

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; Prince & Smolensky, 1993/2004), opacity is challenging for any theory that seeks to express generalization based solely on output.

In Shimakonde (Liphola, 2001; 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.

If we juxtapose the behavior of two different kinds of a tone shift we see similar

behavior. The following examples show a high-tone shift to prominent position as found in Zulu (2a; Downing, 1990a) versus a shift one tone-bearing unit (TBU) to the right as found in Jita (2b; 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 one 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.

Despite the substantive 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 a 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 articulated 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) /p₁e₂t₃-i₄l₅/
 ↓ ↓ ↓ ↓ ↓
 [p₁a₂t₃ee₄l₅]

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 represents 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.¹ 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,

¹ 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/
y→ø/V_V	tee	ee→ie	--
ee→ie	tie	y→ø/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 ²	‘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

² 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/ \rightarrow nabi

b) $N \rightarrow \emptyset / _ S$ /N-supá/ \rightarrow supá

Yao

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

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

Mandar

e) $N \rightarrow T / _ T$ /maN-tunu/ \rightarrow 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 ^w ats	‘stick (v.)’
mətsar	‘thief’
k ^w etʃepe	‘bacteria’
pirek	‘noon’
pytʃæk ^w	‘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] C₀ __

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_ɔ 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 *ʔaʔa*, 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 Mandar 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 _o	PARSE[-VOICE]
ntum			*	
→nd<-voice>um				*
num	*!			
nn<-son>um		*!		

In addition to the ranking of *NC_o » 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]	*NC _o	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

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 _{TONIC}	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) _{TONIC}	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 *kúpátííla* without improving the overall harmony³ of the SR in any way. No conceivable ranking of constraints will result in *kúpátééla* being a better candidate than *kúpátííla*. 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-ííla], which has the same output as the most optimal output in the tableau in (22). Thus, while [kú-pat-ííla] 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:

³ Harmony in the general OT sense, not in the VHH sense.

(23) Palatal harmony

Lexical

- a) pambaz ‘blood’ pembe₃ ‘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:

gəli_ɟpa ‘rich’

sy_ɟɓ ‘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_{ón}-a ‘to get/see’
- b) o-ku-β_{on}-ér-a ‘to get for’
- c) o-ku-β_{on}-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(α 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)⁴.

(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	*		

⁴ 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.)

gét ‘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], wd[σ]), combined with a constraint requiring that the high feature from the root not be deleted (MAX_{RT}(HIGH)):

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

/i-so /	MAX _{RT} (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'	salætum	'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

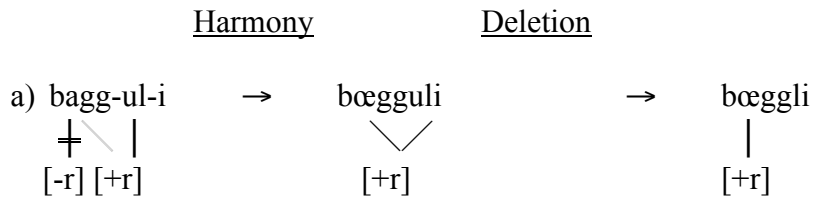
The added naturalness of the type of relationship expressed by alpha rules, where a feature specification is shared between two segments can be expanded further through the use of autosegments.

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.

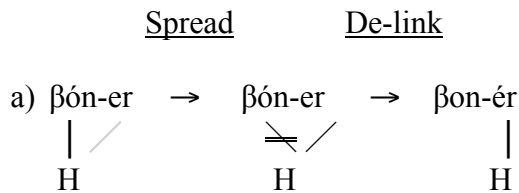
The use of AP remedies the phonetic arbitrariness problem for harmony and umlaut by virtue of constraining possible featural transformations to either the spreading or de-linking of autosegmental features. For example, the spreading of [+round] in Icelandic is a formally simple – and therefore natural – 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

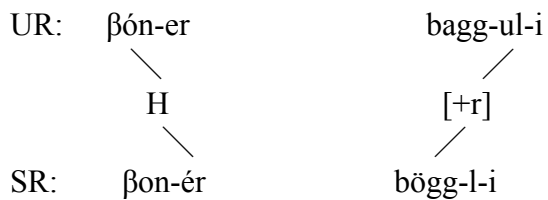


The use of AP is orthogonal to the choice of formal processes over representations. Here, the accounts of umlaut and tone shift are in fact a sequence of two autosegmental rules: spreading followed by deletion or de-linking.

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: ɓəj-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 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	$V \rightarrow V:/ _]_{\sigma}$ $V[-\text{long}] \rightarrow [-\text{ATR}] / [-\text{ATR}] C _ _$	/t-ʃl:bIʃ/ → ?rtʃibi:ʃ (cf. nʃi:b)
	Yokuts epenthesis	$\emptyset \rightarrow i/C _ CC$ $V[\alpha hi] \rightarrow [+rd] / [\alpha hi, +r] C _ _$	/ʔugn-hin/ → ?ugunhun
	Turkish epenthesis	$\emptyset \rightarrow i/CC\#$ $V[+hi] \rightarrow [\alpha r, \alpha bk] / [\alpha r, \alpha bk] C _ _$	/hykm/ → hykym /metn/ → metin
Env.	Icelandic deletion	$V[-\text{stress}] \rightarrow \emptyset / _ _ [\text{COR}] V$ $V \rightarrow [+rd] / _ C_0 u$	/bagg-il-u/ → bægglu

(49) Bleeding

Type	Process	Example rules	Form
Focus			
Env.	Yokuts epenthesis	$V[\alpha hi] \rightarrow [+rd] / [\alpha hi, +r] C _ _$ $\emptyset \rightarrow i/C _ CC$	/logw+ʔas/ → logiwʔas *logiwʔos

(50) Counter-bleeding

Type	Lg./Process	Example rules	Form
Focus	Yokuts epenthesis	V[α h]→[+r]/[α h, +r] C__ [+hi, +lg]→[-hi]	/c'uyi:+l/→c'uyol *c'uyal
Env.	Shimakonde reduction	V→[-high]/[-high, +lo] C__ V→[+lo]/__σ _{wd}	/ku-pet-il-a/→kupateela
	West Greenlandic (Cearley, 1976) epenthesis/deletion	V→[+phar]/__q q→ø/_C ø→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.pɪd

(51) Counter-feeding

Type	Lg./Process	Example rules	Form
Focus	Mafa epenthesis	V→[-bk]/__C [-bk] ø→ə/CC	/ðek-d-a/→ðekəda *ðekida
	Maltese (Puech, 1978) shortening	V→[+rd]/[-lng, +rd] C_ V:→V/_σ	/kitib-u:-l-ok-ʃ/→kitibulékʃ (cf. kitib-om-l-ok)
	Agulus (Armenian) Vaux, 1998) epenthesis	V→[+bk]/[+bk] C ₀ __ ø→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[α h]→[+r]/[α 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 *vandeepeela
	Icelandic epenthesis	V→[+rd]/_C ₀ u ø→u/C_r	/dag+r/→dagur *dögur
	Kalong (Hyman, 2002) tensing	V→[+ATR]/ [+ATR] C ₀ __ V→[+ATR]/__]σ	/kù-lik-a/→kù-lik-a (cf. /kù-tím-à/→kù-tím-è)
	Sea Dayak (K&K, 1979) deletion	V→[+nasal]/ [+nasal] __ C {+voice}→Ø/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.⁵

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

⁵ 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/ → fætnuðum. The suggested derivation (Anderson, 1974) is /fátnað+um/ → fátnaðum → fátnoðum → fátnuðum → fætnuðum. 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/	vandeépeéla	~	vandaápeéla	‘they will harvest for’
b) /vandá-im-il-a/	vandémíila	~	vandemííla	‘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*[aj]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 əɾ/ [hɛ.p əɾ] ‘have her’

b) Transparent lack of devoicing with affixation

/hɛb ərd/ [hɛ.bərt] ‘greedy person’

/hɛb ən/ [hɛ.bɛn] ‘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	~	mɪ.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:v⁶), 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.sɪk]. Therefore, at the word level, harmony and affixation interact opaquely representing a case of intra-level opaque rule ordering.

⁶ 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. /tʃun/+ /fen/ → tʃun.fen) ‘spring equinox’

LM LM → H LM

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

H H → 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 nd tone		
1 st 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>1st 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>1st 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.