes of reduction. This abandons OT's principle of parallel evaluation.

Finally, the three cases of opacity are substantively different - two are instances of under-application and the other is a case of over-application. This presents a problem for any account of opacity that can explain one or the other or that treats the different types of opacity as theoretically distinct (e.g. Candidate Chain OT, McCarthy, 2007; Comparative Markedness, McCarthy, 2003). In contrast with a patchwork approach to understanding Shimakonde opacity, I show that all three cases can be explained using the same input-based generalization. The upshot is that the phonology of Shimakonde consists of two types of phonological processes: phontactics-based surface optimization paired with morphophonological input-output mapping. Whereas recent approaches to phonology focus on the former and the ability of the former to account for the latter (e.g. OT), phontactics does not always overlap with morphophonology; Diagonal Correspondence fills this empirical gap with respect to opacity.

## CHAPTER 4

### OPACITY AND ABSTRACTION

#### 4.1. INTRODUCTION

Phonological opacity presents two related challenges for the language learner. First, the learner must be able to recognize phonotactic generalizations that are not always true of the surface forms (SRs) they hear. Second, for some of the theoretical proposals forwarded to account for opacity, including Diagonal Correspondence Theory (chapter 2), the learner must be able to abstract underlying representations distinct from any heard tokens of a given morpheme.

Consider, for example, the following forms in a dialect of Canadian English:

#### (1) English opacity

##### Voiceless

- |    |              |        |    |                    |          |
|----|--------------|--------|----|--------------------|----------|
| a. | <i>write</i> | [rɔɪt] | c. | <i>writer</i>      | [rɔɪɾər] |
|    |              |        |    | <i>mitre/miter</i> | [mɔɪɾər] |

##### Voiced

- |    |             |        |    |              |                       |
|----|-------------|--------|----|--------------|-----------------------|
| b. | <i>ride</i> | [raɪd] | d. | <i>rider</i> | [raɪɾər]              |
|    |             |        |    | <i>cider</i> | [saɪɾər] <sup>1</sup> |

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<sup>1</sup> This example is not cited in any of the literature as *power* is usually cited as the example of a monomorphemic word without diphthong raising before an underlying voiced consonant. I use *cider* because it reflects a more appropriate minimally different example from *rider* and *miter*. This pronunciation was validated by a speaker of Canadian English.

The crucial generalization here, attributed to Joos (1942) and cited frequently (Chomsky, 1964; SPE; Kenstowicz, 1994; Hayes, 1999; Bermudez-Otero, 2003; Mielke et al., 2003) is that vowel diphthongs are raised before voiceless obstruents. This generalization is opaque, or obscured, in the forms in (c) because the /t/s are flapped and are no longer voiceless obstruents, yet the surface forms still reflect diphthong raising. The language learner therefore has two tasks. First, she must recognize that, despite the existence of raised diphthongs before a segment that is not a voiceless obstruent (the flap), this generalization is true based on the underlying form of the flaps. Second, the learner may use this knowledge to abstract the appropriate underlying representation (UR) for the flaps in (c) and (d) as /t/ and /d/, respectively.

As discussed in chapter two, there are a number of theoretical proposals for incorporating these types of data into a phonological grammar of English. These proposals have different answers as to how these two challenges for the learner are addressed. The theoretical proposals can be grouped into three general strategies:

First, it is possible to deny the existence of opaque interactions in a synchronic phonology (Hooper [Bybee], 1976; Sanders, 2003; Mielke et al., 2003) and posit that Joos's generalization is not productive. Thus, the only generalization for Canadian English would be that unraised diphthongs are prohibited before voiceless obstruents, and otherwise the patterning of the diphthongs in *cider* and *miter* would be morphemic – the two words would be minimal pairs with respect to the vowel. The vowel allophony would therefore be independent of the UR of the flap. This would suggest that the learner does not need to abstract an underlying form or learn a generalization that is not always surface true.

A second class of approaches incorporates serialism into the grammar so that diphthong raising occurs before flapping (SPE; Kiparsky, 1973, 1993, 2000; Bermudez-Otero, 1998; McCarthy, 2007). This would suggest that learners require an ability to “undo” flapping to abstract underlying forms. The diphthong raising generalization would be unaffected by the appearance of opaque examples since it holds at a different level or stratum of grammar where it is always true.

Third, the relationship between diphthong raising and voiceless obstruents can be expressed by some substantive connection between UR and SR. This can include reference to a third form in deriving an SR from a UR (Sympathy Theory, McCarthy, 1998; OO-Correspondence, Benua, 1996) or some reformulation of the relationship between input and output (Constraint Conjunction, Ito & Mester, 1993; Cognitive Phonology, Goldsmith, 1993; Lakoff, 1993; Diagonal Correspondence Theory (DCT), chapter 2) specific to opacity. These approaches require that learners derive abstract representations of SRs; DCT in particular requires that learners derive URs that are potentially distinct from any heard tokens of the SR. This approach allows for some affect of opaque examples on the strength of a generalization since a surface-true transparent generalization is expressed with a different theoretical construct – either rule or constraint than the opaque generalization.

The psychological reality of these three approaches can be assessed by testing learners’ ability to learn opaque interactions and by observing whether they can derive abstract underlying forms and learn a generalization that is not always surface true. In the remaining portion of this chapter, I establish the background for a set of experiments presented in chapter five exploring these abilities.

I begin by discussing the role of URs in phonology and how recent approaches to phonology have sought to limit their importance by eliminating the difference between URs and SRs. I then show how phonological opacity presents a particular problem for approaches that seek to eliminate abstract URs. Then I revisit the challenges opaque interactions present for the language learner discussed above, focusing in particular, on how opaque interactions necessitate acquiring abstract URs. Finally, I review previous experimental work on the productivity of opaque interactions.

#### **4.2. ABSTRACT UNDERLYING FORMS**

A central tenet of generative phonology since the Sound Pattern of English (SPE; Chomsky & Halle, 1968) is the idea that SRs have abstract URs from which they are derived. The reasons for doing so include both theoretical imperatives and psychological evidence, but there is little consensus on how different an underlying form can be from its surface realization, how abstract or concrete an underlying form should be, or on what sort of capabilities language learners have for abstracting underlying forms from surface forms. In this section, I discuss the principles for establishing URs, some experimental evidence for URs, and how URs can be extracted for simple, non-opaque cases.

The theoretical rationale for URs includes a desire to capture consistent patterns and generalizations with a set of rules or constraints as well as a desire to describe a phonological grammar in the most compact or elegant way possible. An example of the former includes the idea of a single underlying form for multiple, predictable surface allophones. For example, in English, *p* is articulated differently depending on its position within a syllable. In a simple onset, as in *pot*, the *p* is aspirated, [p<sup>h</sup>], while in the second

consonant in a complex onset, as in *spot*, the *p* is unaspirated, [p]. One way of capturing this generalization is by positing that both forms have the underlying form /p/, and by virtue of context-sensitive rules or constraints, the /p/ is transformed into [p<sup>h</sup>] syllable-initially, or otherwise remains [p]. A grammar including rules or constraints that generate an aspirated [p<sup>h</sup>] from an underlying /p/ encodes this generalization about English, and can also be expanded to reflect the fact that this generalization also holds for all voiceless stops (*s[k]it* vs. [k<sup>h</sup>it], *s[t]op* vs. [t<sup>h</sup>op]) with a minimal change in its formal declaration.

An example of the latter includes the monomorphemic principle (Hyman, 1975), which posits that each morpheme has a single underlying representation and the surface realizations of a morpheme are generated through rules or constraints of the language. The English plural has three different realizations, [z], [s] and [əz] for the words *toys*, *blocks* and *kisses*, respectively. Applying the monomorphemic principle compels one to posit a single morpheme as the underlying form. The appropriate realization of the plural in different contexts can be generated using /z/ as the plural morpheme with the following set of rules or constraints.

(2) English plural allomorphy

- | <u>As a rule</u>  | <u>As a constraint</u>  |
|---|---|
| a. $\emptyset \rightarrow \emptyset / [\alpha \text{man}, \alpha \text{place}] \_\_\_ [\alpha \text{manr}, \alpha \text{place}] ]_{\sigma}$ | $*[\alpha \text{man}, \alpha \text{pl}] [\alpha \text{man}, \alpha \text{pl}] ]_{\sigma}$ |
| b. $[+\text{cons}] \rightarrow [+voice] / [+cons, +voice] \_\_\_ ]_{\sigma}$  | $*[+\text{cons}, +voice] [+cons, -voice] ]_{\sigma}$                                      |

This has the effect of shrinking the list of individual morpheme forms that need to be listed in the lexicon as part of a grammar of English as well as unifying the allomorphy of

the English plural with the language-wide phonotactics of English. These phonotactic constraints include a ban on adjacent consonants of the same manner and place of articulation and a ban a voiceless consonant followed by a homosyllabic voiced consonant. The phenomenon of the epenthetic schwa in the plural is thus unified with the epenthetic schwa in certain forms of the past tense, e.g. *batt*[əd].

The goals of theoretical elegance and descriptive compactness do not necessarily correlate with the psychological reality of the mental representation of speech, however, since the mind is not compelled to utilize the most compact or elegant instantiation of a grammar. Yet there is also a diverse set of psycholinguistic evidence for positing URs. For the /p/-allophony example above, both *p*'s are represented by the same grapheme, *p*, suggesting that the two unique sounds are somehow the same abstract sound-symbol for English speakers. Similarly, despite the identical pronunciation of the medial consonant in *paddle* and *battle* as a flap, the distinct orthographic representation suggests that these are two distinct sound-symbols whose phonetic realization reflect the merger of /t/ and /d/ through intervocalic spirantization. Distinct underlying representations for surface flaps also serve to account for the diphthong raising discussed above.

Priming experiments also suggest that certain phonological representations are more basic than others. For example, a final voiceless stop can be realized as released, unreleased, glottalized or simply as a glottal stop, with the released form, the citation form, generally accepted by phonologists as the underlying representation. Deelman and Connine (2001) found that the unreleased form is processed slower than the released form supporting the idea that the latter is somehow more primary. Similarly, Sumner and Samuel (2005) found that while words with released, glottalized and glottal *t* all primed a

word equally well in the short term, the released *t* provided the strongest prime over a longer time period. This does not represent abstraction in the sense of having an underlying representation that is more abstract or otherwise distinct from any heard realizations of a form; rather it represents a case of selecting a primary representation from a set of surface forms. It does suggest, however, that if a language learner only heard a particular word with a glottalized *t*, she could abstract a /t/ as UR, for use when appropriate.

Furthermore, Lahiri and Marslen-Wilson (1991) provide evidence from a gating task that phonological representations are underspecified, and therefore abstract. For English speakers, where vowel nasalization is allophonic and not contrastive, underspecification theory predicts that CV (nasalized vowel) sequences should prompt both CVN and CVC words, whereas a model with full specification of representations predict that it should only prompt CVN words. On the other hand, for Bengali speakers, where nasalization is contrastive, underspecification theory predicts that CV sequences will prompt CVC words the most (where the vowel is specified underlyingly as nasal) but not necessarily rule out CVC or CVN words. A fully-specified representation of words predicts that these sequences prompt CVC and CVN words equally well, while participants should not respond with CVC words. The results strongly confirm the underspecification hypothesis, suggesting that the representations have some degree of abstraction.

#### **4.2.1 How Abstract are Underlying Forms?**

The question, then, becomes how much abstractness is appropriate for URs. One extreme,

from SPE, is typified by the analysis of words like *nightingale* and *sigh* as having an underlying velar fricatives (in the place of *gh*) accounting for the quality of the initial vowels and the absence of tri-syllabic laxing in *nightingale* (cf. words like *pinafore*, *ligature*). This sort of approach exemplifies the theoretical imperative of maximizing the generality of the rules of a language, and placing the onus of explanation for alternations and surface forms on underlying representations.

This contrasts with theories such as Natural Generative Phonology (Hooper [Bybee], 1976) or Natural Phonology (Stampe, 1979) that argue for concrete phonological representations and reject any phonological generalization that are not true of all surface forms. Taking up this point of view, exemplar-based approaches to Phonology (Johnson, 1997; Pierrehumbert, 2003; Bybee, 2006) suggest that phonological representations consist of the sum total of all of the heard tokens of any given form, denying any sort of abstraction in representation. Thus, the representation of the word *spot* consists of a cloud of exemplars, all with an aspirated *p*, and with all of the different possible realizations of *t*, i.e the different speech style variants (glottal stop, glottalized, unreleased) and realizations of the *t* in bi-morphemic contexts (flapped as in *spotted*).

This is similar to the approach to (non)-abstractness advocated for in Optimality Theory, which posits an underlying representation, albeit an underlying representation that is identical to the surface form. As discussed in chapter one, /kat/, /k<sup>h</sup>at/, /kat<sup>h</sup>/ and /k<sup>h</sup>at<sup>h</sup>/ would all yield the surface form [k<sup>h</sup>at] based on constraints on the realization of aspiration, but /k<sup>h</sup>at/ would be selected as the underlying form. There would therefore be no abstraction in the underlying representation, while the grammar would still account for the allophonic behavior of voiceless stops by virtue of being able to generate [k<sup>h</sup>at] from

/kat<sup>h</sup>/, for example, even though /kat<sup>h</sup>/ is not an underlying form in the lexicon of English. This is in line with other connectionist approach to phonology, including Rumelhart and McClelland (1986) who argue that perceptual representations evolve directly from perceptual experience, or Elman and Zipser (1988) who argue that representations of spoken words should reflect their experience with what words sound like.

This leaves open the question of how alternations are represented, i.e. how the monomorphemic principle is resolved. So, for the plural morpheme, which undergoes phonologically-conditioned alternations, and word-final *t* which is subject to variation due to a combination of phonological and extra-linguistic factors, it is not possible to assign a single UR based since there are multiple SRs.

#### 4.2.2 Simple Alternations

One solution, demonstrated here for German, is to rely on the grammar as a whole to determine which of the alternants is the underlying form. In German, the realization of the word for *day* is either [tak] ‘day’ or [tag], as in [tag-ə] ‘days’.

(3) German devoicing:

	<u>Voiceless</u>	<u>Voiced</u>
a. Alternating		
	ta:k ‘day’	ta:ge ‘days’
	hant ‘hand’	hande ‘hands’
	lo:p ‘praise’	lobn ‘to praise’

b. Non-alternating

ʃtək	‘stick’	ʃtəke	‘sticks’
gu:t	‘good’	gu:te	‘good (infl.)’
duk	‘duck (v.)’	dukn	‘to duck’

Evidence from other words in German, such as [ʃtəkə], shows that what is involved is not intervocalic voicing of stops, but final devoicing. Therefore, the underlying form for [tak] must be /tag/ and there is no abstraction necessary, rather the grammar selects one of the heard tokens as the underlying form based on the phonological grammar.

For other cases, the language data is equivocal for determining URs, motivating underspecified underlying representations (Inkelas, 1995). Inkelas cites Turkish, among other languages, which exhibits similar behavior to German with respect to final devoicing and voiceless intervocalic stops (3a,b), and has cases of non-alternating final voiced plosives whereas German does not. Therefore, /kanad/ cannot be the underlying form for [kanat], otherwise /etüd/ would surface with a voiceless final stop (c).

(4) Turkish voicing alternations (from Inkelas, 1995):

a. Alternating:

kanat	‘wing’	kanad-ı	‘wing-ACC’
kanatlar	‘wings’	kanad-ım	‘wing-1SG.POSS’

b. Non-alternating voiceless:

sanat	‘art’	sanat-ı	‘art-ACC’
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c. Non-alternating voiced:

etüd            ‘etude’            etüd-ü            ‘etude-ACC’

Instead, Inkelas argues that the alternating segment in the alternating forms be underspecified with respect to voicing: /kanaD/. The phonology of the language then determines the realization of the underspecified feature - voicing - according to constraints on final devoicing or intervocalic voicing wherein underspecified segments are realized as either voiceless or voiced, respectively.

The process of abstraction here is relatively simple as the underspecified *D* is simply the logical intersection of the features of the two different alternants, i.e. the features [+cons, -cont, -nasal, CORONAL] with no specification for voicing (0voice). This can similarly be accounted for using the idea of over-specification, or the union of the feature of the two alternants (Ettlinger, *to appear*; Scobbie, 1991). So, the archiphoneme *D* in /kanaD/ could also represent a segment specified as both voiced and voiceless, merging the different heard tokens of the morpheme. The grammar then selects that appropriate alternant (or deletes or inhibits the inappropriate alternant) depending on grammatical context. As such, it is unclear whether this represents a clear case of abstraction as a difference between underlying and surface forms or simply the merger of multiple concrete representations for the same morpheme.

Therefore, if the theoretical imperative is to eliminate or minimize any sort of abstraction in representations, as argued for in OT and exemplar-based models, these two types of examples do not serve as serious counter-evidence. The question, then, is if there

are any cases of abstraction that are needed on empirical grounds.

### **4.3. OPAQUE ALTERNATIONS**

What presents perhaps the most significant challenge for these surface-based approaches to the representation of phonological forms and represents the strongest case for URs that are different than SRs are cases of phonological opacity. As discussed in chapter one and above, in phonological opacity there are two phonotactic generalizations, one of which renders the other not surface true. There are two types of surface behavior that this interaction can yield: over-application and under-application.

#### **4.3.1. Under-application**

Mafa (chapters 1, 2; Barrateau & Le Bleis, 1990; Ettliger, 2005) serves as an example of under-application. In Mafa there is a process of palatal harmony where all vowels and stridents in a word agree with respect to palatality/frontness (a), while there is a process of assimilation where high vowels adjacent to the palatal glide are fronted (b).

In opaque forms (c), e.g. [si-j-aʔa], the local palatalization of the high vowel to [i] does not trigger front harmony in the object clitic nor does it lead to palatalization of the adjacent strident. Therefore, the interaction is opaque in that there are back vowels and [-palatal] stridents in the surface form despite the existence of the triggering environment in the guise of (high) front vowels [i] or [y].

(5) Mafa counter-bleeding:

a. Front harmony

ðək-aʔa	‘He sows it’	ʃid-eʔe	‘He thanks it’
pəz-aʔa	‘He cultivates it’	piʒ-eʔe	‘Cultivate it!’

b. Local palatalization

gudzə	‘to tremble’	gudzij	‘tremble!’	
sə	‘to drink’	si-j	‘drink!’	*ʃi-j
ku	‘to throw on ground’	kyj	‘throw!’	

c. Opaque interaction of harmony and local palatalization

si-j-aʔa	‘drink it!’	*ʃij-eʔe
kyj-aʔa	‘throw it’	
pəlij	‘in exchange’	*pɨlij

In chapters one and two I argued that this is ideally formalized through Diagonal Correspondence, which establishes a relationship between the clitic and the underlying form of the verb root. From the perspective of abstract URs, DCT requires that the learner derive underlying /sə/ from the SR [si-j-aʔa] because the surface realization of the clitic as [aʔa] means the underlying form of the verb must be non-palatal. In this particular paradigm, this is not a significant problem because the uninflected form is [sə], which can be selected as the underlying representation from the multiple alternants as above. The same cannot be said for examples with *j* in the verb root:

(6) Mafa:

- a.  $\text{syj6-a?a}^2$  'type of plant' \* $\text{ʃyj6-e?e}$
- b.  $\text{6ij-a?a}$  'big' \* $\text{6ij-e?e}$
- c.  $\text{f6k}^w\text{ájím-a?a}$  'cut it' \* $\text{f6k}^w\text{ejime?e}$
- d.  $\text{gǎljǐpá}$  'rich' \* $\text{gilijpe}$

In cases such as these, the underlying form of monomorphemic [6ij] must be /6əj/ so that the correct allomorph of the clitic is used. This UR is distinct from any surface realization of the morpheme and requires the ability to use knowledge about the phonological grammar to abstract its underlying form either based on undoing palatal assimilation, the realization of the clitic, or both.

#### 4.3.2. Over-application

An example of the other type of opacity, over-application, is found in Shimakonde (chapter 3) where mid vowel harmony and mid vowel reduction in pre-penultimate syllables combine to yield opaque forms (7). In the opaque form, (c), the applicative suffix is the target of mid vowel harmony due to the mid vowel in the verb root, and the mid vowel in the verb root is reduced to *a* in the surface form because of its position before the penultimate syllable. There is no way to account for why the applicative suffix

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<sup>2</sup> In addition to serving as an object clitic, the /-a?a/ suffix expresses definiteness when suffixed to a noun, or to an adjective in a noun-adjective phrase:

- i)  $\text{mavar}$  'bowl of rice'
- ii)  $\text{mavər-a?a}$  'the bowl of rice'
- iii)  $\text{mavər 6ij-a?a}$  'the small bowl of rice'

surfaces as *-el-* without reference to the underlying mid vowel in the verb stem.<sup>3</sup>

(7) Shimakonde opacity

<u>Stem</u>		<u>Applicative</u>
a. kú-pí <u>í</u> t-a	‘to pass’	kú-pít-í <u>í</u> l-a
b. kú-pá <u>á</u> t-a	‘to cut’	kú-pát-í <u>í</u> l-a
c. kú-pé <u>é</u> t-a	‘to separate’	kú-pát-é <u>é</u> l-a

So, there is a possibility that a language learner, on hearing only the form *kúpátééla*, be required to abstract an underlying representation for the verb root that she did not hear. Given only the form *kúpátééla* the learner must recognize that the verb is /pet/, not /pat/, as assumed by lexicon optimization. There is adequate information from just *kúpátééla* because of the realization of the applicative allomorph as *-el-* and not *-il-* but no theory of grammar learning (cf. Bermudez-Otero, 2003 for an exception) incorporates this sort of information into how underlying forms are established. In Shimakonde this is less of an issue because of the availability of the transparent form *kupééta*. So, as in the German case, the grammar having mid vowel neutralization allows for selecting /pet/ as the underlying form for [pat]~[pet]. There is another class of examples of over-application that have been analyzed as having abstract URs, however, without recourse to other transparent examples for deriving the UR.

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<sup>3</sup> Or, as discussed in chapters one and two, by reference to some other form – an intermediary form in a serial derivation, a sympathy candidate, or another member of the paradigm - that has a mid vowel in the verb root.

### 4.3.3. Opacity and Abstract Representations

Hyman (1970) argues for abstract URs to account for the behavior of Nupe palatalization and labialization. In Nupe, round vowels trigger labialization in preceding consonants (a), and front vowels trigger palatalization (b). Some consonants are palatalized or labialized before *a*, however (d)

(8) Nupe palatalization and labialization (Hyman, 1970)

- a. eg<sup>w</sup>u ‘mud’  
eg<sup>w</sup>o ‘grass’
- b. eg<sup>j</sup>i ‘child’  
eg<sup>j</sup>e ‘beer’
- c. ega ‘stranger’
- d. eg<sup>w</sup>a ‘hand’  
eg<sup>j</sup>a ‘blood’

While the contrast between the forms in (c) and (d) would normally motivate positing an underlying contrast between C<sup>w</sup>, C<sup>j</sup> and C based on them being a minimal triplet, this clearly misses the generalization exemplified by the examples in (a) and (b) and stipulates that the occurrence of C<sup>w</sup> before round vowels and C<sup>j</sup> before front vowels is essentially a coincidence. Hyman therefore posits a pair of underlying vowels, /ε/ and /ɔ/ which trigger consonant palatalization and labialization, respectively and then are neutralized to [a]. Because /ε/ and /ɔ/ are not realized in the surface form, this represents case of over-application opacity relationship since their effect on preceding consonants is

still observed – palatalization and labialization over-apply.

The evidence for this analysis extends beyond just explanatory adequacy. First, while Nupe has the five vowel system shown above, a number of closely related languages have seven vowel systems with [ɛ] and [ɔ] surface vowels. Second, in borrowings from Yoruba, a seven-vowel system language, [ɛ] and [ɔ] are treated in precisely the same manner as underlying /ɛ/ and /ɔ/:

(9) Nupe borrowing from Yoruba (Hyman, 1970)

- a. kɛkɛ k<sup>l</sup>ak<sup>l</sup>ɔ ‘bicycle’
- b. ɛgbɛ egb<sup>l</sup>ɔ ‘a Yoruba town’
- c. tɔrɛ t<sup>w</sup>ar<sup>l</sup>ɔ ‘to give a gift’
- d. kɔbɔ k<sup>w</sup>ab<sup>w</sup>ɔ ‘penny’

In OT, with the explanation for surface forms shifted from underlying representations to constraints, the necessity of these underlying forms is mitigated and a constraint against unpalatalized stops before front vowels, and one against unlabialized stops before round vowels is sufficient to fully capture the generalizations in (8) as well as generate the appropriate surface forms for Yoruba borrowings. Lexicon optimization would then establish underlying forms for the surface forms in (8) based on the Nupe surface forms, and not the Yoruba surface forms.

Archangeli and Pulleyblank (1994) offer a similar analysis of Barrow Inupiaq, where both palatalized and unpalatalized *l* and *n* are found after surface [i]. For the forms

in (c), they posit an abstract underlying /ɨ/, neutralized to [i], to account for non-palatalized affixes.

(10) Barrow Inupiaq (Kaplan, 1981 via Archangelli & Pulleyblank, 1994)

		<u>‘be able’</u>	<u>‘future’</u>	<u>‘3sg. realis’</u>
a.	niRi ‘eat’	niRiɬɬa	niRiɲiaq	niRiɬuni
	savig ‘wound’	savigɬu	(none cited)	savigɬuni
b.	sisu ‘slide	sisulla	sisuniaq	sisuluni
c.	tiŋi ‘take flight’	tiŋilla	tiŋiniaq	tiŋiluni
	kamik ‘boot’	kamikɬu	--	kamikɬuni

In an analysis of Spanish, Saporta (1965) and Drescher (1981) makes similar use of abstract underlying forms to account for the different behavior of plural forms such as *lunes~lunes* versus *lapis~lapises* (cf. *cuidad-es* ‘cities’). To account for the different realizations of the plural, Saporta posits underlying /θ/ for *lapis*, while Drescher posits an underlying segment underspecified for stridency.

These three examples are opaque in a similar fashion to Shimakonde in that they represent cases of over-application since alternation in a surface form lacks motivation in the surface form. The alternations in these opaque examples are therefore dependent on structure in the underlying form. In Shimakonde, the underlying form is also realized transparently in another surface form (e.g. *kúpééta*), while in the other examples, there are no surface realizations of the abstract underlying representation (e.g. \*<sub>ε</sub>, \*<sub>ɔ</sub> in Nupe).

#### 4.3.4. Abstraction Revisited

All of these opaque examples are relevant to an understanding of abstraction in two ways. First, some of these cases require abstract underlying representations distinct from any heard surface form – a process of abstraction that is difficult to show is necessary for non-opaque data. Second, the opaque generalizations – the harmony in Mafa and Shimakonde – do not hold for surface forms; however, the generalizations can be said to hold at some other level of abstraction, depending on the theory of opacity one adopts. DCT posits the generalizations can hold between elements of the SR and the UR; stratal OT (Kiparsky, 2003; Bermudez-Otero, *in press*) and candidate chain OT (McCarthy, 2007) posits the generalizations hold at some intermediary derivation; Sympathy posits that the generalization holds for some abstract form that is never produced.

At this point, it is also worth revisiting the term “abstract”, which is used to refer to URs. Abstractness, in the traditional sense, involves using non-concrete elements or categories in lieu of concrete representations. For example, /p/ lacks the acoustic and articulatory details of an actual speech sound and represents an abstract category consisting of only a minimal featural specification, which is distinct from [p] or [p<sup>h</sup>] which includes a specification for aspiration, among other phonetic details. In the discussion above, abstractness takes on a different sense. For example, the difference between using /six/ or /sai/ as the UR for [sai] is more about how different a UR can be from an SR than it is about how phonetically impoverished the UR is. Similarly in the case of Mafa, the UR /bəj/ is deemed an abstraction of [bij] because it is different than the SR, not because the concreteness of the sound categories are different. Indeed, the idea of lexicon optimization within OT does not preclude a phonetically detailed UR identical in

all respects to the SR. Similarly, under-specification can either be thought of as abstraction in the sense of a non-concrete representation of a speech sound, or as over-specification of sound per the above experiments suggesting under-specification. So, for the rest of this study, abstraction will refer to whether a UR can be shown to be necessarily different than an SR.

#### **4.4. ACQUIRING OPACITY**

The above opaque interactions present two key problems for the language learner, particularly for a language learner modeled as acquiring a phonological system based on surface forms: acquiring underlying forms, and acquiring non-surface-true generalizations.

##### **4.4.1 Underlying Forms**

The first problem is the one alluded to above with respect to acquiring underlying representations. The older SPE approach to phonology would involve the undoing of phonological rules in a serial manner to get to the (abstract) underlying form – in essence, using phonological knowledge to back into the UR. However, current constraint- and exemplar- based theories of phonology do not have any way of deriving abstract forms distinct from heard surface representations (cf. Bermudez-Otero, 2003 for a demonstration of how serially ordered OT grammars, e.g. stratal OT, can acquire an opaque grammar; see chapter 2 and McCarthy, 2007 for evidence that stratal OT is empirically inadequate). The question, then, is whether learners are indeed able to derive abstract underlying representations distinct from surface forms or whether they are bound

by perceptual experience and are only able to select from among heard tokens of forms.

#### **4.4.2 Productivity of opaque generalizations**

Second, there is the question of how the existence of opaque forms affects the generalizations in a grammar. In Mafa, the generalization is that vowels and stridents have the same frontness/palatality. In the examples above, there are instances where this is not the case.

There are a number of potential ways these opaque data can be incorporated by Mafa speakers into their phonology. One possibility is that these forms can be counted as part of the statistics used for computing their knowledge of phonotactics and be treated as exceptions. This would suggest that the vowel harmony generalization is not absolute and is not as robust as a generalization that is never rendered opaque.

Another possibility is that the generalization could involve considerations beyond just simple co-occurrence frequencies and could take into account morphological knowledge, or the ability of the speaker to “undo” the process of glide assimilation to assess the consistency of the harmony generalization which would then be as robust as any other generalization in the language.

Finally, given some frequency of opaque forms it is quite possible that Mafa phonology does not consist of any overall generalization concerning frontness harmony (in Mafa the frequency of these forms happens to be relatively low) and the appropriate affixes are listed or memorized knowledge. Thus, enough opaque forms can “break” the phonological generalization.

Hudson Kam and Newport (2005) provide evidence that the reconciliation of

exceptions with a generalization depends on the type of learners involved. Using an artificial grammar to test morphological learning, they showed that in adults, the proportion of exceptions is acquired veridically, and so exceptions weaken the generalization in question. Children, however, were shown to over-generalize, and so exceptions had no effect on the strength of the generalization, if there were a sufficient number of regular forms to learn it.

There are also hypotheses with respect to the approximate number of exceptions a generalization will tolerate before no longer being productive. Based on several examples of morphosyntax, Yang (2005) suggests the following ratio of maximum number of exceptions,  $E$ , to forms,  $R$ , for any rule:

(11) Maximum ratio of exceptions to regular forms for any rule:

a.  $E \approx R / \ln(R)$

So, if the number of forms of some rule is 100, then the maximum number of irregular forms can be 22, with 78 regular forms; otherwise, the productivity of the rule starts to break down. This calculation is based on the point at which memorizing a set of individual examples is more efficient than learning a rule, a set of forms that applies to the rule, and a set of exceptions.

This can be extended to phonology as a hypothesis for the number of exceptions a regular phonological generalization can have before no longer being productive. Ignoring, for a moment, opaque interactions, if some language has 100 forms with a strident+ $i$  sequence, then it can tolerate up to 22 forms with  $si$  while still maintaining a

productive  $s \rightarrow \text{ʃ}/\_i$  generalization for the remaining 78.

The question is whether opaque interactions simply count as exceptions in this metric, or whether, by virtue of being a consistent sub-generalization that holds at some other level of abstraction, opaque interactions do not count as exceptions at all, or perhaps something in between.

This represents a new consideration on the status opacity within a language. Whereas opaque relationships are generally considered marked (Kiparsky, 1973; Parker, *in press*) from the perspective of the overall grammar it may be possible for a phonology to tolerate a certain amount of opacity without a problem, so long as there are enough surface-true cases of the generalization in question. Therefore, the existence of opacity and the ability of a phonological system to tolerate non-transparent generalizations may need to be considered with respect to the relative frequency of the different forms subject to the different phonological processes.

#### **4.5. PREVIOUS STUDIES**

A handful of studies have attempted to answer the first question on how productive opaque generalizations are with mixed results.

##### **4.5.1 Bedouin Hijazi Arabic**

An early influential study by Al-Mozainy (1981) is often cited as evidence for the need for abstract representations. The study looked at opaque relationships in Bedouin Hijazi Arabic, which has a constraint against *i* as well as *a* in open syllables motivating alternations:

(12) BHA open-syllable High Vowel Deletion and Raising

- a. *dir.bat* ‘she was hit’                      *ɗrib* ‘he was hit’  
b. *ɟar.bat* ‘she drank’                      *ʃi.rib* ‘he drank’

These data are opaque in that the form [ʃi.rib] seems to defy the constraint against *i* in open syllables. This reflects a chain shift, where  $a \rightarrow i$  and  $i \rightarrow \emptyset$ , but  $a \neq \emptyset$ .

While these phonological processes are reflected in the above alternations, it is quite possible that they do not reflect synchronic knowledge of a speaker of BHA and that these forms are essentially memorized and the constraints are not productive. To test this hypothesis, Al-Mozainy looked at a number of different pieces of convergent evidence.

The first comes from recent borrowings in BHA from other languages. English words such as *cylinder* were borrowed as [slɪndɔː] and Turkish words like *kabak* were borrowed as [ki.bak], suggesting that open syllable high-vowel deletion and open-syllable *a*-raising were synchronically active at the time of borrowing. Second, Al-Mozainy conducted an experiment using a language game that involved rearranging the consonants of a word taking advantage of the one exception to the raising in which pharyngeals block raising (*ɗarab* ‘he hit’, \**ɗiɗarab*). Participants were able to rotate the consonants of [ɗarab] around as part of the language game and the vowels reflect the synchronic application of the raising rule e.g. [biɗar], [ɗibar]. This did not test the productivity of the high-vowel deletion process, however, which is required for the complete opaque

interaction. That is, if high-vowel deletion is not also synchronically active, there is not problem accounting for the grammar with vowel-raising and memorized forms using a surface-based formalism (e.g. see Ettliger, 2008, for an analysis of an opacity in child language as involving two processes that are never contemporaneously productive).

#### 4.5.2 Canadian French

A second test of the productivity of opaque phonological generalization was done for Canadian French (Poliquin, 2007) using nonce-word acceptability judgments. Canadian French has a phonotactic restriction where only lax vowels are permissible in final closed syllables and only tense vowels are allowed in open syllables:

(13) Canadian French open/closed vowel tensing and laxing:

a. Final closed syllable laxing:			b. Open Syllable Tensing		
<u>Tense</u>	<u>Lax</u>		<u>Tense</u>	<u>Lax</u>	
be.ni	e.li	*li	mi.ten	*mi.ten	
kry	a.nɣl	*nyl	ky.lɔt	*kɣ.lɔt	
de.gu	e.gut	*gut	ku.te	*kɯ.te	

The first restriction is violated by a process of pre-fricative tensing where high vowels must be tense and long before fricatives in closed syllables (a). The second is violated by a variable process of regressive lax harmony, which targets high vowels (b).

(14) Motivated exception to open-tense/closed-lax generalization

a. CF pre-fricative tensing

<u>Tense</u>	<u>Lax</u>
sa.li:v	*sa.lɪv
e.kly:z	*e.klyz

b. CF Lax Harmony

<u>Harmonized</u>	~	<u>Unharmonized</u>
fɪ.lɪp	~	fɪ.lɪp
stɪ.pɪd	~	stɪ.pɪd

These two processes interact opaquely since vowels that undergo pre-fricative tensing still trigger lax harmony (a). High vowels that surface as tense as a result of re-syllabification due to suffixation can also trigger lax harmony opaquely (b).

(15) Canadian French lax harmony opacity:

a. Pre-fricative tensing

<u>Harmonized</u>	~	<u>Unharmonized</u>
bɔy.ly:ʁ	~	bɔy.ly:ʁ
mɪ.si:v	~	mi.si:v

b. Affixation-triggered opacity

<u>Harmonized</u>	~	<u>Unharmonized</u>
mɪ.zi.kal	~	my.zi.kal

These forms are opaque because in the final surface form the trigger of harmony – a lax high vowel – surfaces as tense. Thus in *musical*, the lax vowel in the stem form /my.sɪk/ can trigger lax harmony yielding [mɪ.sɪk]; the *-al* suffix causes resyllabification, however, and the lax [ɪ], now in an open syllable, surface as tense, whereas the [ɪ] remains lax.

The question these data raise is whether the lax harmony generalization is productive for Canadian French speakers, especially in light of forms like [mɪ.si:v] where

surface high vowels disagree in laxness in a monomorphemic word. To test this, Polliquin asked participants to judge the acceptability of Canadian French and nonce words exhibiting an opaque relationship between lax harmony and pre-fricative tensing. He first found that participants judged lax vowels in open syllables as unacceptable when there wasn't a lax vowel in a final syllable, showing the synchronic productivity of lax harmony. Second, participants did not judge opaque nonce words any differently than they judged real words suggesting that the opaque interaction is also productive.

There are several problems with these results and the experimental paradigm, however. First, the stimulus was generated by a native CF speaker, the author, clearly presenting a potential bias for the production of words that violated harmony, (e.g. the author produced \**m.l.tɛn* doing "his best" to articulate the crucial lax *I* in the first syllable). The harmony-productivity experiment also only included CF words – and not nonce words – leaving claims of productivity still in question.

Second, statistics were not reported for many of the results and in the instance that they were statistics were used incorrectly. A  $p > 0.1$  was reported for the difference between real and nonce words in the opacity test which is not a valid statistical method for assessing sameness, rather a t-test can only assess whether two distributions are different or not significantly different – not whether they are significantly the same. This lack of appropriate statistics becomes even more problematic because real opaque words were judged with a lower rate of acceptability than real transparent words for the same subjects; these results were reported in two different sections but apparently used the same method and subjects. Furthermore, while the acceptability scores for opaque nonce and familiar words were similar, the nonce words had a very large variance and were not

significantly above chance acceptability. Real opaque words were judged acceptable significantly above chance. The actual statistics for these comparisons were not reported and these observations are made based on the graphs and error bars provided. So there seems to be something going on with opaque patterns; precisely what is going on was not adequately investigated in the experiments.

### 4.5.3 Polish

An argument against the productivity of opaque generalization was made for Polish by Sanders (2003). The Polish opacity discussed involves an interaction between vowel raising before word-final voiced stops and coda devoicing. Devoicing, is a productive, exceptionless, surface-true process:

(16) Polish coda devoicing

- |    |          |        |                                   |
|----|----------|--------|-----------------------------------|
| a. | klubɪ    | klup   | ‘club (PL/SG)’                    |
| b. | tɔɛkavɪ  | tɔɛkaf | ‘ready (regular/short form)’      |
| c. | kɔlənda  | kɔlənt | ‘Christmas carol (NOM SG/GEN PL)’ |
| d. | dva.razɪ | ras    | ‘twice/once’                      |

The other process involved in the opaque relationship is the raising of back vowels before homosyllabic voiced word-final consonants including sonorants. This process, unlike devoicing, is subject to exceptions (b).

(17) Polish vowel-raising

	<u>Stem</u>	<u>Nom Sg.</u>	<u>Nom Pl.</u>	
a.	/dvɔr/	dvur	dvɔrɪ	‘mansion’
	/bɔl/	bul	bɔlɛ	‘ache’
	/pɔkɔj/	pɔkuj	pɔkɔjɛ	‘room’
	/stɔw/	stuw	stɔwɪ	‘table’
b.	/pɔr/	pɔr	*pur pɔrɪ	‘leek’
	/kɔlɔr/	kɔlɔr	*kɔlɔr kɔlɔrɪ	‘card suit’
	/xɔl/	xɔl	*xul xɔlɛ	‘lobby’

The two processes interact opaquely; the underlying voicing of the word-final stops trigger raising, but these stops surface as voiceless, eliminating the environment for raising.

(18) Opaque interaction between devoicing and raising.

a.	/bɔb/	bup	bɔbɪ	‘bean’
b.	/rɔv/	ruf	rɔvɪ	‘ditch’
c.	/lɔd/	lut	lɔdɪ	‘ice’
d.	/dɔvɔz/	dɔvus	dɔvɔzɪ	‘supply’

To assess the productivity of the vowel height alternation, Sanders conducted a wug-test using two Polish speakers. Presented with inflected forms such as [smatɔgi], the two

participants produced [smatɔk] instead of [smatuk] as the bare form, suggesting that raising is not productive: given the form [smatɔgi], the underlying form clearly ends in a voiced stop, which is correctly devoiced in the produced form, but does not trigger raising of the back vowel. The conclusion was that the diachronic change of the final devoicing “broke” the first generalization, which, while productive at one point, is now no longer productive.

Only two subjects were used, however, and no statistical information on the relative frequency of the two alternations, the frequency of words in the neighborhood of the nonce-words, and the applicability of raising for neighborhood forms were not given. Furthermore, this finding is not surprising given the status of recent Polish loans as being impervious to this generalization and the fact that the generalizations are only found in some, but not all, lexical entries. So while these results suggest that at least some cases of opacity are archaic and unproductive, the facts of Polish do not obviate the possibility that other cases of opacity, particularly those that involve morphophonological processes, are productive.

In addition to the specific problems particular to each of these studies, these experiments also have limitations due to the choice of experimental paradigm. In particular, an investigation of linguistic knowledge with un-timed meta-linguistic judgment tasks or games does not provide any insight into the strength or robustness of opaque generalization, only a binary distinction of whether a generalization is productive or not. These experiments can therefore show that opaque generalizations have some effect, but this could be due to the fact that the generalizations are transparent some proportion of the time. If we seek to explore the relative productivity of opaque

generalization with respect transparent ones, data such as reaction time may be informative.

#### 4.5.4 Hebrew and Underlying Forms

In order to explore the degree of abstraction involved in representations, Sumner (2003) conducted a set of priming experiments using Modern Hebrew verbs, which involve phonological opacity. In Hebrew, verbs generally consist of tri-consonantal roots that are combined with morphological templates (19a). Some roots only surface with two consonants however. This can occur for some elements in a paradigm because of post-vocalic deletion of glottal stops (19b 1sg. past and 3sg. past), or for all elements in a paradigm in the case of underlying *j* which is always deleted in analyses that posit its existence the UR. The underlying *j* is a historical artefact, though evidence for it being relevant in the synchronic phonology comes from the vowel alternation in the first person singular past tense form where the *j* surfaces as *i* (*niki-ti*), and in related noun forms such as *nakajon* ‘cleanliness’ and *nikuj* ‘cleaning’.

(19) Hebrew verbs

	1sg. past	3sg. past	3pl. past	
a. /tps/	tapas-ti	tipes	tips-u	‘climb’
b. /mlʔ/	mile-ti	mile	milʔ-u	‘fill’
c. /nkj/	niki-ti	nika	nik-u	‘clean’

The glottal stop in the UR in (19b) is partially abstract in the sense that it does not appear in certain surface forms (e.g. *mile*), although it appears in other elements of the paradigm

(e.g. *milʔ-u*). The UR in (19c) is fully abstract in the sense we have discussed since the glide in the UR never appears in any SR, and therefore requires some amount of reverse derivation. Sumner tested the psychological reality of these abstract representations based on the priming of the consonantal structure of these verbs. For example, the priming effect of a word like *diber* on *tipes* was used as a control. If *mile* similarly primed *tipes*, this suggests that they both have the same underlying CCC structure. If *nika* also primes *tipes*, then this, too, can be assumed to have a tri-consonantal root, providing evidence for the underlying *j*. She found no priming effect for underlying *j* but did find an effect for underlying /ʔ/ for older speakers, but not for younger speakers. Thus, there is no evidence for abstract representations in the sense of abstractness meaning distinct from any heard realizations of a morpheme. This is perhaps unsurprising for Modern Hebrew, particularly underlying /j/, for which the opaque interaction is an unlikely candidate for being synchronic since there is no evidence for the alternation across the language. Compare this to Mafa, for example, where there is evidence from alternations [sə]~[sij] that would enable a learner to derive underlying /ʂəj/ from [ʂij].

#### **4.5.5. Conclusion**

These results provide a decidedly mixed picture of how and when opaque generalizations can be learned, with a lack of definitive support for opaque generalizations being a necessary component of a phonological grammar, but with that possibility not being ruled out, either. There may be many reasons for this. First, it may be the case that some kinds of opacity are not productive and are relics of diachrony (e.g. Polish lexical), while others are productive (e.g. Hebrew morphology). Second, the ability to acquire opaque

relationships may involve aspects of grammar that generally are not included in theories of opacity including the relative frequency of opaque and transparent forms. Third, as suggested in chapters one and two, the type of opacity – e.g. over-application vs. under-application, opacity involving harmony vs. opacity involving prosodic structure - may also play a role.

## CHAPTER 5

### TESTING THE PRODUCTIVITY OF OPAQUE INTERACTIONS

#### 5.1. PRESENT STUDY

As discussed in the previous chapter, there are two crucial questions concerning the acquisition of opacity:

- (20) Questions regarding the acquisition of opaque relationships
  - a. How do opaque interactions impact the robustness and productivity of the generalization rendered opaque?
  - b. Are learners able to abstract underlying representations for opaque forms despite not hearing these forms?

The answers to these questions may depend on a number of factors. First, there are two substantively different types of opaque interactions, overapplication and underapplication, and one may be more easily learned than the other. Second, the proportion of opaque to transparent forms may also impact the ability to abstract underlying forms and the formation of generalizations. Finally, the ability to conduct one task may or may not impact a participant's ability to conduct the other. In other words, the ability to extract generalizations in the face of opaque examples may be correlated with an ability to extract URs or it may not.

To explore these questions I conducted a set of artificial grammar learning experiments testing participants' ability to acquire an opaque grammar. In particular, the

experiments tested whether participants could abstract URs despite never hearing an equivalent SR and whether opaque examples affected the ability of participants to acquire the opaque generalization.

The first experiment tested participants ability to acquire a case of over-application opacity while the second tested under-application opacity. Each experiment also included a manipulation varying the ratio of opaque to transparent examples and included two sets of test items. One set of test items investigated the strength of the opaque generalization by testing the participants' ability to extend the generalization to novel forms. The other test items tested participants on their ability to derive the correct UR for forms they had not heard. The two types of test items were used on the same subjects to explore whether they were correlated.

### **5.1.1 The Artificial Grammar Learning Paradigm**

The artificial grammar learning paradigm goes by a number of different names in the literature including miniature language experiments, toy grammar learning, nonce-language learning and language games. The basic idea is to present participants with a set of forms from an artificially constructed grammar with instructions that they are learning a new language. The goal is to familiarize them with the rules and generalizations of the grammar, generally without explicit instruction, relatively quickly, usually over the course of a one session or several sessions over the course of a week. The participants are then tested on their knowledge of these rules and generalizations by being asked to produce or select grammatical forms as defined by the language.

There are many differences between learning a natural language and learning a small-sized language in a lab. Exploring natural languages do not allow us to control many of the variables that may impact language learning, however. This approach allows us to focus on tightly controlled manipulations that may not be found naturally, but does come with caveats.

The first problem for artificial grammar learning is that participants learn the grammar as a second language, even if they are small children. Therefore, care must be taken to mitigate or minimize the impact the knowledge of their native language may have on the acquisition of the artificial grammar, including, the affect their native sound categories may have on their perception of novel sounds.

The differences between L1 and L2 are well documented (e.g. Thorndike, 1928; Asher, 1972; Ervin Tripp, 1972; Oyama, 1976; Harley, 1986; Harley & Wang, 1997; Lightbrown & Spada, 1999 and many others) as is the affect of age of acquisition and critical periods on learning generalizations and may also impact the results. Relevant to this study, Hudson Kam and Newport (2005) show that adults and children acquire generalizations in a very different manner, with adults tending to reproduce generalization veridically, while children tend to over-generalize. This clearly has the potential to be reflected in the results of this experiment since I am testing details of how and when a generalization is acquired or rejected using an adult population.

Another possible risk may be that participants use general pattern-matching abilities that may not be used or usable for naturalistic acquisition of language. This effect can be minimized by making the learning environment as natural as possible. For example, some examples of this paradigm simply consist of participants hearing pairs of

words, without any other stimulus. This lends itself to simply looking for patterns in the acoustic signal since no vocabulary or grammar needs to be learned. On the other hand, other instantiations have participants learn an actual language, with words or sentences associated with pictures or video vignettes. This diminishes participants' ability to explicitly look for patterns since they also have to pay attention to visual stimuli, learn vocabulary items, and potentially acquire other elements of a grammar that are not explicitly being tested. Still, participant may be successfully trained to learn myriad non-linguistic pattern. Therefore, results from these sorts of experiments should be seen as more of an existence proof that participants may be able to learn a grammar with a particular feature and not as proof that a particular feature is necessarily part of a grammar.

Despite these drawbacks, artificial grammar learning data have been used to show that language learners have biases or capabilities that shape what languages look like. Within the realm of morphophonology, a number of studies have been done including the pioneering study of Esper (1925) and more recently Pater and Tessier (2003), (2005); Pycha et al (2003); Wilson (2003), (2006), (2008); Peperkamp and Dupoux (2006); and Finley (2008). These studies have explored biases associated with phonological processes like vowel harmony (e.g. substantive biases, directional biases), place assimilation (e.g. regressive or progressive directionality) and triggers for palatalization (e.g. which natural classes trigger it). In most of the comprehensive studies, the results of the experiments do not motivate a particular conclusion in and of themselves, rather they are presented as converging with evidence from typological surveys of languages and language acquisition data to motivate a particular conclusion. As such, the results presented here

should be considered in light of the typological data presented in chapters one and two as evidence for any conclusions.

## 5.2. EXPERIMENT ONE

The first experiment tested participants' ability to acquire a phonological grammar that included an instance of over-application opacity. Recall from above that over-application involves an alternation that occurs based on some property of the UR that does not surface in the SR. The artificial language is modeled after one of the examples used throughout this dissertation, that of Shimakonde:

(21) Shimakonde over-application opacity

	<u>Stem</u>		<u>Applicative</u>
a.	kú-píít-a	'to pass'	kú-pít-ííl-a
b.	kú-páát-a	'to cut'	kú-pát-ííl-a
c.	kú-péét-a	'to separate'	kú-pát-éél-a

In the opaque form in (c), the *-el* allomorph is based on the underlying form of the verb root vowel, which surfaces as *a* because of reduction. Mid vowel harmony over-applies because the root mid vowel is not in the SR. Thus, designing an artificial language to test whether opaque relationships are learnable requires having two distinct phonological processes; here those phonological processes are reflected in affix and stem allomorphy.

To create a more realistic language-learning situation, the artificial language has some amount of semantics that needed to be acquired using pictures associated with specific words. Also, to test the two different capabilities, there are two corresponding

sets of test items. Finally, the relative frequency of opaque examples to transparent examples may impact the acquisition of the generalizations and the ability to derive underlying forms, so the experimental manipulation involved varying the proportion of transparent to opaque forms in the stimulus.

## **5.2.1 Method**

### *5.2.1.1. Participants*

Twenty native English speakers participated in the experiment. All were students at University of California, Berkeley and received course credit for participation. Their mean age was 20.1 and there were 12 women and 8 men. Participants were assigned randomly to one of five experimental conditions, with four in each condition.

### *5.2.1.2 Stimulus*

The language consists of 30 stems<sup>4</sup>, corresponding to 30 different nouns, and two affixes, a prefix indicating the diminutive and a suffix marking the plural. The nouns represent morphemes for 30 different animals and household objects. These can combine freely with the affixes to produce up to 120 different words: the bare noun for a single, large picture of each animal, the noun with the plural suffix for multiple large animals, the noun with the prefix for a single small animal and the noun with both for many, small animals. The language is henceforth referred to as Kasashil<sup>5</sup> for convenience.

The phonological inventory of Kasashil is a subset of American English and consists of a 3-vowel system, /i, e, a/, articulated using an American English

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<sup>4</sup> Thirty words were used because forty proved too difficult to learn in one session during pilot experiments and twenty proved too easy such that all pilot participants were at ceiling for all tasks.

<sup>5</sup> The stem *sash* with both affixes.

pronunciation so that new vowel categories need not be learned. Kasashil has an inventory of 25 consonants, each used once in onset and coda position for the 24 CVC nouns and the CV prefix and VC suffix. Care was taken to avoid existing English words, though it is difficult to completely avoid them using only three vowels, distinct consonants and CVC stems. The decision to use as many distinct consonants as possible was in the hopes that having lower neighborhood density and greater distinctness for the Kasashil words would facilitate learning the language with limited exposure.

The suffix forms have an allomorphic alternation dictated by a process of vowel height harmony, a relatively common process cross-linguistically (van der Hulst & van der Weijer, 1995).

(22) Kasashil vowel harmony:

	<u>Singular</u>	<u>Plural</u>
a.	fin	<b>fin-il</b>
b.	mez	<b>mez-el</b>
c.	vab	<b>vab-il</b>

The vowel in the plural suffix defaults to high and is realized as such when the vowel of the noun stem is either high or low. It is realized as mid when the vowel of the noun stem is mid.

The other phonological process is vowel lowering, which reduces adjacent stem mid vowels to *a* when prefixed by the low vowel plural marker:

(23) Kasashil vowel lowering:

	<u>Stem</u>	<u>Diminutive</u>
a.	fin	ka-fin
b.	mez	ka-maz
c.	vab	ka-vab

These two processes interact opaquely in forms with mid vowels:

(24) Opaque interaction:

	<u>Stem</u>	<u>Dim/Pl.</u>
a.	mez	ka-maz-el

This form is opaque because the mid vowel in the noun-stem that triggered the mid vowel of the suffix does not surface as mid, and instead surfaces as low. The transparent correlate of this relationship, with lowering and prefixation preceding suffixation and VHH would result in *kamazil*. This is transparent because the surface realization of the suffix is *-il* based on the surface form of the noun stem, *a*.

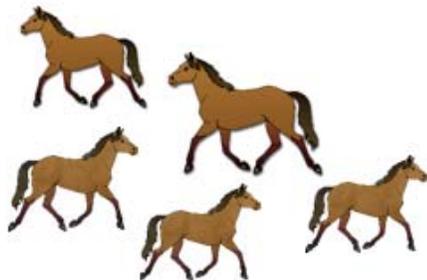
A native American English speaker was recorded saying each of the word forms using Praat (Boersma & Weenink 2006) spoken at a normal rate with English prosody and phonology so as to sound natural and fluent. Stress was always on the noun stem. The pictures of animals were edited using Photoshop and used under a Creative Commons License.

### 5.2.1.3. Procedure

Participants were told that they would be exposed to a language without explicit instruction on the rules of the language and that their task was to try to learn the language from the example words they would hear. They were informed that they would be tested at the end of the experiment.

Participants were exposed to the language for 15 minutes with two self-timed breaks at 5 and 10 minutes. Participants were seated in front of a video monitor where they saw the pictures (and instructions). 500 milliseconds after the picture appeared, they heard a word over headphones that named the picture in Kasashil. The picture remained on the screen for another 1500 millisecond, then the screen went blank for 500 milliseconds before the next picture was presented. Participants were required to learn the language solely from this audio-visual exposure to the words.

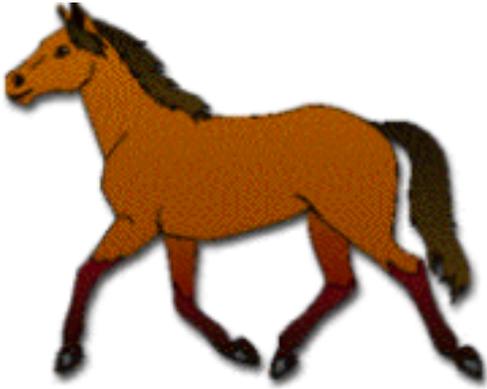
For example, a participant saw the following picture:



**Figure 1:** Example visual stimulus for experiment one for many small horses *kagadel*

and heard *kagadel*, the word for horse (*ged*) with the plural and diminutive affixes.

Or, they saw the following picture:



**Figure 2:** Example visual stimulus for experiment one for single large horse *ged*

and hear *ged*, the bare form.

The exposure set consisted of a presentation of 300 word-picture pairings in a randomized order. To test the productivity of each of the phonological patterns, various parts of the paradigm for certain words were withheld as well as complete paradigms for 18 of the 30 words based on the following experimental manipulation.

#### 5.2.1.4 Experimental Manipulation

Each of the elements of these mini-paradigms provides different information about the phonological grammar:

Element	Form	Meaning	UR	VHH	Reduction
bare	ged	horse	x		
dim.	kagad	small horse			x
pl.	gedel	horses	x	x	
dim. pl.	kagadel	small horses		Op	x

**Table 1:** Examples of each paradigm element and the information it provides

The bare form provides the learner with the UR, the diminutive serves as evidence for the reduction process, the plural serves as evidence of harmony as well as for the underlying form and the diminutive plural provides evidence for reduction and that the two processes interact opaquely.

In the experiment, certain forms of the paradigm are withheld from the stimulus so that the participants can be tested for their knowledge about various aspects of the language. The following categories of presented vs. withheld forms are used for noun stems with mid vowels:

Category	Bare	Dim.	Pl.	Dim. Pl.	Tests
None					H, UR, Op
Full	x	x	x	x	
Transp	x		x		Op
Opaque		x		x	UR

**Table 2:** Paradigm categories with included forms and what is tested

Each category trains and tests the participants on different aspects of the phonology. Paradigms that are withheld completely (None category) are tested as novel words, testing the acquisition of all aspects of the phonology. For the Full category, presenting all four elements of the paradigm tests participants ability to remember the different forms, but not necessarily their knowledge of the phonology and trains them on all aspects of the phonology we are interested in: harmony, the URs for the words, and how the interaction of harmony and reduction interacts opaquely. The transparent category provides (transparent) evidence for the harmony generalization, while testing on the diminutive plural form tests participants' knowledge of how the two processes interact. For example, when given the forms *ged* and *gedel*, asking the diminutive plural for horse require the learner to know that harmony and reduction interact opaquely, yielding

*kagadel*, and not transparently (*kagadal*). The opaque category provides opaque evidence for how harmony works and how harmony and reduction interact and tests participants' ability to derive URs. Thus, if presented with *kagad* and *kagadel*, the learner can be tested as to whether they can use the realization of the plural suffix to derive *ged* as the singular form.

Recall that the manipulation in this experiment is a variation of the ratio of opaque to transparent forms, or of the plural to the diminutive plural forms for noun stems with mid vowels. To control this manipulation, each stem is assigned to a category, with the same number of high- and low- vowel noun stems as mid vowel noun stems for each. Furthermore, a number of the words were withheld from exposure (the None category) for each condition.

For example, in one instantiation of experiment 1 (condition 2), the full paradigm is presented for one stem for each vowel, the transparent paradigm is presented for two stems each for each vowel and the opaque paradigm is used for one stem for each vowel, leaving six stems for each vowel withheld. All of the presented forms are randomized in the stimulus.

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	2	2	2	2	1	0	12	2	0
Opaque	1	1	1	2	0	1	6	0	1
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>3</b>	<b>2</b>
<b>Token</b>				10			<b>300</b>	<b>30</b>	<b>20</b>

**Table 3:** Assignment of nouns to categories for condition 2

Because there are four distinct forms for the full paradigm, this results in 12 unique

words for the three noun stems; because there are two distinct forms for the transparent paradigm, this yields 12 unique words for the six noun stems in this category; the two distinct forms for the opaque paradigm yields  $3 \times 2 = 6$  forms, for a total of 30 unique words across all paradigm categories. Furthermore, for mid vowel stems the full paradigm has one transparent form (the plural) and one opaque form (dim. plural), the transparent category has one transparent form and the opaque paradigm has one opaque form yielding a type ratio of 3 to 2 for transparent to opaque interactions. All unique words are presented an equal number of times since type/token differences are controlled. For 300 stimulus items, each word is repeated 10 times so the token ratio of transparent to opaque forms is 30/20.

The stimulus therefore consisted of the following thirty forms, each repeated ten times:

Noun	Par.Cat.	Bare	Dim	Pl.	Dim. Pl.
vab	full	vab	kavab	vabil	kavabil
tac	trans	tac		tacil	
cav	trans	cav		cavil	
that	opaque		kathat		kathatil
ged	full	ged	kagad	<b>gedel</b>	<b>kagadel</b>
pesh	trans	pesh		<b>peshel</b>	
mez	trans	mez		<b>mezel</b>	
shap	opaque		kashap		<b>kashapel</b>
kim	full	kim	kakim	kimil	kakimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	opaque		kazij		kazijil
Total		<b>9</b>	<b>6</b>	<b>9</b>	<b>6</b>

**Table 4:** Stimulus words for condition 2

Of the thirty, three (*gedel*, *peshel* and *mezel*; each repeated ten times) provide transparent evidence that mid vowels take the mid vowel suffix, while two (*kagadel*, *kashapel*) are

opaque. Thus for condition 2, the proportion of transparent forms is 60%.

One shortcoming of using this proportion of different forms is that each noun is not presented the same number of times since nouns associated with the Full category are heard twice as often (4 forms x 10 tokens = 40) as nouns associated with the Transparent and Opaque categories (2 forms x 10 tokens = 20). Doubling the number of times each Transparent or Opaque noun is heard, however, skews the type and token ratios, increasing the token ratio, but keeping the type ratio 3:2. Because we are primarily interested in the potentially subtle differences the ratio of transparent to opaque forms can have, and the evidence on whether type and token frequencies are more important is not conclusive (Frisch, et al., 2000, Coleman & Pierrehumbert, 1997), it was decided to focus on maintaining those ratios and recognize the potential affect differing amount of exposure to each noun could have on the results.

The other four conditions for experiment one are as follows:

Category	i	e	a	<i>Forms</i>	$F_{trans}$	$F_{opaque}$	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	3	3	3	2	1	0	18	3	0
Opaque	0	0	0	2	0	1	0	0	0
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>4</b>	<b>1</b>
<b>Token</b>				10			<b>300</b>	<b>40</b>	<b>10</b>

**Table 4:** Assignment of nouns to categories for condition 1

Category	i	e	a	<i>Forms</i>	$F_{trans}$	$F_{opaque}$	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	1	1	1	2	1	0	6	1	0
Opaque	1	1	1	2	0	1	6	0	1
<b>Type</b>	<b>9</b>	<b>9</b>	<b>9<sup>6</sup></b>				<b>24</b>	<b>2</b>	<b>2</b>
<b>Token</b>				12			<b>288</b>	<b>20</b>	<b>20</b>

<sup>6</sup> Three words not used so there was an equal number of transparent and opaque forms.

**Table 5:** Assignment of nouns to categories for condition 3

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	1	1	1	2	1	0	6	1	0
Opaque	2	2	2	2	0	1	12	0	2
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>2</b>	<b>3</b>
<b>Token</b>				10			<b>300</b>	<b>20</b>	<b>30</b>

**Table 6:** Assignment of nouns to categories for condition 4

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	0	0	0	2	1	0	0	0	0
Opaque	3	3	3	2	0	1	18	0	3
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>1</b>	<b>4</b>
<b>Token</b>				10			<b>300</b>	<b>10</b>	<b>40</b>

**Table 7:** Assignment of nouns to categories for condition 5

A summary of the number of tokens of each form for the five different conditions is as follows and the full lists of stimuli for the other conditions are in Appendix I.

Condition	Bare	Dim	Pl.	Dim. Pl.	Total	Tr/(Tr+Op)
1	120	30	120	30	300	80%
2	90	60	90	60	300	60%
3	72	72	72	72	288	50%
4	60	90	60	90	300	40%
5	30	120	30	120	300	20%

**Table 8:** Number of each form for each condition

### 5.2.1.5 Tests

At the conclusion of the exposure portion of the experiment, participants were given a self-timed break, after which they were given two different types of tests to evaluate their performance. The first one given examined their knowledge of known nouns for both heard and unheard words, while the second test given examined their ability to extend

their knowledge to the withheld nouns.

In the first test, the participants saw a picture of a noun and heard two words. Their task was to select the appropriate word for the picture using a button box. They were instructed that the left button corresponded to the first-heard word and the right button corresponded to the second-heard word. The picture either be one they had seen before (familiar) and their task was to remember the appropriate form, or it would be a picture of a noun they had seen before, but with an unknown inflection (unfamiliar) and their task was to select the appropriate form based on their knowledge of the phonology of the language. For example, if the noun *ged* ‘horse’ was in the Transparent paradigm category, the participants will have seen pictures and heard the forms for the bare noun (*ged*) and the plural (*gedel*). During test, the participants saw pictures of a small (diminutive) and many small (diminutive plural) horses for the unfamiliar items. For the picture of the single small horse, the participants heard the choices *kagad* and *kaged* and for the picture of many small horses, the participants heard the choice *kagadel* and *kagadil*. The first item tested their ability to form the diminutive, which is not of interest here, and so served as a distractor item, while the second item tested knowledge of the opaque interaction of the plural and diminutive forms. For bare forms, the incorrect choice reflected a transparent interaction of the processes; for diminutive forms, the incorrect choice reflects non-application of reduction; for plural forms the incorrect choice reflect non-harmony, while incorrect choice for the diminutive plural forms reflect transparent interaction of the two processes. Thus, when the appropriate use of the suffix was tested, the two forced-choice options had the two allomorphs of the suffix, either *-il* or *-el* (e.g. *kagadel*, *kagadil*) and when the UR of the stem was tested, the two forced

choice options had the correct stem and the noun with one of the other two vowels. Participants had 2000 milliseconds to respond as reaction time was tracked.

For test one, each paradigm item was used twice, so there were (12 exposure nouns x 4 paradigm items x 2 =) 96 items. For conditions 1, 2, 4 and 5, this consisted of 60 familiar and 36 unfamiliar items. For condition 3 there were only 9 exposure noun or 36 paradigm items and 72 test items, 72 familiar and 24 unfamiliar. These were presented in a random order.

Condition	Familiar				Unfamiliar			
	Bare	Dim	Pl.	Dim. Pl.	Bare	Dim	Pl.	Dim. Pl.
1	24	6	24	6	0	18	0	18
2	18	12	18	12	6	12	6	12
3	18	18	18	18	6	6	6	6
4	12	18	12	18	12	6	12	6
5	6	24	6	24	18	0	18	0

**Table 9:** Number of familiar vs. unfamiliar test items for each condition for each word

In the second test (presented second for every participant) the participants saw a new picture with a new noun (selected from the group of withheld nouns) for 1500 millisecond. They then saw another picture with the same noun but a different inflection and, as in the previous test, two words that they were required to select from with a button-press.

The presentation order was more tightly controlled for test two because it was important to ensure that the bare form was not presented before the diminutive plural, for example, since the test explored participants ability to derive the bare form. The diminutive plural was the prompt for the bare form for half the nouns, to test UR abstraction, and the bare form was the prompt for the plural for the other half to test

harmony. For example, the participant saw a picture of a new object, a bird, heard *nef*, and then saw a picture of many birds and had to select between *nefel* and *nefil* or the participants saw a picture of many small giraffes and heard *karasel*, then saw a single giraffe and had to select from *res* and *ras*. Each item was tested once, in a randomized order, for a total of 18 test items, 9 Dim. Pl. cuing the Bare form and 9 Bare forms cuing the Dim. Pl.

In the tests, the following results are of main interest.

First, the ability to select the correct bare form for *e* stems suggests that participants are able to derive underlying forms that are distinct from any heard realization of a morpheme.

Second, performance on the selection of the plural and diminutive plural for *e* stems reveals participants' knowledge of the (opaque) harmony generalization. The ability to select the correct diminutive plural also suggests that participants know that the two phonological processes interact opaquely, rather than transparently.

Finally, performance on the plural and diminutive plural for *a* stems also establishes proficiency with harmony and its opaque interaction with reduction since opaque *e* words with an *el* suffix provide (incorrect) evidence that the *el* suffix combines with surface *a* words.

## **5.2.2. Results**

### *5.2.2.1 Test one*

The following are the percent correct for test one items for each of the conditions for familiar and unfamiliar words across all four subjects for each vowel:

i	Familiar				Unfamiliar				Total			
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.
1	100%	100%	97%	88%		96%		96%	100%	97%	97%	94%
2	100%	94%	96%	94%	100%	94%	100%	94%	100%	94%	97%	94%
3	100%	94%	100%	94%	100%	100%	88%	88%	100%	96%	96%	92%
4	94%	92%	94%	96%	94%	100%	100%	88%	94%	94%	97%	91%
5	100%	94%	100%	97%	96%		92%		97%	94%	94%	97%

e	Familiar				Unfamiliar				Total			
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.
1	94%	100%	97%	88%		83%		83%	94%	88%	97%	84%
2	100%	94%	96%	81%	88%	94%	88%	81%	97%	94%	94%	81%
3	94%	88%	75%	<b>69%</b>	<b>63%</b>	88%	<b>63%</b>	<b>50%</b>	83%	88%	71%	<b>63%</b>
4	94%	92%	<b>69%</b>	71%	<b>38%</b>	88%	<b>56%</b>	<b>50%</b>	<b>66%</b>	91%	<b>63%</b>	69%
5	75%	91%	75%	75%	<b>17%</b>		<b>46%</b>			91%	<b>59%</b>	75%

a	Familiar				Unfamiliar				Total			
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.
1	100%	100%	97%	88%		96%		79%	100%	97%	97%	91%
2	96%	94%	96%	100%	100%	94%	100%	81%	97%	94%	97%	94%
3	94%	94%	88%	88%	88%	100%	88%	<b>75%</b>	92%	96%	88%	83%
4	94%	88%	94%	83%	94%	100%	88%	<b>75%</b>	94%	91%	91%	<b>78%</b>
5	100%	91%	88%	88%	96%		<b>75%</b>		97%	91%	<b>78%</b>	88%

**Table 10:** Percent correct for each paradigm group for each item

In bold and shaded are scores that are not significantly above chance and dark shaded scores with light lettering are significantly below chance (one-tail t-tests for each). Overall, participants did better with familiar words than unfamiliar words across all vowels (.92 vs. .83; two sample t-test:  $t(1478)=20.45, p<.001$ ).

### Stems with *i*

For *i* stems participants had no trouble with any of the word forms as one might expect since there are no opaque interaction because reduction does not apply to high vowels, nor do any of the surface forms merge with the *e*-stem when reduced, as they do with *a* stems.

### Stems with *a*

For *a* noun stems, participants were within error of being perfect for all familiar words. For unfamiliar words, participants were not above chance for plural forms in condition 5 (20% transparent) and for diminutive plurals for conditions 3 and 4 (50%, 40% transparent, respectively; there are no unfamiliar dim. pl. forms in condition 5 because there are all presented during training).

Participants were still above chance for forming the plural for *a* nouns ( $t(23)=2.77, p<.05$ ), in condition 5, however, so despite the existence of only one *a* plural form (*vabil*) during training participants still acquired the appropriate inflection for *a* stems. The preponderance of reduced mid vowels with *el* suffixes (e.g. *kagadel*) may have created problems for acquiring the harmony generalization.

For the diminutive plural forms for *a* words, participants were just barely not above chance ( $t(7)=-1.53, p=.085$ ) for conditions 4 and 5, partially due to the low number of trials.

### Stems with *e*

In conditions 1 and 2, participants had no trouble with the any forms, including the opaque diminutive plural for *e*-stems despite minimal evidence for the opaque interaction. They began having trouble with various forms when transparency reached 50% or less. Participants had trouble forming the plural and diminutive plural in conditions 3 through 5, as they did not score above chance and had trouble with deriving the bare forms being at chance in condition 3 and actually below chance in conditions 4

and 5. This also began to affect recall for familiar words as the percent correct on familiar bare forms in condition 5 was not above chance.

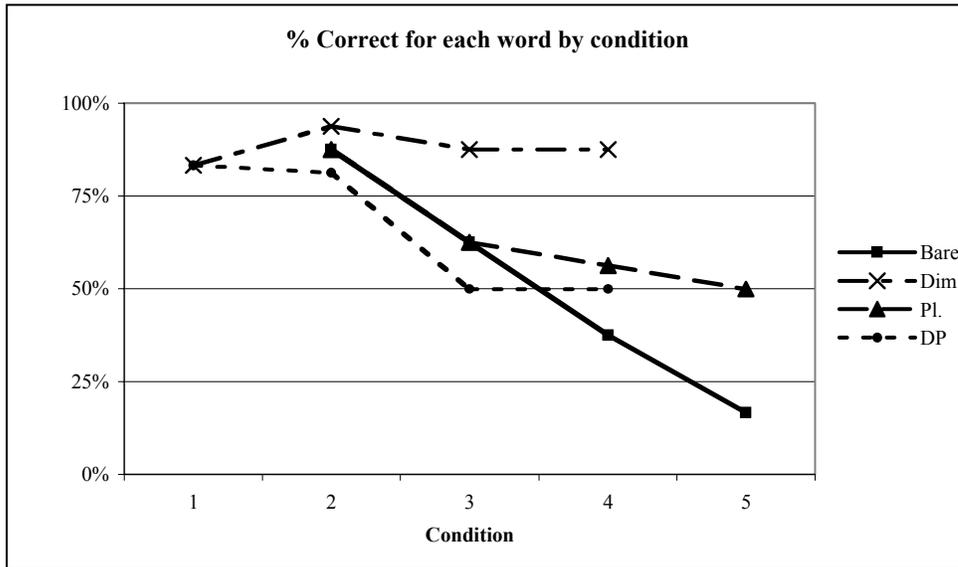


Figure 3: Graph of % correct for each paradigm type by condition

Finally, performance on the bare, plural and diminutive plural forms correlated with the ratio of transparent to opaque forms. As the ratio decreased, performance decreased as shown in the above graph.

This interaction is significant for each word type except diminutive forms, which is at ceiling for all conditions. Note that plural formation is close to linear ( $r=.73$ ) when a linear regression is conducted using the percent-transparent for each condition:

Word type	Intercept	Slope	P (slope)
Bare	-0.19	1.625	<.001
Diminutive	0.98	-0.16	.598
Plural	0.33	0.727	.055 <sup>7</sup>
Dim. Pl.	0.36	0.613	.036

**Table 11:** Linear regression of performance on all four conditions in experiment 1

<sup>7</sup> While this is barely not significant, it is extremely close and there is clearly a trend.

### 5.2.2.2 Test two

The percent correct for test two are as follows:

Cond	Dim Pl => Bare			Bare => Pl			%Tr
	i	e	a	i	e	a	
1	100%	92%	100%	100%	100%	100%	80%
2	100%	83%	83%	92%	<b>75%</b>	83%	60%
3	100%	<b>50%</b>	83%	100%	<b>50%</b>	<b>58%</b>	50%
4	100%	<b>25%</b>	<b>75%</b>	92%	<b>42%</b>	<b>50%</b>	40%
5	92%	<b>8%</b>	<b>75%</b>	100%	<b>50%</b>	<b>42%</b>	20%

**Table 12:** % correct in each condition for each stem type for both item types in test two

As above, bold cells are significantly below 100%, but above chance, bold shaded cells are not above chance, and dark cells with a light font are significantly below chance (one-tail t-tests).

#### Stems with *i*

Opacity had no impact on performance on plural formation and abstraction of stems with *i* as no variance in percent correct was attributable to condition for either test (ANOVA: Dim.Pl.=>Bare:  $F[1, 58]=2.300, p=0.135$ ; Bare=>Pl.:  $F[1, 58]=.733, p=0.383$ ).

#### Stems with *a*

In conditions 1 and 2, opacity had no impact on *a* nouns. For the formation of the plural form from the bare forms, participants were not above chance in conditions 3, 4, and 5, , however, nor were they below chance.

While participants were still able to select the correct UR for *a* words, even without the harmony generalization, participants did relatively worse in conditions 4 & 5.

While an analysis of variance is almost, yet not significant ( $F[1, 58]=3.053$ ,  $p=0.0859$ ), a two-sample t-test comparing conditions 1,2 and 3 to 4 and 5 is significant ( $t(77)=3.638$ ,  $p<.001$ ).

### Stems with *e*

As with *a* stems, command of the harmony generalization decayed in condition 3, at 50% transparent. For conditions 3, 4 and 5, participants were not above chance in their ability to select the correct *el* allomorph for mid vowel stems. Decreased performance on condition 2 did lead to a linear regression/ANOVA being significant, ( $t(58)=3.133$ ,  $p<.005$ ), so the ability to derive the harmony generalization was proportionally related to the number of observable transparent interactions of harmony. Furthermore, a linear regression using percent correct and percent transparent for each condition shows the correlation to be close to 1:1 ( $r=.9167$ ).

Participants were able to abstract underlying forms from the diminutive plural in conditions 1 and 2 for *e* stems, but this, too, suffered from increased opacity in the language. In condition 3, participants were not above chance, and in conditions 4 and 5, participants performed significantly below chance

### *5.2.2.3 Between-tests findings*

Finally, there are some interesting results when comparing performance on test one and test two. As noted above, plural formation began to show signs of decline in test one for *a* and *e* stems at around condition 3 and more definitively in condition 4, while in test two, performance seemed decline earlier, with participants having trouble in condition 3

across the board. Indeed, comparison of performance in conditions 3 and 4 for plural formation for both vowels was worse for test two than for test one. This difference is significant, or almost significant for each condition and significant across all conditions in a two-sample t-test:

Cond	Test one		Test two		P
	e	a	e	a	
3	63%	88%	50%	58%	.058
4	56%	88%	42%	50%	<.005
5	46%	75%	50%	42%	.067
Total	49%		67%		.019

**Table 13:** Comparison between performance on test one and test two for conditions 3-5 for plural formation.

### 5.2.3 Discussion

The above results motivate a number of different conclusions.

First, participants' ability to learn the vowel harmony generalization is dependent on the proportion of transparent forms in the stimuli. In test two, when transparency drops below 50%, vowel harmony ceases to be productive and participants could not select the correct plural allomorph for novel forms. Participants never reached below chance, however, because the data is not set up to establish an anti-harmony generalization.

In test one, performance was higher, but success in test one does not necessarily imply that participants acquired vowel harmony. For test one items it is also possible that participants used the diminutive plural forms to ascertain the appropriate plural form for each individual word. For example, the affix in the training form *katacil* could have motivated the correct form *tacil* as opposed to knowing that all *a* stems take *il* suffixes.

Indeed, the lack of positive evidence for harmony in surface forms, the results for *a* stem diminutive plurals and the results for test two suggest that this is, indeed, the case. This may be because of the effect the small number of nouns and the reuse of stems for both exposure and test has on performance. Thus, the opaque diminutive plural forms may have had the effect of both weakening the harmony generalization, as expected, as well as training the participants on the correct inflection for each individual noun as memorized knowledge.

The ability to learn the harmony generalization is also gradiently correlated with the proportion of transparent forms which has impact on the appropriate theory of opacity. A theory that has separate levels, with harmony being completely true at one level would not be able to accommodate this sort of gradient data, whereas a theory that has an independent constraint for opaque harmony, distinct from one for surface-true harmony, can.

For test one and two, the point at which lack of transparency affects acquisition is around 1:1, or 50% transparent (condition 3) to 2:3 (40%) (condition 4) which is significantly lower than what is predicted by the equation above where rules lose productivity somewhere between 74% and 60% (condition 2) using token or type frequency, respectively.<sup>8</sup> Furthermore, the correlation between percent correct and percent transparent is close to 1:1 for both test one and test two, suggesting the acquisition of harmony is veridically matched to the stimulus.

Second, participants ability to select the correct bare form given only the diminutive plural, particularly in test two, supports one of the two main hypotheses of

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<sup>8</sup> The equation  $n/\ln(n)$  yields 11 exception for 40 tokens (or 73% transparent) and 5 for 12 types (60% transparent).

this study: That language learners can derive URs that are different than SRs by using the grammar as a whole. This partially depends on enough having enough transparent forms as performance begins to degrade when transparency is at around 50%, in concert with losing the harmony generalization. So, participants were unable to use the evidence of pairs like *ged~kagadel* to derive *shep* from *kashapel*, as this analogy partially involves understanding the input-based harmony generalization.

For conditions 4 and 5 in both test one and test two, participants were actually below chance for selecting the bare form for *e* stems (consistently selected *shap* instead of the correct *shep*). So, in addition to there being no harmony generalization at these levels of transparency, participants used the surface forms (*kashap*, *kashapel*) to determine the underlying forms for words. Indeed, this even impacted familiar bare forms in test one, where they were not above chance and therefore alternated between using the bare form they heard or using the diminutive and diminutive plural realization of the stem. Thus, they began leveling the paradigm, selecting the surface form as the UR since no harmony generalization could provide information as to the underlying form for words like *kafasel*. In contrast, participants were significantly above chance for *a* stems potentially reflecting a bias towards select a UR matching the SR, all things being equal. Having more opaque forms does create some amount of ambiguity and confusion since the stimuli included examples where surface *a* correlated with underlying *e*, however.

Finally, in addition to learning a generalization that is not surface true, as well as potentially derive abstract URs for form distinct from any heard SRs, language learners learning an opaque interaction must also learn that the interaction is indeed opaque. This was tested by the formation of the diminutive plural in test one.

Participants were significant above chance in conditions 1 and 2. That is, they were able to select *kapashel* (versus transparent *kapashil*) despite only one form in the stimulus reflecting the opaque interaction (*kagadel*), while many forms reflected surface-true harmony (*vabil*, *peshel*). While this may seem intuitive at first, seen in light of the supposed unmarkedness of feeding transparent relationships, this is interesting. It suggests that the form *kagadel* was all participants needed to learn that the processes interacted opaquely and not transparently. This suggests a kind of morpheme faithfulness where allomorphy driven by the underlying form over-rides the preference for reduction feeding harmony, supporting Diagonal Correspondence Theory.

Participants were not above chance for this task in conditions 3-5 suggesting that participants had trouble recognizing that harmony and reduction apply opaquely yielding *CaC-el* surface forms for *e* stems. Thus, participants apparently attempted to include some number of *el* forms for surface *a* words randomly. So, participants likely recognized that some words with surface *a* took *el* suffixes, but there were not sure why given the equal distribution of *kagadel* and *tacil* stimuli.

### **5.3. EXPERIMENT 2**

Having explored the learnability of over-application opacity, the next natural step is to ask the same questions for under-application to explore whether it is similarly learnable, especially in light of the fact that under-application opacity is hypothesized to be more marked.

Under-application is argued to be more marked than over-application from the perspective of rule-based phonology based on the principle of maximization of rule

application. So, under-application is marked both because it is opaque since harmony is not surface true, and also because it reflects less rule utilization because harmony under-applies (Kiparsky, 1968; Kiparsky, 1972; Parker, *in press*). In contrast, over-application is only marked because it is opaque, but not with respect to rule utilization because harmony does apply (the under-application example is described further below):

(25) Contrast between under and over application opacity

a.	<u>Over-application</u>	b.	<u>Under-application</u>
	/ka-ged-il/		/ke-vab-il/
Harmony	ka-ged-el	Harmony	--
Reduction	ka-gad-el	Raising	kevebil
	[kagadel]		[kevebil]
Transparent	*[kagadil]		*[kevebel]

This assertion that under-application is more marked is countered by an assessment of markedness by comparing the constraint violations incurred by the two different types of opacity within OT. As discussed in chapter 1, over-application reflects harmonic bounding where no conceivable re-ranking of constraints can ever yield the actual opaque form. For example, in the forms above, the realization of the plural suffix as *el* reflects a violation of a faithfulness constraint that is unmotivated by a markedness constraint. So transparent *kadadil* violates a subset of the constraint violated by *kagadel* and is more marked in all respects. In contrast, under-application opacity only reflects a constraint ranking paradox where a re-ranking of constraint can yield the appropriate surface form –

the relative markedness of *kevebil* and *kevebel* is language dependent.

Experiment two is essentially a replication of experiment one, except with an under-application opacity, rather than over-application. This also allows for testing the acquisition of opaque generalizations, and the abstraction of underlying forms not heard in the stimulus, just as in experiment one. Furthermore, keeping everything the same between the two experiments can assess the hypothesis that under-application is more marked by comparing the results between the two experiments.

Therefore, even though there is no under-application in Shimakonde, all of the aspects of the artificial language modeled on Shimakonde (aside from the opaque interaction) were the same. The minimal modification that yields under-application instead of over-application is to change the diminutive prefix to *ke* and have it trigger raising of low vowels to mid vowels rather than triggering reduction. This is reflected in the language's name, *Kemeril* and in the following examples:

(26) Kemezil vowel lowering:

	<u>Stem</u>	<u>Diminutive</u>
a.	fin	ke-fin
b.	mez	ke-mez
c.	vab	ke-veb

Vowel harmony is the same:

(27) Kemeril vowel harmony:

	<u>Singular</u>	<u>Plural</u>
a.	fin	fin-il
b.	mez	mez-el
c.	vab	vab-il

And these two processes interact opaquely for stems with underlying low vowels<sup>9</sup>:

(28) Opaque interaction in Kemeril:

	<u>Singular</u>	<u>Plural</u>
a.	vab	ke-veb-il

This form is opaque because the mid vowel in the surface realization of the *a* noun stem does not trigger vowel harmony in the suffix. Instead, the suffix is determined by the underlying form of the noun, with underlying *a* (and *i*) taking the *il* suffix. Only an underlying *e* will therefore receive the *el* suffix independent of surface form.

### 5.3.1 Method

As mentioned above, an effort was made to hold everything constant between the two experiment, which is reflected in the experimental method.

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<sup>9</sup> That the opaque interaction is found on low vowel stems, rather than mid vowel stems reflects another small difference between the two experiments. This could have been avoided by having the prefix trigger raising of mid vowels to high (*mer* ~ *ki-mir*) and harmony changing underlying mid vowel affixes to high (*fin* ~ *fin-il*). This would have yielded an opaque under-application interaction for mid vowel stems (*ki-mir-el*) but would have changed the substance of the harmony generalization. It was anticipated that this chance would have had more of an effect and therefore made comparison more difficult than the one used.

#### *5.3.1.1 Participants*

Twenty native English speakers participated in the experiment. All were students at University of California, Berkeley and received course credit for participation. Their mean age was 23.0 and there were 14 women and 6 men. Participants were assigned randomly to one of five experimental conditions, with four in each condition.

#### *5.3.1.2 Stimulus*

All of the details concerning language stimulus in experiment 2 are the same as in experiment 1 except for the difference in the phonological process associated with the diminutive prefix outlined in (25-27). The language consisted of the same 30 stems, corresponding to the same 30 nouns, with four words for each: the bare form, the plural, the diminutive, and the diminutive plural. They were created by the same speaker as experiment 1 also using Praat.

#### *5.3.1.3 Procedure*

The experimental procedure was also the same as in experiment 1: 15 minutes of training stimulus consisting of word-picture pairings dictated by the experimental manipulation below.

#### *5.3.1.4 Experimental Manipulation*

The experimental manipulation is essentially the same as in experiment 1. Recall that each stem can combine with either or both of the two affixes yielding a paradigm. Each member of the paradigm provides different information about the phonological processes

of the language:

Element	Form	Meaning	UR	VHH	Raising
bare	vab	horse	x		
dim.	ke-veb	small horse			x
pl.	mez-el	dogs	x	x	
dim. pl.	ke-veb-il	small horses		Op	x

**Table 14:** Examples of each paradigm element and the information it provides about the grammar.

The bare form provides the learner with the UR; the diminutive serves as evidence for raising; the plural serves as evidence for harmony as well as the UR; and the diminutive plural provides evidence for raising as well as that harmony under-applies with respect to raising.

A subtle difference between the two experiments is that different stems provide the crucial evidence for each category. So, while *a* stems show the effect of prefixation and raising, *e* stems provide evidence for mid vowel harmony. This is the nature of the difference between the two types of opacity since under-application, by definition, does not exhibit the generalization in question. Therefore, a different form is required to show that generalization.

The paradigm categories are the same and test the same knowledge, but again, different stem types are involved.

Category	Bare	Dim.	Pl.	Dim. Pl.	Tests
None					H, UR, Op
Full	x	x	x	x	
Transp	x		x		Op
Opaque		x		x	UR

**Table 15:** Paradigm categories with included forms and what is tested

So, the transparent category includes the forms *ged* and *vab* with corresponding plurals *gedel* and *vabil*. Querying the diminutive plural for *vab* assess whether participants learned that raising and harmony apply opaquely (*kevebil*) or transparently (*kevebel*). If the opaque category includes *keveb* and *kevebil*, querying the bare, or underlying form, assesses whether the learner can use the suffix of *kevebil* to ascertain that the UR is *vab* and not *veb*.

The manipulation is the same in that it involves varying the ratio of transparent to opaque forms and observed how that impact the ability to acquire the harmony generalization and derive the correct UR from different SRs using that knowledge. Each of the 30 stems are assigned to one of the paradigm categories, including 18 in the None, or completely-withheld category. Because an equal number of each stem type is assigned to each category, the difference of opacity being realized on one stem type (*a* stems), and harmony being evident on another (*e* stems) has no impact on the stimulus.

The numbers of types and tokens of each stem type and of transparent and opaque forms for each condition are as follows:

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	3	3	3	2	1	0	18	3	0
Opaque	0	0	0	2	0	1	0	0	0
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>4</b>	<b>1</b>
<b>Token</b>				10			<b>300</b>	<b>40</b>	<b>10</b>

**Table 16:** Assignment of nouns to categories for condition 1

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	2	2	2	2	1	0	12	2	0
Opaque	1	1	1	2	0	1	6	0	1
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>3</b>	<b>2</b>
<b>Token</b>				10			<b>300</b>	<b>30</b>	<b>20</b>

**Table 17:** Assignment of nouns to categories for condition 2

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	1	1	1	2	1	0	6	1	0
Opaque	1	1	1	2	0	1	6	0	1
<b>Type</b>	<b>9</b>	<b>9</b>	<b>9<sup>10</sup></b>				<b>24</b>	<b>2</b>	<b>2</b>
<b>Token</b>				12			<b>288</b>	<b>20</b>	<b>20</b>

**Table 18:** Assignment of nouns to categories for condition 3

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	1	1	1	2	1	0	6	1	0
Opaque	2	2	2	2	0	1	12	0	2
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>2</b>	<b>3</b>
<b>Token</b>				10			<b>300</b>	<b>20</b>	<b>30</b>

**Table 19:** Assignment of nouns to categories for condition 4

Category	i	e	a	<i>Forms</i>	<i>F<sub>trans</sub></i>	<i>F<sub>opaque</sub></i>	Total	T <sub>trans</sub>	T <sub>opaque</sub>
None	6	6	6	0	0	0	0	0	0
Full	1	1	1	4	1	1	12	1	1
Transp	0	0	0	2	1	0	0	0	0
Opaque	3	3	3	2	0	1	18	0	3
<b>Type</b>	<b>10</b>	<b>10</b>	<b>10</b>				<b>30</b>	<b>1</b>	<b>4</b>
<b>Token</b>				10			<b>300</b>	<b>10</b>	<b>40</b>

**Table 20:** Assignment of nouns to categories for condition 5

As an example, the stimulus for condition 2 consisted of the following thirty form types,

<sup>10</sup> Three words not used so there was an equal number of transparent and opaque forms.

each repeated ten times for a total of 300 tokens.

Noun	Par.Cat.	Bare	Dim	Pl.	Dim. Pl.
vab	full	vab	keveb	<b>vabil</b>	<b>kevebil</b>
tac	trans	tac		<b>tacil</b>	
cav	trans	cav		<b>cavil</b>	
that	opaque		kethet		<b>kethetil</b>
ged	full	ged	keged	gedel	kegedel
pesh	trans	pesh		peshel	
mez	trans	mez		mezel	
shep	opaque		keshep		keshepel
kim	full	kim	kekim	kimil	kekimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	opaque		kezij		kezijil
Total		<b>9</b>	<b>6</b>	<b>9</b>	<b>6</b>

**Table 21:** Stimulus words for condition two, experiment 2.

Of the thirty, three (*gedel*, *peshel* and *mezel*; each repeated ten times) provide transparent evidence that mid vowels take the mid vowel suffix, while two (*kevebil*, *kethetil*) are opaque yielding a 60% proportion of transparent forms. The full lists of stimuli for the other conditions are in Appendix II.

A summary of the number of tokens of each form for the five different conditions is as follows:

Condition	Bare	Dim	Pl.	Dim. Pl.	Total	Tr/(Tr+Op)
1	120	30	120	30	300	80%
2	90	60	90	60	300	60%
3	72	72	72	72	288	50%
4	60	90	60	90	300	40%
5	30	120	30	120	300	20%

**Table 22:** Number of each word type for each condition in experiment 2

### 5.3.1.5 Tests

The tests for this experiment are essentially the same as above except for a couple of differences as to which stems provide evidence for the phonological knowledge of the participants.

In test one, participants are tested on members of the paradigm withheld for known noun stems. Paradigm elements were withheld for nouns in the Transparent and Opaque paradigm categories. For nouns in the transparent paradigm category (e.g. *vab* ‘cat’) the participant will have heard *vab* and *vabil*. The familiar test items tested their ability to recall these items, while the unfamiliar test items tested their ability to correctly form the diminutive and diminutive plural. The diminutive choices were *keveb* and *kebab*, testing fluency with the raising generalization while the diminutive plural choices were the correct and opaque *kevebil* and the transparent, incorrect *kevebel*. This tested whether subjects knew that the two processes interacted opaquely. For the two nouns *tac* ‘dog’ and *mez* ‘bird’ in the Opaque paradigm category, participants will have heard the diminutive *ketec* and *kemez* and the diminutive plural *ketecil* and *kemezil*. The unfamiliar test items ask whether participants can correctly form the bare and plural forms. The bare form for *ketecil* requires that participants derive *tac* as the UR based on the suffix and not based on the heard surface form, *tec*, which is the other choice. Plural formation assess whether participants acquired harmony and can correctly select *mezel* based on mid vowel harmony instead of *mezil* based on the occurrence of the *il* suffix with surface mid vowels as in *ketecil*.

In test two, for one item type, participants saw a picture of a new noun, for example a mouse, heard *shep*, then saw a picture of many large mice and had to select

either *shepel*, reflecting knowledge of harmony, or *shepil* reflecting the fact that (opaque) stimulus items had *il* for surface *e* stem vowels. For the other test two item type, participants saw a picture of many small instances of a new noun, for example, many small pigs, heard *kewemil*, saw a picture of a single large pig and had to correctly select *wam* as the underlying form, rather than the heard *wem*.

Time constraints and number of test items is the same as above as is the proportion of familiar and unfamiliar items (table 9).

The following results are of primary interest:

First, the ability to select the correct bare form for *a* stems suggests that participants are able to derive underlying forms that are distinct from any heard realizations of a morpheme.

Second, performance on the selection of the plural and diminutive plural for *a* stems reveals participants' knowledge of the harmony generalization as well as that raising interacts opaquely with harmony, rather than transparently.

Finally, performance on the plural and diminutive plural for *e* stems also assesses proficiency with harmony since opaque *a* words with the *el* suffix provide counter evidence for harmony suggesting (incorrectly) that *il* appears randomly with surface *e*.

## **5.3.2 Results**

### *5.3.2.1 Test one*

The following are the percent correct for test one items for each of the conditions for familiar and unfamiliar words across all four subjects for each vowel. In bold and shaded are scores not significantly above chance, while bold and reverse colors are significantly

below chance.

i	Familiar				Unfamiliar				Total				
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP
1		97%	88%	84%	88%		96%		79%	97%	94%	84%	81%
2		88%	100%	96%	88%	100%	94%	100%	100%	91%	97%	97%	94%
3		94%	88%	94%	81%	100%	88%	100%	100%	96%	88%	96%	88%
4		88%	92%	88%	92%	81%	88%	88%	88%	84%	91%	88%	91%
5		100%	91%	100%	84%	83%		96%		88%	91%	97%	84%

**Table 23:** Percent correct for *i* stems across all subjects for test one, experiment two

e	Familiar				Unfamiliar				Total				
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP
1		91%	100%	97%	100%		83%		96%	91%	88%	97%	97%
2		83%	88%	96%	81%	88%	81%	100%	94%	84%	84%	97%	88%
3		81%	81%	88%	<b>69%</b>	88%	88%	100%	100%	83%	83%	92%	79%
4		81%	79%	81%	<b>71%</b>	81%	88%	<b>75%</b>	75%	81%	81%	78%	72%
5		88%	81%	88%	84%	92%		<b>71%</b>		91%	81%	75%	84%

**Table 24:** Percent correct for *e* stems across all subjects for test one, experiment two

a	Familiar				Unfamiliar				Total				
	Cond	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP	Bare	Dim	Pl.	DP
1		97%	100%	94%	88%		75%		83%	97%	81%	94%	84%
2		96%	94%	96%	94%	100%	81%	100%	88%	97%	88%	97%	78%
3		94%	94%	88%	100%	88%	<b>75%</b>	<b>75%</b>	<b>75%</b>	92%	88%	83%	92%
4		94%	88%	81%	96%	<b>19%</b>	88%	<b>69%</b>	<b>63%</b>	56%	88%	75%	88%
5		100%	91%	88%	88%	<b>13%</b>		<b>67%</b>		34%	91%	<b>72%</b>	88%

**Table 25:** Percent correct for *e* stems across all subjects for test one, experiment two

Participants did significantly better on familiar words than unfamiliar words across all vowels (.89 vs. .81;  $t(1155)=4.73, p<.001$ ) and for the opaque *a* vowel (.93 vs. .66). For *i* and *e*, participants were close to ceiling for both familiar and unfamiliar items and were therefore not significantly different.

### Stems with *i*

Participants had no trouble with any of the familiar or unfamiliar words as performance was significantly above chance for every single word.

### Stems with *e*

For *e* stems, participants were above chance for all familiar and unfamiliar bare and diminutive forms. For formation of the plural (*gedel*), participants were above chance for all familiar words, but below chance for unfamiliar word in conditions 4 and 5. Similarly, participants were not above chance for the diminutive plural in condition 4.

These results can be compared to the results in experiment one, though to the *a* stems, and not the *e* stems. This because the *e* stems in experiment two are not the opaque items, but serve as the evidence for transparent surface harmony. Similarly, in experiment one, *a* stems are not opaque, but reflect surface true harmony.

Comparing the results for unfamiliar plural (harmony) words between the two tests shows no significant difference, while the diminutive plural is significant different with experiment one at 79% and experiment two at 93% (two-sample t-test:  $t(93)=-2.19$ ,  $p<.05$ )

For familiar diminutive plurals, participants were surprisingly not above chance for conditions 3 ( $t(15)=1.57$ ,  $p=.138$ ) and 4 ( $p=.064$ ). These results may be considered anomalous in light of the findings for unfamiliar diminutive plural (no other words across all experiments shows worse performance for familiar than unfamiliar) and the formation of the diminutive plural in conditions 2 and 3 (all above chance) and it is likely that these are outliers.

### Stems with *a*

In conditions 1 and 2, participants showed no trouble with any of the words, performing above chance on all of them. Participants were also above chance for every familiar word

in all conditions.

For the formation of the plural, participants were not above chance in conditions 3-5 and performance was also gradient, as shown by a linear regression ( $F[1,54]=4.543$ ,  $p<.05$ ) with a slope of  $r=.73$ . Performance on the formation of the diminutive plural was essentially the same, with performance similarly not above chance for conditions 3-5.

Formation of the bare forms – abstracting an underlying form different from any heard example – was significantly below chance for conditions 4 and 5 meaning participants were inclined to select *e* as the underlying vowel based on the diminutive and diminutive plural forms (e.g. *tec* from hearing *ketec* and *ketecel*).

Participants were not above chance for the diminutive in condition 4, perhaps owing to the low number of trials (2 per participant).

In comparing the results across experiments for the opaque *a* stems and the opaque *e* stems in experiment 1 across all conditions none of the forms were significantly different, but focusing on conditions 3, 4 and 5, suggests some potentially interesting differences had there been more trials. First, for the diminutive plural participants did worse in experiment 1 (50% vs. 69%) though this was not significant (two-sample t-test  $t(30)=-1.07$ ,  $p=.17$ ). Second, plural formation was better in experiment 1 for conditions 3, 4, and 5 (.52 vs. .69) but also not significantly ( $t(93)=-1.68$ ,  $p=.09$ ).

#### 5.3.2.2 Test two

As with experiment one, the trials in test one may not have accurately captured the productivity of the harmony generalization because there were no stems presented that did not have either the plural or diminutive plural in the stimulus. This could have also

impacted the formation of the bare forms and the diminutive plural since knowledge of harmony is crucial to acquiring the opaque interaction of the plural with raising. This was remedied in test two by testing on completely novel stems. The percent correct for each are as follows:

Cond	Dim Pl => Bare			Bare => Pl			%Tr
	i	e	a	i	e	a	
1	92%	100%	100%	100%	100%	100%	80%
2	100%	92%	100%	83%	83%	92%	60%
3	100%	83%	<b>67%</b>	100%	<b>58%</b>	<b>58%</b>	50%
4	92%	<b>83%</b>	<b>50%</b>	92%	<b>67%</b>	<b>50%</b>	40%
5	100%	<b>75%</b>	<b>25%</b>	92%	<b>58%</b>	<b>42%</b>	20%

**Table 26:** Percent correct in each condition for each stem type for both item types in test two fir experiment 2

#### Stems with *i*

Opacity had no significant impact on performance on either test item type (ANOVA: Dim. Pl.=>Bare:  $F[1, 58]=.504, p=.480$ ; Bare=>Pl.:  $F[1,58]=.26, p=.61$ ).

#### Stems with *e*

In the formation of the plural, participants were not above chance for conditions 3-5 and a linear regression is significant ( $F[1, 58]= 6.63, p<.05$ ) for a slope of .71. For the formation of the bare form, participants were above chance for all conditions except 5 and a linear regression is almost significant ( $F[1, 58]=3.71, p=.059$ ).

#### Stems with *a*

Performance on the plural formation for *a* stems is above chance for conditions 1 and 2

and at chance for conditions 3-5 and a linear regression is significant ( $F[1,58]= 16.069$ ,  $p<.001$ ). For the formation of the bare forms from the diminutive plural, participants were not above chance in condition 3, and significantly below chance in condition 5 and a linear regression is also significant ( $F[1, 58]=30.6$ ,  $p<.001$ ) with a slope of  $r=1.08$ .

As before, comparing these results to the results of experiment one requires flipping the vowels such that *e* is compared to *a* and *a* is compared to *e* so opaque forms are compared to opaque forms across the two experiments:

T2	Dim Pl => Bare				Bare => Pl			
	Exp 1		Exp 2		Exp 1		Exp 2	
Cond	Op ( <i>e</i> )	Tr ( <i>a</i> )	Op ( <i>a</i> )	Tr ( <i>e</i> )	Op ( <i>e</i> )	Tr ( <i>a</i> )	Op ( <i>a</i> )	Tr ( <i>e</i> )
1	92%	100%	100%	100%	100%	100%	100%	100%
2	83%	83%	100%	92%	75%	83%	92%	83%
3	50%	83%	67%	83%	50%	58%	58%	58%
4	25%	75%	50%	83%	42%	50%	50%	67%
5	8%	75%	25%	75%	50%	42%	42%	58%
Total	52%	83%	68%	87%	63%	67%	68%	73%

**Table 27:** Comparison of test two between experiment 1 and 2

The only difference that is significant is the difference between performance on forming the bare form from the diminutive plural for the opaque vowels (e.g. Exp1: *ged* from *kagadel*; Exp. 2: *vab* from *kevebil*;  $F[1,117]=5.49$ ,  $p<.05$ ). Otherwise, performance was the same.

### 5.3.3 Discussion

The results on the formation of the bare form of the diminutive plural in conditions 1 and 2 suggest that, as with over-application, under-application opacity is learnable. Participants had no trouble acquiring the opaque interaction, which was shown to be

productive for both novel words for known nouns (test one) and novel nouns (test two).

As the proportion of transparent forms decreased, so too did participants ability to learn both the opaque harmony generalization and the opaque interaction as reflected in the significances of the linear regression for both test items. As with experiment 1, this effect was close to linear, or 1:1, with the percent correct closely matching the proportion of transparent forms in the stimulus.

In the formation of bare forms, the percent correct was below chance for condition 5 as participants selected *veb* given forms like *kevebil* instead of the correct *vab* as suggested by the suffix allomorph. This effect was only found in condition 5, however and not in conditions 3 and 4 where the harmony generalization is no longer productive. This suggests that while the precise nature of harmony is not known, participants still recognize that there is some sort of input-output relationship in the data. For under-application, this only requires knowledge of an *a*-stem UR – *il* affix relationship and not harmony (because it under-applies). This allow for the delay of leveling of the paradigm, as found in paradigm one, and participants are still unsure of the UR for *kevebil* until there are virtually know *a* stems in the stimulus in conditions 5.

Finally, comparing the formation of the bare forms in test two for opaque items in experiment one and experiment two provides insight into the learnability and markedness of under-application relative to over-application. Above, the principle of maximal rule usage – which is still generally accepted as a principle assessing markedness (e.g. Parker, *in press*) - was contrasted with the principle of constraint violations making different predictions as to whether over-application or under-application was more marked. Under-application is more marked in terms of rule application by definition since harmony

under-applies. On the other hand, over-application is more marked in terms of constraint violations because in over-application, opaque forms are harmonically bound by the transparent form, and therefore incur more constraint violations. These results support the latter view.

#### **5.4. CONCLUSION**

In this chapter, I presented the results of a set of experiments testing the acquisition of opaque interactions and the conditions which may impact learnability. Of primary interest are the effects of the type of opacity – under-application versus over-application – and of the proportion of transparent to opaque forms in the stimulus on acquisition. Furthermore, learning opaque interactions is not a singular process and involves a number of components. Participants must be able to learn phonological generalizations that are not true of all surface forms and many cases of phonological opacity require a process of abstraction wherein underlying representations are formed for words that may not have a corresponding SR.

The results suggest that the ratio of transparent to opaque forms in the stimulus has a significant gradient effect on participants' ability to acquire opacity and opaque generalizations. This bears on theories of opacity in two ways. First, it introduces a new dimension to the typological and historical study of opacity. While opacity is generally simply considered marked, the ability of an opaque relationship to be learned and persist in a language also depends on the relative frequency of opaque to transparent forms. This accords with theories of markedness that are based on frequency (Hume, 2003) rather than one based on any inherent properties of a phonological generalization. Thus, opacity

in language can be stable so long as the lexicon is such that there are enough transparent forms to learn the opaque generalization. As the lexicon shifts and the relative frequency of opaque and transparent forms changes, the markedness of opaque interactions may lead to its eventual disappearance as seen when the percentage of transparent forms dropped below 50%.

This particular ratio – 50% - can also be considered with respect to the predictions made on the effect of exceptions on learning. Based on the formulation in Yang (2005), the prediction would be that the harmony generalization degenerates at between 25%-40% opaque. In contrast, Hudson Kam and Newport (2005) suggest the adults reproduce variable input veridically, with output tracking with input. The results support with latter approach as a linear model comparing percent correct to percent transparent in the input was close to 1 for all of the results for plural formation.

Second, this result suggests that any theory of opacity must have a unique set of constraints or rules for opaque interactions independent of the constraints for transparent interaction based on the gradient performance in the experiments. Gradience in phonology in OT has been modeled through constraint re-ranking. For example, if flapping in English occurs 50% of the time, this is modeled through the variable ranking of the flapping constraint over the constraint maintaining the underlying form of a /t/ or /d/ 50% of the time. If opaque generalizations can be similarly gradient, this requires that there base a constraint for it that can be ranked variably. In stratal OT, for example, this is not the case. Opacity is generated through the serial ordering of processes. So, for the artificial languages above, harmony would be true at one level for one phonological grammar, while reduction/raising would occur afterwards in another grammar, rendering

it opaque. There is no interaction between the two levels, however. Therefore there is no way to establish opaque interaction as marked, or that opaque interactions affect the learnability of the generalization at the first level. On the other hand, a theory like Diagonal Correspondence has a constraint for opaque harmony and transparent harmony. Based on ambiguous stimulus, this can be variably ranked with respect to transparent harmony so that there is gradient knowledge of the opaque interaction.

The results also suggest that over-application is more marked, or harder to learn, than under-application. This runs counter to the prevailing assumption that phonological systems seek the maximization of rule application. An alternate theory of markedness is based on the idea of constraint violations which makes the opposite prediction and accords with the results of these experiments.

Lastly, these results show that phonological opacity and abstract URs can, indeed, be acquired. This is no trivial finding in light of some theories that advocate for a direct/realist approach to phonology where the only generalizations that are known are those that are true of surface forms. This parallels these approaches' stance on underlying representations where underlying forms are not abstracted from surface forms, but are instead selected or amalgamated from surface forms. Thus, if a learner without the capability to abstract hears a form like *kagadel*, as in the experiments above, she is limited to selecting *gad* as the representation of the morpheme. In cases of opacity, however, this form could arise from underlying *ged*. A learner with some capacity for abstraction can correctly derive this UR with proper knowledge of the phonology of the language by using the suffix to ascertain that the UR. The experimental results reported here suggest that this is, indeed, a capability language learners have.

**Appendix I:** All stimuli for each condition for experiment one

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	kavab	vabil	kavabil
tac	trans	tac		tacil	
cav	trans	cav		cavil	
that	trans	that		thatil	
ged	full	ged	kagad	gedel	kagadel
pesh	trans	pesh		peshel	
mez	trans	mez		mezel	
shep	trans	shep		shepel	
kim	full	kim	kakim	kimil	kakimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	trans	zij		zijil	
<b>Total</b>		<b>12</b>	<b>3</b>	<b>12</b>	<b>3</b>

Table 29: Stimulus words for condition 1

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	kavab	vabil	kavabil
tac	trans	tac		tacil	
cav	trans	cav		cavil	
that	opaque		kathat		kathatil
ged	full	ged	kagad	<b>gedel</b>	<b>kagadel</b>
pesh	trans	pesh		<b>peshel</b>	
mez	trans	mez		<b>mezel</b>	
shep	opaque		kashap		<b>kashapel</b>
kim	full	kim	kakim	kimil	kakimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	opaque		kazij		kazijil
<b>Total</b>		<b>9</b>	<b>6</b>	<b>9</b>	<b>6</b>

Table 30: Stimulus words for condition 2

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	kavab	vabil	kavabil
cav	trans	cav		cavil	
that	opaque		kathat		kathatil
ged	full	ged	kagad	gedel	kagadel
mez	trans	mez		mezel	
shep	opaque		kashap		kashapel
kim	full	kim	kakim	kimil	kakimil
bis	trans	bis		bisil	
zij	opaque		kazij		kazijil
<b>Total</b>		<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>

Table 31: Stimulus words for condition 3

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	kavab	vabil	kavabil
tac	transp	tac		tacil	
cav	opaque		tacav		kacavil
that	opaque		kathat		kathatil
ged	full	ged	kagad	gedel	kagadel
pesh	transp	pesh		peshel	
mez	opaque		kamaz		kamazel
shep	opaque		kashap		kashapel
kim	full	kim	kakim	kimil	kakimil
fin	transp	fin		finil	
bis	opaque		kabis		kabisil
zij	opaque		kazij		kazijil
<b>Total</b>		<b>6</b>	<b>9</b>	<b>6</b>	<b>9</b>

Table 32: Stimulus words for condition 4

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	kavab	vabil	kavabil
tac	opaque		katac		katacil
cav	opaque		tacav		kacavil
that	opaque		kathat		kathatil
ged	full	ged	kagad	gedel	kagadel
pesh	opaque		kapash		kapashel
mez	opaque		kamaz		kamazel
shep	opaque		kashap		kashapel
kim	full	kim	kakim	kimil	kakimil
fin	opaque		kafin		kafinil
bis	opaque		kabis		kabisil
zij	opaque		kazij		kazijil
<b>Total</b>		<b>3</b>	<b>12</b>	<b>3</b>	<b>12</b>

Table 33: Stimulus words for condition 5

**Appendix II:** All stimuli for each condition for experiment two

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	keveb	vabil	kevebil
tac	trans	tac		tacil	
cav	trans	cav		cavil	
that	trans	that		thatil	
ged	full	ged	keged	gedel	kegedel
pesh	trans	pesh		peshel	
mez	trans	mez		mezel	
shep	trans	shep		shepel	
kim	full	kim	kekim	kimil	kekimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	trans	zij		zijil	
Total		<b>12</b>	<b>3</b>	<b>12</b>	<b>3</b>

Table 34: Stimulus words for condition 1

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	keveb	vabil	kevebil
tac	trans	tac		tacil	
cav	trans	cav		cavil	
that	opaque		kethet		kethetil
ged	full	ged	keged	<b>gedel</b>	<b>kegedel</b>
pesh	trans	pesh		<b>peshel</b>	
mez	trans	mez		<b>mezel</b>	
shep	opaque		keshep		<b>keshepel</b>
kim	full	kim	kekim	kimil	kekimil
fin	trans	fin		finil	
bis	trans	bis		bisil	
zij	opaque		kezij		kezijil
Total		<b>9</b>	<b>6</b>	<b>9</b>	<b>6</b>

Table 35: Stimulus words for condition 2

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	keveb	vabil	kevebil
cav	trans	cav		cavil	
that	opaque		kethet		kethetil
ged	full	ged	keged	gedel	kegedel
mez	trans	mez		mezel	
shep	opaque		keshep		keshepel
kim	full	kim	kekim	kimil	kekimil
bis	trans	bis		bisil	
zij	opaque		kezij		kezijil
<b>Total</b>		<b>6</b>	<b>6</b>	<b>6</b>	<b>6</b>

Table 36: Stimulus words for condition 3

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	keveb	vabil	kevebil
tac	transp	tac		tacil	
cav	opaque		kecev		kecevil
that	opaque		kethet		kethetil
ged	full	ged	keged	gedel	kegedel
pesh	transp	pesh		peshel	
mez	opaque		kemez		kemezel
shep	opaque		keshep		keshepel
kim	full	kim	kekim	kimil	kekimil
fin	transp	fin		finil	
bis	opaque		kebis		kebisil
zij	opaque		kezij		kezijil
<b>Total</b>		<b>6</b>	<b>9</b>	<b>6</b>	<b>9</b>

Table 37: Stimulus words for condition 4

<b>Noun</b>	<b>Par.Cat.</b>	<b>Bare</b>	<b>Dim</b>	<b>Pl.</b>	<b>Dim. Pl.</b>
vab	full	vab	keveb	vabil	kevebil
tac	opaque		ketec		ketecil
cav	opaque		kecev		kecevil
that	opaque		kethet		kethetil
ged	full	ged	keged	gedel	kegedel
pesh	opaque		kepesh		kepeshel
mez	opaque		kemez		kemezel
shep	opaque		keshep		keshepel
kim	full	kim	kekim	kimil	kekimil
fin	opaque		kefin		kefinil
bis	opaque		kebis		kebisil
zij	opaque		kezij		kezijil
<b>Total</b>		<b>3</b>	<b>12</b>	<b>3</b>	<b>12</b>

Table 38: Stimulus words for condition 5

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