1996

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Studies in Afroasiatic Grammar

Papers from the
Second Conference on
Afroasiatic Languages
Sophia Antipolis, 1994

edited by
Jacqueline Lecarme, Jean Lowenstamm & Ur Shlonsky

Holland Academic Graphics
The Hague

1996

Ritter, Elizabeth (1991) Two Functional Categories in Noun Phrases: Evidence from Modern Hebrew, In *Syntax and Semantics* 26, ed. Susan Rothstein, 37–62. Academic Press, San Diego.

Rouveret, Alain (1994) Syntaxe du gallois: le groupe nominal, Ms., Université de Paris VIII.

Shlonsky, Ur (1991) Hebrew Construct State Nominals, Arabic Verb-Initial Clauses and the Head Movement Constraint, Ms., Université du Québec à Montréal.

Siloni, Tali (1990) Hebrew Noun Phrases: Generalized Noun Raising, Ms., Université de Genève.

Siloni, Tali (1994) *Noun Phrases and Nominalizations*, Doctoral dissertation, Université de Genève.

Szabolcsi, Anna (1981) The possessive construction in Hungarian: a configurational category in a non-configurational language, *Acta Linguistica Academiae Scientiarum Hungaricae* 31:261–289.

Szabolcsi, Anna (1983) The possessor that ran away from home, *The Linguistic Review* 3:89–102.

Szabolcsi, Anna (1989) Noun phrases and clauses: is DP analogous to IP or CP?, to appear in *The Structure of Noun Phrases*, ed. John Payne. Mouton de Gruyter, Berlin.

Travis, Lisa (1984) *Parameters and Effects of Word Order Variation*, Doctoral dissertation, MIT, Cambridge, Massachusetts.

Woisetschlaeger, Erich (1983) On the Question of definiteness in 'An Old Man's Book', *Linguistic Inquiry* 14, 1:137–154.

Remarks on Phonological Opacity in Optimality Theory

John J. McCarthy *

βλέπομεν γὰρ ἄρτι δι' ἐσόπτρου ἐν αἰνίγματι
1 Corinthians 13: 12

1 *Introduction*

Opacity is a measure of how well the context or consequences of a phonological process can be determined from examination of surface structure. Kiparsky (1971, 1973: 79) introduced this notion, defining it approximately as follows:

(1) Opacity
A phonological rule $\mathcal{P}$ of the form A → B / C_D is *opaque* if there are surface structures with any of the following characteristics:
a. instances of A in the environment C_D.
b. instances of B derived by $\mathcal{P}$ that occur in environments other than C_D.
c. instances of B not derived by $\mathcal{P}$ that occur in the environment C_D.
A rule without these characteristics is *transparent*.

Kiparsky's concern is with understanding how minimization of opacity drives diachronic change. My goal is different: to observe some implications of opacity for phonological theory.

Opacity often arises through the interaction of phonological processes. When Kiparsky first proposed this definition, phonological interaction meant just one thing:

* I am grateful to the organizers and participants in the Second Colloquium for their comments on my presentation, as well as to Diana Archangeli, Sharon Inkelas, Chuck Kisseberth, Orhan Orgun, and the participants in Linguistics 751 (Spring, 1995) for further reactions to this work. I particularly acknowledge the help of my research assistants — John Alderete, Jill Beckman, Laura Benua, Amalia Gnanadesikan, and Suzanne Urbanczyk — and of Alan Prince. This work was supported by the National Science Foundation under grant SBR-9420424.

rule ordering in a serial derivation. Consider, for example, Tiberian Hebrew post-vocalic consonant spirantization. Among other alternations, underlying *k* surfaces as *x* after a vowel. The triggering vowel can be one that is present underlyingly and preserved at the surface (2a), present only at the surface because it is epenthetic (2b), or present only underlyingly because it is deleted (2c):

(2) Spirantization in Tiberian Hebrew (Prince 1975; Malone 1993 and refs. cited there)

a. After a vowel:		
/*malakīm*/	*məlāxīm*	'kings'
b. After an epenthetic vowel:[1]		
/*malk*/	*melex*	'king'
c. After a deleted vowel:		
/*malakē*/	*malxē*	'kings of'

The final case, (2c), is a typical situation of opacity. The phonological process $\mathcal{P}$ is post-vocalic spirantization, which yields (among other things) *x* in the environment /V_. The form *malxē* (2c) contains an *x* in an environment other than /V_, satisfying clause (1b) of the definition of opacity. Hence, Hebrew spirantization is an opaque rule. In the serial-derivational terms current in 1973, the reason for the opacity lies in rule ordering, as the following derivation shows:

(3) Opacity of Hebrew Spirantization in a Serial Derivation

Underlying	/*malakē*/
Spirantization: k → x /V_	*malaxē*
Syncope: V → Ø / VC_CV	*malxē*

Spirantization is opaque because it is followed by syncope, which may obliterate the context that triggered spirantization in the first place.

Rule ordering, the serial derivation, and rewrite rules like $\mathcal{P}$ are no longer common currency; they have been largely or entirely replaced by theories based on satisfaction of *surface* constraints (Cognitive Phonology: Lakoff 1993; Constraint-Based Phonology: Bird 1990, Scobbie 1992; Government Phonology: Kaye, Lowenstamm, & Vergnaud 1985; Harmonic Phonology: Goldsmith 1993; Montague Phonology: Bach & Wheeler 1981, Wheeler 1981, 1988; Optimality Theory: Prince & Smolensky 1993; Two-Level Phonology: Koskenniemi 1983, Karttunen 1993; and others). This change in the phonological terrain means that phonological opacity must be re-examined. Here, I hope to take some steps toward understanding opacity in terms of output constraints within Optimality Theory (Prince & Smolensky 1993)[2]. The richness of the problem is by no means exhausted by the remarks I offer here, and I make no claim to comprehensiveness.

The rest of this paper is organized as follows. Section 2 gives a brief overview of some aspects of Optimality Theory; anyone already familiar with OT should skip

1 Hebrew nouns like 'king' have different stems in the singular and plural. The singular stem is /CVCC/; the plural stem is /CVCaC/.

2 See Jensen 1995 for a forceful characterization of the opacity question in relation to a particular view of phonology within Optimality Theory.

it. Section 3 introduces a model of opacity in OT and a theoretical context for that model, based on the idea of correspondence of linguistic representations (McCarthy & Prince 1995). The Tiberian Hebrew example, and plausible (though hypothetical) variations on it are analyzed. Section 4 then turns to some alternatives: the structural approach to opacity in OT taken by Prince & Smolensky (1993), and the Two-Level Phonology of Koskenniemi (1983) and others. The Hebrew illustration is continued in this section, and another case is introduced, from the well-known Icelandic *u*-umlaut phenomenon. Section 5 summarizes the results.

2 *Theoretical Background*

Optimality Theory (Prince & Smolensky 1993) asserts that the correct surface form is selected by a set of well-formedness constraints that are ranked in a hierarchy of relevance, so that a lower-ranked constraint may be violated in order to satisfy a higher-ranked one. The constraints themselves are universal, except for the fixing of particular arguments within general constraint schemata; only the ranking is language-particular. The constraint hierarchy of each language is called on to evaluate a (potentially infinite) set of candidate outputs relative to some input; the candidate that best satisfies the particular hierarchy is the actual output form.

On the basis of their function, Optimality-Theoretic constraints can be divided into two classes, *structural* constraints and *faithfulness* constraints. The structural constraints express, as categorical statements, such preferences as any theory of Universal Grammar must demand: syllables have onsets; vowels are not both front and rounded; metrical feet are binary; nasals agree in place of articulation with following consonants. Through ranking, the faithfulness constraints can determine the extent of activity of these broad categorical statements. Faithfulness constraints assert that the surface form and lexical form are identical. Thus, if the relevant faithfulness constraints are top-ranked, a structural constraint will typically show no phonological activity; it will be violated in any language with this ranking. With the opposite ranking, the structural constraint is triumphant, and faithfulness of the surface form to the lexical representation must suffer.

Applying these ideas to the Hebrew example (2) will make them more concrete. Let us assume that UG includes the structural constraint No-V-Stop, which asserts that the sequence vowel+stop consonant is prohibited. UG also provides various antagonistic faithfulness constraints, among them Ident(-cont), which says that an underlying stop cannot be replaced by a surface fricative. In a language like Tiberian Hebrew, with postvocalic spirantization, the structural constraint dominates the faithfulness constraint:[3]

3 In a fuller analysis, No-V-Stop must dominate the constraint barring non-strident fricatives, which is otherwise obeyed in Hebrew, since non-strident fricatives are observed *only* in (underlying or surface) post-vocalic contexts. This is, then, a typical situation of an allophonic alternation in OT, on which see McCarthy & Prince (1993: §3.3) and Kirchner (1995a).

(4) NO-V-STOP >> IDENT(-cont) in Tiberian Hebrew

/katab/	NO-V-STOP	IDENT(-cont)
a. ☞ *kāθaβ*		**
b. *kātab*	** !	
c. *kāθab*	* !	*
d. *kātaβ*	* !	*

This *constraint tableau* observes certain notational conventions: constraints are written in their domination order, violations are marked by "*", and crucial violations are also called out by "!". Shading emphasizes the irrelevance of the constraint to the fate of the candidate. A loser's cells are shaded after a crucial violation; the winner's, when there are no more competitors. As a reminder of their special status, constraints regarded as part of an Optimality-Theoretic hierarchy are in small capitals.

The tableau shows that surface post-vocalic spirants are favored over stops, even at the expense of faithfulness to the lexical form. The tableau also shows, incidentally, that multiple loci of violation do not affect the outcome: the Optimality-Theoretic imperative to violate minimally sorts out the plethora of candidates, favoring the one in which there are no post-vocalic stops whatsoever.

With the opposite ranking of these two constraints, we obtain the case of languages without post-vocalic spirantization, such as Arabic:

(5) IDENT(-cont) >> NO-V-STOP in Arabic

/katab/	IDENT(-cont)	NO-V-STOP
a. ☞ *katab*		**
b. *kaθaβ*	** !	
c. *kaθab*	* !	*
d. *kataβ*	* !	*

With this ranking, preservation of the lexical form takes precedence over obedience to the structural constraint. In this way, it makes sense to say that structural constraints like NO-V-STOP are truly universal; they are present in the grammars of all languages, but when they are low-ranking, they are violated freely. Significantly, this is not an empty claim: even when crucially dominated by faithfulness constraints, structural constraints like NO-V-STOP can be active in circumstances where faithfulness is not at issue, such as in determining the form of epenthetic segments or of reduplicative copies, both of which are known to favor structurally unmarked configurations. This phenomenon, called "emergence of the unmarked", is studied in McCarthy & Prince (1994). The possibility of emergence of the unmarked separates OT from parametric theories, in which markedness constraints like NO-V-STOP are either "on" or "off" — and if "off", then completely inactive.

The surface forms evaluated by an Optimality-Theoretic grammar show the effects of various phonological processes *in parallel*; there is no serial derivation. The Tiberian Hebrew examples (2b) and (2c) involve epenthesis or syncope in addition to spirantization. In accordance with parallelism, the consequences of all of these processes

are realized simultaneously rather than serially in the candidate surface forms under evaluation. For example, consider the derivation of *melex* from /malk/ (disregarding the vowel-quality alternation in the first syllable). The constraint responsible for epenthesis is a structural one, *COMPLEX, which prohibits tautosyllabic clusters. It crucially dominates the faithfulness constraint DEP (stated below), which prohibits phonological epenthesis. The requirements of top-ranked *COMPLEX and NO-V-STOP are satisfied together, in parallel, in the observed surface form *melex*. (The dotted lines indicate constraints that are not ranked, usually because they do not conflict.)

(6) *COMPLEX, NO-V-STOP >> DEP, IDENT(-cont)

/malk/	*COMPLEX	NO-V-STOP	DEP	IDENT(-cont)
a. ☞ *melex*			*	*
b. *melek*		* !	*	
c. *melk*	* !			
d. *melx*	* !			*

The optimal form (6a) uniquely satisfies both of the high-ranking constraints. In rule-based theories, a serial derivation like (3) is called on to deal with this interaction of epenthesis and spirantization. In OT (and in the other constraint-based approaches cited in section 1) there is no serial derivation; rather, the surface form is determined by evaluating the effects of all phonological alternations simultaneously.

3 *Phonological Opacity Within Optimality Theory*

This brings us to the topic of these remarks. Rule-based theories account for opacity in terms of ordering in a serial derivation, such as (3). Under parallelism, though, there is no rule ordering and no serial derivation: the effects of all processes are felt simultaneously, through best-satisfaction of a language-particular constraint hierarchy. Therefore, opaque interactions must be understood in different terms; indeed, Chomsky (1994) has cited Hebrew spirantization facts like *malxē* (2c) as evidence of *prima facie* failure of OT[4]. In actual fact, there is no mystery about how OT addresses phonological opacity, as the discussion of Prince & Smolensky's "Containment" model in section 4 makes clear. Nonetheless, there are interesting questions of detail: precisely *how* are the specifics of phonological opacity to be understood in terms of constraint satisfaction? This section contains one answer to that question; section 4 evaluates alternatives.

The account of opacity I will offer rests on two developments. The first is a theory of faithfulness constraints, which has been motivated on grounds that are quite distinct from the problem of opacity. The other is a theory of markedness constraints which incorporates a novel element motivated by the need to analyze opaque phonological interactions. Taken together, these two developments allow us to ana-

4 For further development of Chomsky's argument, see Idsardi (1995).

lyze opaque interactions in a fully parallel way, thereby remaining consistent with this premise of Optimality Theory.

I begin with the theory of faithfulness. Faithfulness is regulated by constraints that are sensitive to a relation of **correspondence** between two structures, the lexical form and the surface form:

(7) Correspondence
Given two strings S_1 and S_2, **correspondence** is a relation $\mathcal{R}$ from the elements of S_1 to those of S_2.
Segments $\alpha \in S_1$ and $\beta \in S_2$ are referred to as **correspondents** of one another when $\alpha\mathcal{R}\beta$.

This definition, and indeed the Correspondence Theory of faithfulness in which it is embedded, are from McCarthy & Prince (1995), which may be consulted for additional formal details. The text below briefly summarizes some of the relevant points from this work.

In this model, candidate surface forms are subject to evaluation together with the correspondent lexical form and some particular $\mathcal{R}$ that relates them. Faithfulness constraints assess each candidate pair with its $\mathcal{R}$, considering such aspects of faithfulness as the completeness of correspondence in S_1 or S_2, the featural identity of correspondent elements in S_1 and S_2, and so on. In general, it will often be enough to leave the details of each particular $\mathcal{R}$ implicit, or to make them explicit by coindexation of segments in the input and output, as in the following hypothetical illustrations:

(8) Hypothetical Illustrations, From Input = / $p_1\ a_2\ u_3\ k_4\ t_5\ a_6$ /

$p_1\ a_2\ u_3\ k_4\ t_5\ a_6$	A fully faithful analysis – perfect correspondence.
$p_1\ a_2\ ?\ u_3\ k_4\ t_5\ a_6$ ▲	Hiatus prohibited (by high-ranking ONSET), so epenthesis of ʔ, which has no correspondent in the input.
$p_1\ u_3\ k_4\ t_5\ a_6$ ▲	Hiatus prohibited, leading to V-deletion. The segment a in the input has no correspondent in the output.
$p_1\ a_2\ u_3\ t_4\ t_5\ a_6$ ▲	The k_4 in the input has a non-identical correspondent in the output, for phonological reasons.
b l u r k ▲▲▲▲▲	No element of the output stands in correspondence with any element of the input. Typically fatal.

The variety of forms shown emphasizes some of the richness of the candidate set. It falls to the language-particular constraint hierarchy to determine what is optimal and what is not.

The comments on the hypothetical illustrations hint at some of the faithfulness constraints that can be formulated under Correspondence Theory. They are formalized as follows:

(9) MAX

Every segment of S_1 has a correspondent in S_2.
(I.e., there is no phonological deletion.)

(10) DEP

Every segment of S_2 has a correspondent in S_1.
(I.e., there is no phonological epenthesis.)

(11) IDENT(γF)[5]

Let α be a segment in S_1 and β be a correspondent of α in S_2. If α is [γF], then β is [γF].
(I.e., underlying [γF] cannot change to [-γF], assuming full specification.)

DEP and IDENT are, of course, the same constraints seen in (6), which illustrates their use.

Correspondence is the theory of faithfulness that will be called on in the analysis of opacity. The other main idea, with links to Correspondence Theory, is a particular conception of how markedness constraints are formulated – that is, a partial theory of the non-faithfulness portion of Con, the UG component of constraints whose rankings make up particular grammars.

One fundamental idea of OT, shared with some other approaches, is that markedness constraints specify only targets, and not the repairs that lead to satisfaction of those targets (Prince & Smolensky 1993). This is an important and compelling insight because, both across languages and within a language, we find homogeneity of the target and heterogeneity of the repair (i.e., conspiracies, in the sense of Kisseberth 1970). For example, a target like ONSET ("vowel-initial syllables are prohibited") is satisfied in different languages by consonant epenthesis (/pa+i/ → *paʔi*), vowel deletion (/pa+i/ → *pa* or *pi*), or devocalization (/pa+i/ → *paj*). Even within a single language, this heterogeneity of repair can be found: in Axininca Campa (McCarthy & Prince 1993), the prohibition on vowel-initial syllables is satisfied by epenthesis under suffixation (/iŋkoma+i/ → *iŋkomati*) and by incomplete copying in reduplicative morphology (/osampi+RED/ → *osampi–sampi*).

The target-defining constraints in OT have been formalized in various ways. To make headway on the problem of opacity, it will be necessary to make some decisions about exactly how constraints are to be formalized, and some oversimplification is necessary. I will assume that every constraint is a *prohibition* or *negative target* defined over no more than two segments, α and β. That is, the canonical constraint is something like *{α, β}, with appropriate conditions imposed on α and β. These conditions are as follows:

(i) a specification of the featural properties of α and β as individual segments.

(ii) a specification of the linear order relation between α and β ($\alpha < \beta$, $\beta < \alpha$, or both in the case of mirror-image rules (on which see Bach 1968; Anderson 1974)).

5 For the distinction between IDENT(-F) and IDENT(+F), see Pater (1995).

(iii) a specification of the adjacency relation between α and β (e.g., strict adjacency, vowel-to-vowel adjacency, etc. (see Myers 1987; Selkirk 1988; Archangeli & Pulleyblank 1987, 1994.))

This decomposition of the conditions on α and β is inspired by the ideas about formalization in Archangeli & Pulleyblank 1994: Chapt. 4, though it should be noted that the conditions they discuss are somewhat different, having been designed for phonological operations rather than targets. The proposal made here will ultimately need to be elaborated in light of their results and the empirical material they discuss.

This decomposition of the conditions imposed by a phonological constraint will be crucial in accounting for the range of opacity phenomena. Even more important, though, is this: each condition – the featural composition of α, the featural composition of β, linear order, and adjacency – must also name the level (underlying, surface, or either) at which it obtains. Correspondence Theory allows us to make sense of conditions obtaining at one level or the other. As a bookkeeping device, I will state constraints in the form of a table (also inspired by Archangeli & Pulleyblank 1994):

(12) Canonical Constraint Schema

*	Condition	Level
α		
β		
Linear Order		
Adjacency		

The large "*" is a reminder that, in this schema, constraints specify negative targets or prohibited configurations. Thus, any structure matching the conditions and levels specified is in violation of this constraint. The conditions on α and β are featural; the conditions of linear order are α first, β first, or indifferent (for mirror-image configurations); the conditions of adjacency include strict linear adjacency and the various types of non-strict adjacency afforded by phonological theory. The permissible level specifications include surface, underlying[6], and indifferent.

This final aspect of the proposal echoes some of the ideas of Two-Level Phonology (Koskenniemi 1983), which I discuss below in section 4. It also recalls some of the work on global rules, especially Kisseberth (1973). In global-rule terms, opacity ensues when, by virtue of a stipulation in the form of the rule itself, it "applies to structures of a specified sort provided they do not arise through the operation of particular rules" or it "applies in a given environment if that environment occurs either in the input or is present in an 'ancestral' structure but has been distorted by particular rules" (Kisseberth 1973: 436). The latter type of global interaction subsumes the non-surface level specifications of the proposal above; differences come from

6 As Sharon Inkelas has pointed out to me, this proposal presupposes that there is an underlying representation. It is therefore incompatible with the handful of works arguing that underlying representations should be replaced by constraints (Golston 1995; Hammond 1995; Russell 1995). Furthermore, as Diana Archangeli has pointed out to me, it presupposes that underlying representations have linear order, even between morphemes.

the use of constraints rather than rules, the limitation to two levels (underlying and surface), and the details of how constraints are formalized in the schema (?).

Through Correspondence Theory, this constraint schema imposes a set of conditions on the surface segments α_s and β_s and/or the underlying segments α_u and β_u[7]. Surface α_s, if any, stands in correspondence with underlying α_u, if any, and likewise for β_s and β_u. In this way, conditions may be met specifically at the surface level or at a combination of the underlying and surface levels. Suppose, for instance, that the condtion α=V is specified for the underlying level, β=C is specified for the surface level, and α > β ("α precedes β") is specified for the underlying level. Then, for the constraint to be applicable, a surface C (identifed as β_s) must have an underlying correspondent β_u which is preceded by a vowel (identified as α_u). Conditions which are not mentioned are irrelevant, as usual; thus, it does not matter whether β_u is a consonant, nor does it matter whether α_u has a surface correspondent α_s, or even whether $\alpha_s > \beta_s$[8]. In this way, the (negative) targets defined by phonological constraints are more complex than simple output-string configurations: they include aspects of the input as well, through the input/output correspondence relation.

Accepting Kiparsky's (1971, 1973) dictum that phonological opacity is marked, I will stipulate that the default form of a phonological constraint – the form in which it is represented in UG has all of its level specifications set to "surface". A constraint of this type is a *true output target* of the type usually contemplated in naive theorizing about constraints. It is not opaque, since the conditions of obedience or violation can be read off of surface structure in a completely transparent way. For example, the constraint responsible for Tiberian Hebrew spirantization, *without opacity* (that is, with *malkē* rather than *malxē* for (2c)), is represented in UG as (13). (Spirantization of voiced stops in Spanish is a real example of this type, since all and only surface vowels trigger the process.)

(13) No-V-Stop, Default Version (no opacity)

*	Condition	Level
α	V	Surface
β	[-son, -cont]	Surface
Linear Order	α > β	Surface
Adjacency	Strict	Surface

The column labeled "Condition" characterizes the prohibited configuration: the segment α, which is a vowel, is immediately followed by the segment β, which is a stop. Since these conditions must be met at the surface, the form *malkē* obeys this constraint – the underlying vowel of /malakē/ has no bearing on the result. In this hypothetical language, then, *malkē* is optimal; since it and the competing candidate

7 Compare the proposal in Orgun (1995), which would limit correspondence to faithfulness constraints only, as in McCarthy & Prince (1995).

8 Of course, expressions like $\alpha_s > \beta_u$ are meaningless, since α_s and β_u are elements in different strings, related to one another through correspondence, rather than elements in the same string. Linear precedence makes sense only within a string and not between different strings.

malxē equally obey (13), the decision falls to the faithfulness constraint IDENT(-cont), which selects the more faithful *malkē*.

In real Tiberian Hebrew, though, the constraint NO-V-STOP is different from the default (13). Rather, as in (14), it characterizes a situation of opacity, in which some of the operative conditions can be met at the underlying level as well as at the surface:

(14) NO-V-STOP, Tiberian Hebrew Version (with opacity as in (2c))

*	Condition	Level
α	V	Indifferent
β	[-son, -cont]	Surface
Linear Order	α > β	Indifferent
Adjacency	Strict	Indifferent

In correspondence terms, the meaning of this constraint is as follows: the constraint is violated if a surface stop β *or its underlying correspondent* is immediately preceded by a vowel. That is to say, the prohibited configuration is one in which a stop is immediately preceded by a vowel in the candidate surface form (i.e., just as in (13)) or in which *the segment that underlies the stop* is immediately preceded by a vowel. Thus, even if surface β_s is not preceded by a vowel, but its underlying correspondent β_u is preceded by a vowel, then the constraint is violated. This is a type of opacity.

The following diagram shows in a schematic way how this constraint can be interpreted. Several *faithful* pairings of underlying forms and their surface candidates are given; each involves a post-vocalic stop which ought to be a fricative, so (14) is violated. In the pairings, segments standing in correspondence with one another are linked by vertical lines:[9]

(15) Constraint (14) Applied

	a.	b.	c.
Underlying	malakīm	mal k	malakē
	| |||||	| || |	| || ||
Surface Candidate	məlākīm	melek	mal kē
Required Conditions for Constraint Applicability	Conditions Observed in These Candidate S/U Pairings		
α = V at S or U	α = V at S and U	α = V at S	α = V at U
β = stop at S	β = stop at S and U	β = stop at S and U	β = stop at S and U
α > β at S or U	α > β at S and U	α > β at S	α > β at U
α ⌒ β at S or U	α ⌒ β at S and U	α ⌒ β at S	α ⌒ β at U
Conclusion	(14) is applicable and violated	(14) is applicable and violated	(14) is applicable and violated

It is crucial that the constraint be applicable to these faithful candidates and that

9 The vertical lines in (15) should not be confused with autosegmental association lines. The lines in (15) join segments standing in correspondence — in effect, they express a derivational relationship between two representations. Autosegmental association lines express a relationship of simultaneity within a single representation. Interestingly, though, autosegmental association is reducible to correspondence; see McCarthy & Prince (1995).

they violate it, to compel spirantization. The individual examples can be understood as follows:

- In case (15a), the surface *k* and its underlying correspondent are both immediately preceded by a vowel; hence the conditions are met and the constraint is violated by **məlākīm*, as desired. Since that candidate is ruled out by top-ranked NO-V-STOP (14), the less faithful *məlāxīm*, which violates only low-ranking IDENT(-cont), is chosen instead.

- In case (15b), the triggering vowel is epenthetic. Hence, the condition can only be met at the surface: the surface *k* is immediately preceded by a vowel, *tout court*. This and (15a) together constitute what I have designated as the default case, in which a surface vowel and only a surface vowel is sufficient to induce spirantization.

- The case of greatest interest is (15c), since it is a situation of opacity. Here, the surface stop *k* is not immediately preceded by a vowel, but its underlying correspondent is. The conditions are met, so **malkē* violates the constraint. Opacity arises here because a condition is satisfied in part by the underlying correspondent of a surface segment rather than by the surface segment itself.

Another type of opacity is logically possible. In Bedouin Arabic dialects such as the one described in Al-Mozainy 1981, velar palatalization is triggered by exactly the *underlying* front vowels; underlying *i*, regardless of whether it is deleted, triggers the process, but epenthetic *i* does not. As a hypothetical variation on the Hebrew spirantization pattern, this would yield a language with *məlaxim* and *malxē*, but *melek*. The *melek* type of opacity conforms to clause (1a) of Kiparsky's definition, combined with the (1b) type of opacity seen in *malxē*. Facts like these will follow, *ceteris paribus*, if the level specifications for NO-V-STOP are set as follows:

(16) NO-V-STOP for a Language with *məlāxīm*, *melek*, and *malxē*

*	Condition	Level
α	V	Underlying
β	[-son, -cont]	Surface
Linear Order	α > β	Underlying
Adjacency	Strict	Underlying

In correspondence terms, for this constraint to be violated, a surface stop must have an underlying correspondent that is preceded by a vowel. Even if the vowel itself is deleted, the constraint is violated. Yet if the vowel is epenthetic, the constraint is obeyed, since the stop's *underlying correspondent* is not postvocalic. These circumstances can be schematized as follows:

(17) Constraint (16) Applied

	a.	b.	c.
Underlying	malakīm | |||||	mal k ||| |	malakē | || ||
Faithful Cand.	məlākīm	melek	mal kē
Required Conditions for Constraint Applicability	Conditions Observed in These Candidate S/U Pairings		
α = V at U β = stop at S α > β at U α ⌒ β at U	α = V at S and U β = stop at S and U α > β at S and U α ⌒ β at S and U	α = V at S ! β = stop at S and U α > β at S ! α ⌒ β at S !	α = V at U β = stop at S and U α > β at U α ⌒ β at U
Conclusion	(16) is applicable and violated	(16) is inapplicable, so obeyed	(16) is applicable and violated

The symbol "!" calls out any conditions obtaining in the candidate under evaluation that do not match what the constraint looks for. In such cases, the constraint is inapplicable, and so it is obeyed. Thus, the faithful output, which obeys the next-ranked constraint IDENT(-cont), is optimal. That is exactly the case in (17b), which yields the faithful output *melek*. In this candidate, it is not true that β_u is post-vocalic, yet post-vocalic β_u is exactly what the constraint looks for. Hence, the constraint isn't relevant to this form; it is obeyed.[10]

Configurations like (16) are interesting for another reason as well. Observe that only the β condition obtains at the surface; all other conditions hold of underlying structure. Since the members of a candidate set differ in surface structure (and the correspondence relation $\mathcal{R}$) but share the same underlying structure, it follows that the decisive difference between candidates with respect to this constraint lies in whether or not they match the β condition. To put the matter more directly, the constraint (16) fully determines β as the locus of repair, regardless of the ranking among the various faithfulness constraints. This observation points to an interesting singularity: a constraint in which all the level specifications are set at underlying is of no interest. Since it is equally obeyed or violated by all candidates in a given candidate set (depending on what the lexical form is), it cannot arbitrate between them, and so it can never be decisive.

In the constraints seen so far, the level specifications for linear order and adjacency are coupled with those of α, the "triggering" segment. Whenever this is true, the precedence and adjacency relations between α and β must hold at whatever level where the α condition is met. But this is not necessarily true, and in fact de-coupling the linear order and adjacency relations from the featural conditions on the segments bearing those relations is crucial to dealing with the full range of opacity phenomena.

10 In addition to this opacity-yielding condition and the one in (17c), it's worth noting a further prediction: if the stop is epenthetic, then the constraint is also obeyed, since an epenthetic stop has no underlying correspondent (i.e., β_u does not exist), and therefore its underlying correspondent cannot be post-vocalic. Thus, epenthetic stops should not spirantize in a language that imposes (16). Rule-ordering theories make no such prediction, since the ordering of C-Epenthesis with respect to Spirantization is independent of other aspects of rule ordering.

A final hypothetical variation on Tiberian Hebrew illustrates this possibility. Suppose spirantization is observed only after a vowel that is present at both the underlying and surface levels, yielding spirantized *məlaxīm* versus unspirantized *melek* and *malkē*. (In rule-based theories, this result can be obtained from the ordering Syncope > Spirantization > Epenthesis.) The constraint driving the alternation is one that prohibits a surface stop whose *underlying* correspondent is preceded by a vowel and whose *surface* correspondent is adjacent to a vowel – a conjunction of conditions that only a non-epenthetic, undeleted vowel can match:[11]

(18) NO-V-STOP for Language with *məlāxīm*, *melek*, and *malkē*

*	Condition	Level
α	V	Underlying
β	[-son, -cont]	Surface
Linear Order	α > β	Underlying
Adjacency	Strict	Surface

The role of the separate conditions on adjacency and featural composition can be seen in the following schematization:

(19) Constraint (18) Applied

	a.	b.	c.
Underlying	malakīm | ||||||	mal k | || |	malakē | || ||
Faithful Cand.	məlākīm	melek	mal kē
Required Conditions for Constraint Applicability	Conditions Observed in These Candidate S/U Pairings		
α = V at U β = stop at S α > β at U α ⌒ β at S	α = V at S and U β = stop at S and U α > β at S and U α ⌒ β at S and U	α = V at S ! β = stop at S and U α > β at S ! α ⌒ β at S	α = V at U β = stop at S and U α > β at U α ⌒ β at U !
Conclusion	(18) is applicable and violated	(18) is inapplicable, so obeyed	(18) is inapplicable, so obeyed

Since the constraint (18) is obeyed by both (19b) and (19c), the faithful, unspirantized output is optimal. Only a vowel present at both underlying and surface representation, as in (19a), will suffice to trigger the alternation, because only such a vowel can precede the stop at the underlying level and be adjacent to it at the surface.

This variety of examples, real and hypothetical, shows that the constraint schema (12) is equipped to handle a range of opacity phenomena. The core notions are these:

- A markedness constraint describes a target. For simplicity, I have assumed that all targets are expressed as prohibitions.

11 Equivalently, the linear-order condition can be set to the surface level and the adjacency condition to the underlying level. These alternatives can be teased apart empirically only in languages where the linear order and adjacency relations vary independently – e.g., in metathesis.

- Markedness constraints impose separate conditions on the featural composition of segments, their linear order relation, and their adjacency relation.
- In its default form, every markedness constraint imposes conditions on surface structure only. But through correspondence, specified conditions can be imposed on underlying structure or on either underlying or surface structure.

Opacity will arise whenever non-surface conditions obtain in constraint satisfaction and violation.

4 *Comparison with Other Theories of Opacity*

Having presented one approach to the analysis of opacity within Optimality Theory, I will now proceed to look at two alternatives. The first, due to Prince & Smolensky (1993), is by-and-large standard in OT work today. The second is Two-Level Phonology (Koskenniemi 1983) and extensions. I will show that both approaches encounter problems in dealing with the full range of observed opacity phenomena.

Prince & Smolensky (1993) proceed as I have done, by relating opacity to faithfulness. The details of their approach, though, are different: they conceive of faithfulness, and hence of opacity, in structural or representational terms, rather than via correspondence. The main idea is this: the phonetically obvious surface structure is enriched by the inclusion of information about the character of the underlying form. This model, which is dubbed "Containment" in McCarthy & Prince 1993, will be referred to here as the *structural approach*, contrasting it with the *correspondence approach* introduced in section 3.

In the structural approach, segments that are (to-be) deleted are present in the output, but not parsed syllabically, making use of the notion of Stray Erasure in Steriade 1982. The constraint PARSE (rather than MAX) militates against these unparsed segments. In a parallel way, epenthesis is understood as the result of providing prosodic structure with no segment to fill it, the phonetic identity of the epenthetic segment being determined by extra-systemic rules of phonetic interpretation, exactly as in Selkirk 1981, Lowenstamm & Kaye 1985, and Itō 1986. The constraint FILL (rather than DEP) militates against these unfilled prosodic nodes. An alternative is that epenthetic segments are identified by their lack of morphological affiliation with the constraint MSEG (McCarthy 1993, McCarthy & Prince 1994). In both deletion and epenthesis, the characterization of faithfulness is given an interpretation in terms of prosodic or morphological structure.

The predicates "parsed" and "morphologically affiliated", when applied to constraints other than the faithfulness variety, yield a range of transparent and opaque interactions comparable to what we saw in section 3. Consider the Tiberian Hebrew spirantization phenomenon and its hypothetical variants. In the structural approach, the constraint prohibits a vowel+stop sequence outright, with differences in opacity determined by conditions imposed on the triggering vowel. The following table shows the range of possibilities; in keeping with the tenets of the structural approach, unparsed (≈ deleted) and morphologically unaffiliated (≈ epenthetic) segments are

designated formally by angled brackets and outlining, respectively. The equivalents in the correspondence approach are noted in the column headed "Comments".

(20) Opacity and Transparency in Output-Structural Terms[12]

	Condition on V	*Observed Results*	*Comments*
a.	Parsed	*mə́lāxīm* *mel⊡x* *mal⟨a⟩kē*	Alternation triggered by epenthetic but not deleted vowel (equivalent to (13)). Fully transparent.
b.	None	*mə́lāxīm* *mel⊡x* *mal⟨a⟩xē*	Alternation triggered by epenthetic or deleted vowel (equivalent to (14)). This is real Hebrew, with opacity in *mal⟨a⟩xē*.
c.	Morphologically Affiliated	*mə́lāxīm* *mel⊡k* *mal⟨a⟩xē*	Alternation not triggered by epenthetic vowel (equivalent to (16)). Opaque in *mal⟨a⟩xē* and *mel⊡k*.
d.	Parsed and Morphologically Affiliated	*mə́lāxīm* *mel⊡k* *mal⟨a⟩kē*	Alternation triggered by neither epenthetic nor deleted vowel (equivalent to (18)). Hence opacity in *mel⊡k*.

The equivalent of the default, non-opaque, surface-only constraint (13) is the one where V must be parsed (20a). The condition (20b), where no limitations are placed on V, yields the situation in actual Tiberian Hebrew, with opacity.

It's clear from this analysis that the structural approach to faithfulness and opacity is equivalent in many respects to the correspondence approach of section 3. Both approaches yield much the same array of opaque and transparent phonological relationships. Both can contend with opacity and transparency by imposing special conditions on general constraint schemata. Presumably, both theories must regard those conditions as learned rather than innate aspects of the grammar.

There are differences, however. One has to do with the conception of faithfulness and its relation to other kinds of linguistic identity relations; it is explored in McCarthy & Prince 1995. Another difference has to do with opacity and the analysis of opaque alternations.

The structural approach permits a type of opacity that is impossible in the correspondence approach. Specifically, as Paul Smolensky has noted, it makes sense in the structural approach to both epenthesize a segment and delete it. An epenthetic segment is nothing more than a morphologically unaffiliated one added to the underlying string; a deleted segment is nothing more than a syllabically unparsed one; the conjunction of these two properties, represented as ⟨⊡⟩, makes perfect sense within the structural approach.[13] Yet it is an impossibility under the correspondence approach. Under correspondence, deleted segments are those which have underlying but not surface correspondents, and epenthetic segments are just the opposite. A deleted epenthetic segment is an inherent contradiction.

12 I am indebted to Alan Prince for discussion of this material.

13 As Orhan Orgun has emphasized to me, diacritical as well as structural approaches to faithfulness predict the existence of deleted epenthetic elements, since nothing prevents a segment from bearing both faithfulness diacritics simultaneously.

In the structural approach, deletion of an epenthetic segment will involve violation of both PARSE and FILL/MSEG, which militate against deletion and epenthesis, respectively. Since the result is phonetically no different from the input, such a form might seem pointless and therefore unproblematic, since this greater descriptive freedom of the structural approach would never be judged as optimal under any ranking of the constraints supplied by UG. But in fact there are constraints that directly require deletion and other constraints that indirectly prohibit it. Through interaction of these constraints, situations can be created which would be expected to favor deletion of an epenthetic segment, yet no such phenomenon is observed.

A real-life example comes from Prince & Smolensky's (1993: Chapt. 7) analysis of the Australian language Lardil. They argue that apocope in Lardil is a consequence of satisfying the constraint FREE-V, which directly requires deletion :

(21) FREE-V in Lardil (Prince & Smolensky 1993: 101)
Word-final vowels must not be parsed (in the nominative).

Through domination of PARSE, FREE-V is visibly active in Lardil, compelling apocope.

Another high-ranking constraint of Lardil is antagonistic to FREE-V. This constraint is ALIGN:[14]

(22) ALIGN
The final edge of the stem corresponds to the final edge of a syllable.

ALIGN is obeyed by any form whose stem-final segment is also syllable-final. Since ALIGN demands parsing of stem-final segments (so they can be syllable-final), and since FREE-V demands *non*-parsing of stem-final segments, the two constraints are in conflict. The ranking favors FREE-V:

(23) FREE-V >> ALIGN, from /yiliyili/ → *yiliyil* 'oyster species' (cf. *yiliyilin* 'id. (non-fut. acc.)')

	Candidates	FREE-V	ALIGN
a.	☞ σ σ σ /| /| /|\ yi li yil i		*
b.	σ σ σ σ /| /| /| /| yi li yi li	* !	

In (a), the stem-final segment is unparsed, so it is not also syllable-final, violating ALIGN but satisfying FREE-V. Form (b) shows the opposite outcome, fatally violating the higher-ranked constraint.

It is possible in principle, however, to satisfy both FREE-V and ALIGN, by simultaneous deletion and epenthesis (cf. Prince & Smolensky 1993: 111–112). Compare the actual output (a) with the form in (b):

[14] High-ranking ALIGN is required to account for cases of augmentation in Lardil, such as /maɽ/ → *maɽ[ə]a*, **maɽa*.

(24) Combined Deletion and Epenthesis

	Candidates	FREE-V	ALIGN
a.	σ σ σ /| /| /|\ yi li yil <i>		*
b.	σ σ σ σ /| /| /| /| yi li yi li <ə>		

The normal epenthetic vowel in Lardil is ɑ, so there is nothing unusual about form (b). It satisfies FREE-V because the word-final vowel is unparsed. It also satisfies ALIGN, because the stem-final vowel is also syllable-final. (The epenthetic vowel has no morphological affiliation; hence, it is not in the morphological constituent stem.) Therefore, (b) ought to be optimal, but is not.

The only mechanism available to exclude form (b) is constraint ranking: if the anti-epenthesis constraint FILL/MSEG dominates ALIGN, then (b) will not be optimal. But this seems a less-than-ideal solution – the situation in (24) ought to be ruled out universally rather than parochially, as Prince & Smolensky (1993: 112fn.) observe in a comparable case. It should not be necessary to stipulate, through language-particular ranking, that apocope cannot be rendered vacuous by combining it with epenthesis. In this respect, the greater descriptive freedom of the structural approach seems to be a liability and the correspondence approach seems preferable.

There are other circumstances, however, where the correspondence approach to opacity, as laid out in section 3, opens up wider descriptive possibilities than the structural approach, to the advantage of correspondence. This happens when there is radical de-coupling of the level specifications on the featural, linear order, and adjacency conditions in the standard constraint schema (12). I will illustrate this point by examining one case in some detail, the well-known Icelandic *u*-umlaut phenomenon (Anderson 1974; Kiparsky 1985). My analysis depends entirely on Anderson's characterization of the facts and descriptive generalizations.

In Icelandic, the vowel ɑ is realized as *ö* when followed by orthographic *u* (phonetic [ʊ]) in the next syllable (25a). The triggering *u* may be present underlyingly, though deleted at the surface (25b). The triggering *u* and affected ɑ can even be separated by another vowel underlyingly, so long as the intervening vowel is deleted at the surface (25c). Yet epenthetic *u* does not trigger umlaut (25d). Finally, there is a complex interaction between *u*-umlaut and a process reducing *ö* to *u* in unstressed syllables. (In Icelandic, stress falls on the initial syllable.) The product of *u*-umlaut in an unstressed syllable is *u* rather than *ö* (25e). Strikingly, the *u* derived in this way can itself serve as a trigger for *u*-umlaut (25f), leading to "iteration" of *u*-umlaut.

(25) Icelandic Data (Represented Orthographically)

a. Simple Cases (Anderson 1974: 141)
/barn+um/ *börnum* 'child (dat.)' cf. *barn* 'child'

/svang+u/	*svöngu*	'hungry (neut. dat. sg.)'	cf. *svangt* 'hungry (neut. nom. sg.)'
/kall+um/	(*við*) *köllum*	'we call'	cf. (*ég*) *kalla* 'I call'

b. Deleted *u* as Trigger (Anderson 1974: 143)

/bagg+ul+i/	*böggli*	'parcel (dat. sg.)'	cf. *baggi/böggull* 'pack/parcel'
/jak+ull+i/	*jökli*	'glacier (dat. sg.)'	cf. *jaki/jökull* 'piece of ice/glacier'
/þagull+an/	*þöglan*	'taciturn (m. acc. sg.)'	cf. *þagga/þögull* 'to silence/taciturn'

c. Derived Adjacency (Anderson 1974: 142–143)

/katill+um/	*kötlum*	'kettle (dat. pl.)'	cf. *ketill/katli* 'kettle/(dat. sg.)'
/ragin+um/	*rögnum*	'gods (dat. pl.)'	cf. *regin/ragna* 'gods/(gen. pl.)'
/alin+um/	*ölnum*	'ell of cloth (dat. pl.)'	cf. *alin* 'ell of cloth'
cf. /akkerum/	*akkerum*	'anchor (dat. pl.)'	

d. Epenthetic u Not a Trigger (Anderson 1974: 192f.)

/akr/	*akur*	'field'	cf. *akri/ökrum* 'field (dat. sg.)/(dat. pl.)'
/aldr/	*aldur*	'age'	cf. *aldri/öldrum* 'age (dat. sg.)/(dat. pl.)'
/fagr/	*fagur*	'beautiful (m. nom. sg.)'	cf. *fagran/fögru* 'id. (acc. sg.)/(dat. sg.)'

e. Interaction with Vowel Reduction – Simple Case (Anderson 1974: 186)

/dómar+um/	*dómurum*	'judge (dat. pl.)'	cf. *dómari* 'judge'
/hérað+um/	*héruðum*	'region (dat. pl.)'	cf. *hérað* 'region'

f. Interaction with Vowel Reduction – "Iteration" (Anderson 1974: 186, 1972: 16)

/bakar+um/	*bökurum*	'baker (dat. pl.)'	cf. *bakari* 'baker'
/fatnað+um/	*fötnuðum*	'suit of clothes (dat. pl.)'	cf. *fatnað* 'suit of clothes'
/safnaðar+um/	*söfnuðum*	'congregation (dat. pl.)'	cf. *safnaðar* 'congregation'

This is obviously a complex pattern of opacity (25b, d) and transparency (25a, c, e, f). In rule-based theories, it requires significant departure from linear ordering, in the direction of Local Ordering (Anderson 1974) or the phonological cycle (Kiparsky 1985). In Optimality Theory enhanced by the constraint schema (12), though, a fully parallel analysis of Icelandic is possible, as I will now show.

As a preliminary, we need to gain some control over the phonology of Icelandic vowels. The system of short vowels is given below in both orthographic and phonetic

(bracketed) form:

(26) Icelandic Short Vowels[15] (Anderson 1972: 19)

a. In Stressed Syllables

i/y	[i]	u	[ü]
e	[e]	ö	[ö]
		a	[ɑ]
		o	[ɔ]

b. In Unstressed Syllables[16]

i/y	[i]	u	[ü]
		a	[a]

The system is sharply skewed toward the front. In unstressed syllables, there is significant reduction of contrasts, with no mid vowels and only an unrounded low vowel. The *u*-umlaut phenomenon, then, involves raising, fronting, and rounding of ɑ before a high, front, rounded vowel. In stressed syllables, where mid vowels are permitted, the result of *u*-umlaut is mid *ö*; in unstressed syllables, which bar mid vowels, the result is high *ü*, just like the triggering vowel.

In Optimality Theory, the geometry of a particular vowel system is determined in the usual OT way: by the interaction of markedness constraints and faithfulness constraints (Prince & Smolensky 1993: Chapt. 9). Some of the main features of the Icelandic vowel system are determined by the following rankings:

(27) Constraint Rankings for Icelandic Vowel System

a. *[+back, -low] >> IDENT(+back)
Non-low back vowels are prohibited (cf. Anderson 1972: (24)).

b. *[-stress, -high, -low] >> IDENT(-high)
Unstressed mid vowels are prohibited (cf. Anderson 1972: (11)).[17]

Assume for the moment the existence of a constraint UMLAUT which bars the sequence [ɑC_0*ü*]. (This constraint is studied in detail below.) To trigger alternations, it must dominate a set of faithfulness constraints, since UMLAUT-triggered alternations affect all of the features in which [ɑ] differs from [ö] and [ü]:

(28) Constraint Ranking for *u*-Umlaut Phenomenon

UMLAUT >> IDENT(+low), IDENT(-round), IDENT(+back), IDENT(-high)

What we have, then, are three top-ranked markedness constraints (UMLAUT included) which dominate a set of faithfulness constraints on vowel features, as in (27, 28). These rankings are sufficient to fully determine the surface form. The most complex case, "iterative" umlaut, shows the result clearly:

15 The remaining vowels are all diphthongal, represented orthographically as *í, é, ú, ó, ei, au, œ,* and *á*.

16 There are exceptions to this generalization, such as *akkeri* 'anchor' or *japani/japönum* 'Japanese nom. sg./dat. pl.'.

17 The expression "-stress" is obviously an ad hoc notation for the prominential conditions defining unstressedness.

(29) Rankings Applied to /bakar+um/ → [bökürüm]

/bakar+um/	*[+back, -low]	*[-stress, -high, -low]	UMLAUT	IDENT (-high)	IDENT (+back)	IDENT (+low)	IDENT (-round)
a. ☞ [bökürüm]				*	**	**	**
b. [bakarüm]			* !				
c. [bakürüm]			* !	*	*	*	*
d. [bakörüm]		* !			*	*	*
e. [bokurüm]	** !			*		**	**
f. [bükürüm]				**!	**	**	**

The actual output form [bökürüm] (orthographic *bökurum*) violates all of the low-ranked faithfulness constraints, sometimes more than once. Nonetheless, it is optimal, since the alternatives are worse. Forms (29b, c) are in fatal violation of UMLAUT, since they exhibit the prohibited configuration of [a] followed by [ü]. Form (29d) violates the restriction against mid vowels in unstressed syllables, again with fatal results. Form (29e) contravenes another unviolated structural constraint of Icelandic, which prohibits non-low back vowels. Finally, form (29f) shows the result of /a/ → [ü] in a *stressed* syllable: an unmotivated violation of the faithfulness constraint IDENT(high).

This sets the scene in which the umlaut constraint is active. We turn now to the actual statement of the constraint, focusing on the opacity problem. Within the correspondence-based view developed in section 3, UMLAUT is formulated as follows:[18]

(30) UMLAUT

*	Condition	Level
α	a	Surface
β	ü	Indifferent
Linear Order	α > β	Underlying
Adjacency	V-to-V	Indifferent

The configuration prohibited by this constraint is essentially [aC_0ü] that is, an [a-ü] sequence under V-to-V adjacency, as is typical of harmony and umlaut processes. The interest of the constraint and the complexity of the results it yields come from the level specifications:

- The constraint looks for *surface* α=a; hence, it is satisfied by surface sequences where the first vowel is not a, in particular [öC_0u] (in [börnüm]) or [üC_0ü] (like [dómürüm]).

[18] The formulation of this constraint raises an issue which is important but orthogonal to the main topic of these remarks. Icelandic *u*-umlaut is really the effect of an assimilatory constraint demanding a positive target, rather than the negative target I assume in (30). Indeed, this understanding of the operative constraint is necessary to explain why *o* (phonetic [ɔ]) is not the result. Ultimately, then, it is necessary to extend the proposals made here to positive targets in general and to assimilation in particular.

- The condition β=ü is level-indifferent; this means that the triggering ü can be present both underlyingly and at the surface ([börnüm]), only underlyingly ([bögglí] from /baggüli/), or only at the surface ([bökürüm] from /bakarüm/).

- The V-to-V adjacency condition can also be satisfied at either level: it is satisfied underlyingly in syncopating forms like [bögglí] and it is satisfied at the surface in other syncopating forms like [rögnüm] from /raginüm/. (These are the "derived adjacency" cases of (25c).)

- Finally, the linear order condition must be met at underlying representation. Since α must precede β underlyingly, it follows that epenthetic β will not meet the conditions of this constraint, and so forms like [akür] (from /akr/) will not show umlaut, since they will obey the constraint.

Succinctly, in correspondence terms, this constraint prohibits surface [a] when its underlying correspondent is followed by a segment any of whose correspondents is ü, providing that some correspondent of the [a] is V-to-V adjacent to some correspondent of the ü.

To illustrate how UMLAUT is applied, I will schematize the results as in section 3, focusing for the moment on the cases where the alternating vowel is in the stressed (initial) syllable. As before, the candidates considered are faithful ones, in which UMLAUT is crucially violated, thereby favoring alternative candidates with unfaithful treatment of the underlying /a/ vowel.

(31) Application of (30), Core Cases

	a.	b.	c.
Underlying	barnüm	baggüli	raginüm
	||||||	|||| ||	|||||
Faithful Cand.	barnüm	bagg li	rag nüm
Required Conditions for Constraint Applicability	Conditions Observed in These Candidate S/U Pairings		
α = a at S	α = a at S and U	α = a at S and U	α = a at S and U
β = ü at S or U	β = ü at S and U	β = ü at U	β = ü at S and U
α > β at U	α > β at S and U	α > β at U	α > β at S and U
α ⌒ β at S or U	α ⌒ β at S and U	α ⌒ β at U	α ⌒ β at S
Conclusion	(30) is applicable and violated	(30) is applicable and violated	(30) is applicable and violated

In these cases, the umlaut alternation affects a under the influence of underlying /ü/ in the next syllable. The candidate S/U pair in (31a) is the simplest, since the featural, linear order, and adjacency relations of the triggering and target vowels are identical. The interaction of syncope and umlaut leads to opacity, as (31b) shows, where an underlying /ü/ suffices to trigger the alternation. This is possible because the conditions on the featural make-up of β and on its relation to a in the string can (or must) be met in underlying representation. The final case, (31c), shows that the V-to-V adjacency condition can be satisfied at the surface, even if it is not satisfied at underlying structure.

The interaction of umlaut and epenthesis leads to a different kind of opacity, in which epenthetic ü does not suffice to trigger the alternation. As formulated in (30), the UMLAUT constraint is violated only when trigger follows target in underlying representation. When the trigger is itself epenthetic, this condition is not met, the constraint is inapplicable, and the faithful output emerges instead. The following schematization illustrates this result:

(32) Application of (30), Epenthesis Case

Underlying	ak r || |
Faithful Cand.	akür
Required Conditions for Constraint Applicability	Conditions Observed in This Candidate S/U Pairing
α = a at S	α = a at S and U
β = ü at S or U	β = ü at S
α > β at U	α > β at S !
α ⌒ β at S or U	α ⌒ β at S
Conclusion	(30) is inapplicable, so obeyed

This candidate S/U pairing obeys UMLAUT because the conditions for applicability of this constraint are not met. Specifically, the α argument does not precede the β argument at underlying structure. Hence, the constraint is irrelevant (it is vacuously obeyed), and faithful [a] rather than unfaithful [ö] is optimal.

The final and most complex cases involve the interaction of the *u*-umlaut alternation with reduction of mid vowels to high in unstressed syllables:

(33) Application of (30), Unstressed Syllable and "Iterative" Cases

	a.	b.
Underlying	dómarūm |||||||	bakarūm |||||||
Faithful Cand.	dómarūm	bakürūm
Required Conditions for Constraint Applicability	Conditions Observed in These Candidate S/U Pairings	
α = a at S	α = a at S and U	α = a at S and U
β = ü at S or U	β = ü at S and U	β = ü at S
α > β at U	α > β at S and U	α > β at S and U
α ⌒ β at S or U	α ⌒ β at S and U	α ⌒ β at S and U
Conclusion	(30) is applicable and violated	(30) is applicable and violated

In example (33a), UMLAUT is violated in the familiar way, and an unfaithful candidate is chosen instead: [dómürūm]. In this case, because the affected syllable is unstressed, the vowel [ü] rather than [ö] is chosen, for the reasons given in (29). In (33b), the basis for "iteration" of *u*-umlaut is shown. Because the condition on the featural make-up of α can be met at the surface level, a [ü] derived from /a/ is sufficient to

trigger umlaut. The α> β condition must be met at underlying structure for the constraint to be applicable. In this case, it is, since neither trigger nor target is epenthetic. This stands in contrast to the case of [akür] in (32), which does not match the α> β condition in underlying representation.

In summary, the correspondence approach to Icelandic *u*-umlaut rests on decoupling conditions on the featural make-up, linear order, and adjacency of segments from each other with respect to the levels at which those conditions obtain. By virtue of this move, two crucial results are obtained:

- The V-to-V adjacency requirement can be met at underlying or surface structure, correctly yielding umlaut in cases where the triggering vowel is deleted (/baggüli/ → [böggli]) and where deletion of an intervening vowel creates the requisite adjacency condition (/raginüm/ → [rögnüm]).
- When the vowel [ü] is derived by umlaut, it can itself serve as a trigger for umlaut (/bakarum/ → [bökürüm]). But when [ü] is derived by epenthesis, it does not match the α> β condition *at underlying structure*, and so no umlaut is observed (/akr/ → [akür]).

In contrast, the structural approach encounters difficulties with exactly these cases. The problems center around consistency in the treatment of unparsed or morphologically unsponsored segments:

- Forms like [bögg⟨ü⟩li] show that even unparsed *ü* triggers the alternation. Why then doesn't unparsed *i* in [köt⟨i⟩lüm] render the vowels of the first and last syllables non-adjacent? Unparsed elements are inconsistently visible to the constraint, depending on whether their role is crucial or contextual.
- Forms like [ak$\boxed{\text{ü}}$r] show that morphologically unsponsored (i.e., epenthetic) [ü] does not trigger the alternation. But in [bökürüm], a vowel which is morphologically unsponsored *as* [ü] *does* trigger the alternation. Evidently, two different notions of morphological sponsorship will be required.[19]

These are exactly the thorniest cases of co-existing opacity and transparency in Icelandic. Technical solutions within the structural approach are no doubt possible, though it remains to be seen whether they will differ in any interesting way from the correspondence approach.

[19] This issue does not arise if epenthetic vowels are phonologically just empty nodes, with their quality determined extra-systemically, by the phonetics. Then, phonetic [akür] is phonological [akΔr], with no [ü] in sight, and no need to limit the constraint to morphologically-sponsored segments. In contrast, I assume here that the quality of epenthetic segments is under grammatical control: independently-required constraints on featural markedness select the least offensive material to satisfy the driving syllabic constraints. In this way, the featural make-up of epenthetic segments can figure in grammatial generalizations, as in Yawelmani (Kuroda 1967, Archangeli 1985). See Prince & Smolensky (1993), Chapt. 9; Smolensky (1993); McCarthy (1993); McCarthy & Prince (1994) for relevant discussion.

We turn now to Two-Level Phonology (Koskenniemi 1983; Karttunen 1993), which in some respects anticipates the proposal made in section 3. Each constraint of Two-Level Phonology consists of a licensed input:output relation and a context in which that relation obtains. This aspect of Two-Level Phonology is exactly like the rewrite rules of standard generative phonology. Unlike the standard theory, though, it recognizes *only* the input and output levels, with no intermediate stages. Thus, there can be no rule-ordering — all constraints are applied in parallel. Many of the effects of rule ordering, including the treatment of phonological opacity, are obtained by specifying whether the contextual conditions obtain at the underlying level, the surface level, or either — exactly as in section 3.

Koskenniemi offers a notation for two-level rules that allows independent specification of the level at which any contextual conditions apply. Here are some examples for Tiberian Hebrew spirantization and variants:

(34) Two-Level Rule Notation Illustrated

	Formulation	Interpretation
a.	Stop : Fricative ⇐ :V_	Only a surface vowel triggers the alternation (like (13), (20a)).
b.	Stop : Fricative ⇐ V: | :V _	Any vowel, even deleted or epenthetic, triggers the alternation. (This is real Hebrew, as in (14), (20b))
c.	Stop : Fricative ⇐ V:_	Only underlying vowel triggers the alternation (like (16), (20c)).
d.	Stop : Fricative ⇐ V:V_	Only a vowel present at both levels triggers the alternation. (Neither epenthetic nor deleted vowels serve as triggers, like (18), (20d)).

The left-hand side of the rule (before the "⇐"), like a standard rewrite rule, expresses the licensed input:output relationship between underlying stop and surface fricative. The right-hand side of the rule expresses the context, where the expression "α:" denotes an underlying context and ":α" a surface context. Boolean combinations are permitted, as in (34b, d).

This quick summary shows that there is considerable overlap, descriptively and even conceptually, between the Two-Level Theory and the correspondence or structural approaches to opacity in Optimality Theory. But there are differences too. One significant point of difference is that OT sees phonological alternations in terms of the interaction of markedness constraints and faithfulness constraints. That is, OT markedness constraints specify a target, but not a repair. The reason for this: within and between languages, targets are homogeneous even when the repairs are not. This point is central to Prince & Smolensky (1993) and is reiterated above in section 3.

In contrast, Two-Level Phonology expresses target and repair together, in a single constraint, just like the rewrite rules of standard phonology. A loss of generalization is inevitable whenever one language or several languages support a single target in different ways. This loss of generalization can be seen plainly in Lakoff's (1993: 124) two-level analysis of Lardil, with two distinct constraints whose effect is to delete unsyllabifiable consonants. This is a significant retrograde step in comparison to the rule-based accounts of Lardil in Itô 1986, 1989 and Wilkinson 1986, 1988, as well as the

Optimality-Theoretic analysis in Prince & Smolensky (1993: Chapt. 7). (For further criticism of Two-Level Phonology from this perspective, see Orgun 1995.)

Another point of difference is that Two-Level Phonology, as formalized by Koskenniemi (1983), is unable to deal with complex systems of opacity and transparency like Icelandic. Therefore, Lakoff's (1993) extension of Two-Level Phonology, called Cognitive Phonology, analyzes Icelandic by calling on *three* levels (see also Goldsmith's 1993 Harmonic Phonology). The three levels are dubbed M(orphemic), W(ord), and P(honetic), connected as M → W → P. Constraints license transitions between a particular pair of adjacent levels or any pair of adjacent levels.

For Icelandic, Lakoff (1993: 132f.) proposes an M:W constraint of Syncope, a W:P constraint of Epenthesis, and the following constraints to govern umlaut and related alternations:

(35) Cognitive Phonology Constraints for Icelandic

a. *u*-Umlaut (M:W)

$$\left.\begin{array}{ll} \text{M:} & \text{a} \\ & \quad | \\ \text{W} & \begin{bmatrix} \text{-low} \\ \text{-back} \\ \text{+rnd} \end{bmatrix} \end{array}\right\} \; C_0u$$

(i.e., before C_0u at either M or W level)

b. Vowel Reduction (W)

If [+syll, -stress, -low], then [+high].[20]

(In citing these constraints and the derivation below, I have used Icelandic orthography, as Lakoff does.) Applied to the crucial data, these constraints yield the following results:

(36) Cognitive Phonology Analysis Applied

	a.	b.	c.
M:	barnum	bagguli	raginum
	Umlaut	*Syncope, Umlaut*	*Syncope, Umlaut*
W:	börnum	böggli	rögnum
P:	börnum	böggli	rögnum

	d.	e.	f.
M:	akr	dómarum	bakarum
		Umlaut	*Umlaut*
W:	akr	dómurum *Reduction*	bökurum *Reduction*
	Epenthesis		
P:	akur	dómurum	bökurum

These examples nicely illustrate all of the main points of the analysis.The context for *u*-Umlaut — that is, before C_0u — can be met at M or W, as in (36b) and (36c) respectively. Epenthesis cannot feed Umlaut because these two constraints are in a

20 I have modified this constraint from the original by removing unnecessary [-back] from the antecedent and incorrect [+round] from the consequent.

counter-feeding order, by virtue of the levels to which they are assigned. Umlaut and Vowel Reduction interact in examples (36e, f), with M:W Umlaut conditioned by a *u* that is itself derived by virtue of W-internal Vowel Reduction.

It's clear that the correspondence-based constraint (30), set within Optimality Theory, is not too different from the Two-Level/Cognitive Phonology formulation of Umlaut in (35c). Both constraints see the role of *u* as trigger and the adjacency relation between α and *u* as conditions that can be met at either the underlying or the derived level. In (30), this characterization of the umlaut conditions is explicit, while in (35c) it is implicit in the expression "}C_0u". But there are significant differences as well.

One point of difference, which it shares with Two-Level Phonology, is that Cognitive Phonology generally combines target and repair in a single constraint. As I have already noted, this leads to significant loss of generalization (in comparison to OT) when a single target is satisfied by different repairs, within a language or between languages. Problematically, though, Cognitive Phonology also recognizes one-level constraints like Reduction (35b), which make no mention of the repair.[21] Cognitive Phonology has no theory of faithfulness beyond "default identity" (Lakoff 1993: 141), so the mode of satisfying one-level constraints is not guaranteed to be determinate. For instance, why is Reduction satisfied by further vowel raising rather than, say, moving the stress? In OT, this is a straightforward matter of constraint interaction through ranking: the constraint demanding initial stress dominates IDENT(-high).[22]

Another point of difference is that Cognitive Phonology (like Harmonic Phonology) posits three levels to OT's two. Forms like *akur* provide the crucial argument for three levels. As (36d) makes clear, the lack of epenthesis/umlaut interaction is achieved by judicious assignment of the constraints to particular levels. Umlaut licenses transitions from the M to the W level, while Epenthesis licenses transitions from the W to the P level. In this way, Epenthesis cannot feed Umlaut. If constraints were assigned to levels on a principled basis, this analysis would have a clear advantage over the stipulations inherent in the correspondence-based account (30). But the word "level", however much it might recall to us the ideas of the Structuralists[23] or of Lexical Phonology, has no meaning in Cognitive Phonology beyond the stipulated ordering of the constraints. Thus, Epenthesis is no more or less "phonetic" than Umlaut, and Umlaut is no more or less "word"-phonological than Epenthesis. The schema (30) is an alternative to the three levels: it successfully disposes of *akur* by

21 Within Cognitive Phonology, there is no real alternative to stating Reduction as a one-level constraint. Reduction must feed and be fed by Umlaut. This could be accomplished by assigning Reduction to M:W and Umlaut to *both* M:W and W:P. But then it would be impossible to explain why Epenthesis does not feed Umlaut, since Epenthesis must also be assigned to W:P. The only escape is to posit a *fourth* level to assign Epenthesis to.

22 This problem is even more obvious in Lakoff's (1993:140) analysis of Yawelmani Yokuts rounding harmony. For reasons similar to Icelandic, Harmony is a one-level constraint; it asserts that successive vowels agree in rounding if they agree in height. But without a theory of faithfulness it's impossible to explain why the second vowel changes to agree with the first, instead of the other way around, and why rounding assimilates instead of height *dissimilating*, which would equally satisfy the constraint.

23 Furthermore, as Orhan Orgun observes, the three levels of the Structuralists were defined by different alphabets (morphophonemic, phonemic and allophonic), while the three levels of Cognitive Phonology necessarily call on the *same* alphabet.

de-coupling featural, adjacency, and linear order conditions from one another, separately specifying the level of each. Combining this schema with the core OT idea of the markedness/faithfulness dichotomy, the need for a third level in Icelandic is eliminated.

5 *Conclusion*

In these remarks, I have examined the problem of phonological opacity for theories without serial ordering of rules, focusing on Optimality Theory. I have argued in favor of extending a correspondence-based approach to faithfulness to the statement of phonological markedness constraints. The core of the proposal is separate specification of the levels at which featural, adjacency, and linear order conditions must be met. I have compared this approach to two others, noting many similarities and a few differences: the structural approach adopted in Prince & Smolensky (1993) and most other OT work, and the Two-Level or Cognitive Phonology of Koskenniemi (1983) and Lakoff (1993). Obviously, these few pages give scant treatment to a complex array of issues[24], and much remains to be done.

References

Al-Mozainy, Hamza Q. (1981) *Vowel Alternations in a Bedouin Hijazi Arabic Dialect: Abstractness and Stress*. Ph.D. Thesis, University of Texas, Austin.

Anderson, Stephen R. (1972) Icelandic u-umlaut and breaking in a generative grammar, in Evelyn Scherabon Firchow, Kaaren Grimstad, Nils Hasselmo, & Wayne O'Neil (eds.) *Studies for Einar Haugen Presented by Friends and Colleagues*, 13–30. The Hague: Mouton.

Anderson, Stephen R. (1974) *The Organization of Phonology*. New York: Academic Press.

Archangeli, Diana (1985) Yokuts harmony: Evidence for coplanar representation in nonlinear phonology, *Linguistic Inquiry* 16, 335–372.

Archangeli, Diana, & Douglas Pulleyblank (1987) Minimal and maximal rules: Effects of tier scansion, in Joyce McDonough & Bernadette Plunkett (eds.), 16–35. *Proceedings of* NELS 17.

Archangeli, Diana & Douglas Pulleyblank (1994) *Grounded Phonology*. Cambridge, Massachusetts: MIT Press.

Bach, Emmon (1968) Two proposals concerning the simplicity metric in phonology, *Glossa* 2, 128–149.

Bach, Emmon & Deirdre Wheeler (1981) Montague phonology: A first approximation, *University of Massachusetts Occasional Papers in Linguistics* 7, 27–45.

Bird, Steven (1990) *Constraint-based Phonology*, Ph.D. Thesis, University of Edinburgh.

Chomsky, Noam (1994) Bare phrase structure. *MIT Occasional Papers in Linguistics* 5.

Goldsmith, John (1993) Harmonic phonology. In John Goldsmith (ed.) *The Last Phonological Rule*. Chicago: University of Chicago Press.

24 For example, chain shifts are a type of opacity that presents its own problems. For relevant discussion, see McCarthy 1993, Orgun 1995, and Kirchner 1995b. Likewise, I have not dealt with instances of opacity involving prosodic structure, as when closed syllables created by syncope act as open, or open syllables created by epenthesis act as closed.

Golston, Chris (1995) Direct Optimality Theory: Representation as constraint violation. Rutgers Optimality Archive #71.

Hammond, Michael (1995) There is no lexicon. Rutgers Optimality Archive #43.

Idsardi, William (1995) Dressing up a 'bare' argument. Handout of talk presented at Montréal-Ottawa-Toronto (MOT) phonology workshop. February 4, 1995.

Itō, Junko (1986) *Syllable Theory in Prosodic Phonology*, Ph.D. Thesis, University of Massachusetts, Amherst.

Itō, Junko (1989) A prosodic theory of epenthesis, *Natural Language & Linguistic Theory* 7, 217–260.

Jensen, John (1995) Constraints and opaque interactions, *Cahiers linguistiques d'Ottawa* 23, 1–9.

Karttunen, Lauri (1993) Finite-state constraints, in John Goldsmith (ed.) *The Last Phonological Rule*, 173–194. Chicago: University of Chicago Press.

Kaye, Jonathan, Jean Lowenstamm, & Jean-Roger Vergnaud (1985) The internal structure of phonological elements: A theory of charm and government, *Phonology* 2, 305–328.

Kiparsky, Paul (1971) Historical linguistics. In W. Dingwall (ed.) *A Survey of Linguistic Science*. College Park, MD: University of Maryland Press.

Kiparsky, Paul (1973) Phonological representations. In Osamu Fujimura (ed.), *Three Dimensions of Linguistic Theory*, 1–136. Tokyo: Taikusha.

Kiparsky, Paul (1985) On the lexical phonology of Icelandic, in C. C. Elert, I. Johansson & E. Stangert (eds.) *Nordic prosody* III, 135–164. University of Umeå.

Kirchner, Robert (1995a) Contrastiveness is an epiphenomenon of constraint ranking. Forthcoming in Berkeley Linguistics Society Proceedings. Rutgers Optimality Archive #51.

Kirchner, Robert (1995b) Going the distance: Synchronic chain shifts in OT. Ms., UCLA. Rutgers Optimality Archive #66.

Kisseberth, Charles (1970) On the functional unity of phonological rules, *Linguistic Inquiry* 1, 291–306.

Kisseberth, Charles (1973) Is rule ordering necessary in phonology? In Braj B. Kachru et al. (eds.), *Issues in Linguistics: Papers in Honor of Henry and Renée Kahane*, 418–441. Urbana: University of Illinois Press.

Koskenniemi, Kimmo (1983) *Two-level Morphology: A General Computational Model for Word-form Recognition and Production*, Publication no. 11, Department of General Linguistics, University of Helsinki.

Kuroda, S.-Y. (1967) *Yawelmani Phonology*. Cambridge, Massachusetts: MIT Press.

Lakoff, George (1993) Cognitive phonology, in John Goldsmith (ed.) *The Last Phonological Rule*, 117–145. Chicago: University of Chicago Press.

Lowenstamm, Jean & Jonathan Kaye (1985) Compensatory lengthening in Tiberian Hebrew, in Leo Wetzels & Engin Sezer (eds.) *Studies in Compensatory Lengthening*, 97–132. Dordrecht: Foris.

Malone, Joseph (1993) *Tiberian Hebrew Phonology*. Winona Lake, Indiana: Eisenbrauns.

McCarthy, John (1993) The parallel advantage: Containment, consistency, and alignment. Handout from talk presented at Rutgers Optimality Workshop I, Rutgers University, New Brunswick, N.J.

McCarthy, John & Alan Prince (1993) *Prosodic Morphology I: Constraint Interaction and Satisfaction*. To appear, Cambridge, Massachusetts: MIT Press.

McCarthy, John & Alan Prince (1994) The emergence of the unmarked: Optimality in Prosodic Morphology. In Mercè Gonzàlez, ed., *Proceedings of the North East Linguistic Society* 24, 333–379. Amherst, Massachusetts: Graduate Linguistic Student Association. Rutgers Optimality Archive #13.

McCarthy, John & Alan Prince (1995) Faithfulness and reduplicative identity in Jill Beckman, Laura Dickey, & Suzanne Urbanczyk, eds., *University of Massachusetts Occasional Papers in Linguistics 18: Papers in Optimality Theory*, 249–384. Also to appear in René Kager, Harry van der Hulst, & Wim Zonneveld (eds.) *The Prosody Morphology Interface*. Rutgers Optimality Archive #60.

Myers, Scott (1987) *Tone and the Structure of Words in Shona*, Ph.D. Thesis, University of Massachusetts, Amherst.

Orgun, Cemil Orhan (1995) Correspondence and identity constraints in two-level Optimality Theory. To appear in WCCFL proceedings. Rutgers Optimality Archive #62.

Pater, Joe (1995) Austronesian nasal substitution and other NÇ effects. In René Kager, Harry van der Hulst, & Wim Zonneveld, eds., *The Prosody Morphology Interface*. Rutgers Optimality Archive #92.

Prince, Alan S (1975) *The Phonology and Morphology of Tiberian Hebrew*, Ph.D. Thesis, MIT.

Prince, Alan & Paul Smolensky (1993) *Optimality Theory: Constraint Interaction in Generative Grammar*. To appear, Cambridge, Massachusetts: MIT Press.

Russell, Kevin (1995) Morphemes and candidates in Optimality Theory. Rutgers Optimality Archive #44.

Scobbie, J. (1992) Towards Declarative Phonology. *Edinburgh Working Papers in Cognitive Science* 7, 1–26.

Selkirk, Elisabeth O. (1981) Epenthesis and degenerate syllables in Cairene Arabic, in Hagit Borer & Joseph Aoun (eds.) *Theoretical Issues in the Grammar of the Semitic Languages*. Cambridge, Massachusetts: MIT Dept. of Linguistics & Philosophy.

Selkirk, Elisabeth O. (1988) Dependency, place, and the notion 'tier', Ms., University of Massachusetts, Amherst.

Smolensky, Paul (1993) Harmony, markedness, and phonological activity. Talk presented at Rutgers Optimality Workshop I, Rutgers University, New Brunswick, NJ. Rutgers Optimality Archive #87.

Steriade, Donca (1982) *Greek Prosodies and the Nature of Syllabification*, Ph.D. Thesis, MIT.

Wheeler, Deirdre (1981) *Aspects of a Categorial Theory of Phonology*, Ph.D. Thesis, University of Massachusetts, Amherst.

Wheeler, Deirdre (1988) Consequences of some categorially motivated phonological assumptions in Richard Oehrle, Emmon Bach, & Deirdre Wheeler (eds.) *Categorial Grammars and Natural Language Structures*, 467–488. Dordrecht: Reidel.

Wilkinson, Karina (1986) Syllable structure and Lardil phonology, Ms., University of Massachusetts, Amherst.

Wilkinson, Karina (1988) Prosodic structure and Lardil phonology, *Linguistic Inquiry* 19, 325–334.