MINIMAL CONTRAST AND THE PHONOLOGY-PHONETICS INTERACTION

by

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ABSTRACT

This dissertation investigates the role of minimal contrast in phonetic patterns and phonological phenomena. Two sounds are minimally contrastive when they differ in just one property. The main findings are that (i) minimal contrast can influence the outcome of phonetic effects and that (ii) phonological processes may single out minimally contrastive elements. A *contrast-coindexing function* is developed in order to mark elements that are minimally contrastive for some property.

An experimental study is conducted to test the influence of minimal length contrast on the phonetic voicing effect, a pattern by which vowels are longer before voiced than before voiceless obstruents, in Lithuanian. In Lithuanian, only high and low vowels are minimally contrastive for length. Mid vowels are always long. The experimental results indicate that contextual modification of vowel duration is more limited for those vowels that are minimally contrastive for length than for those that are not. These results are argued to stem from the functional requirement to maintain distinct contrasts.

The experimental results show that phonetic patterns can be sensitive to minimal contrast. Therefore, I argue that the phonological representation must include information about minimal contrast, which the phonetic component can access. I formalize this contrast with a *contrast-coindexing* function. Framed within Optimality Theory, c*ontrast-coindexing* applies to minimally contrastive segments capable of distinguishing pairs of words, adopting a systemic approach to contrast. Under the *contrast-coindexing* analysis, length contrasts are represented using the

same mechanisms as for other contrasts. This approach has implications for the moraic representation of length contrasts, which fails to capture minimal length contrast.

The proposal to incorporate minimal contrast into the phonological representation predicts that this kind of contrast might also be active in phonological phenomena. Evidence for this prediction is presented from vowel height harmony in Lena Asturian. In Lena, only vowels that are minimally contrastive for height can trigger harmony. The typology of vowel harmony illustrated by several varieties related to Lena lends further support to the claim that minimal contrast is active in the phonology. The contrast-coindexing proposal is extended to other phonological patterns, in which minimally contrastive elements are singled out.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This dissertation examines the role of minimal contrast in phonetic patterns and phonological phenomena. Two sounds are minimally contrastive when they differ in just one property. The main findings are that (i) minimal contrast can influence the outcome of phonetic effects and that (ii) phonological processes have the potential to single out minimally contrastive elements. In view of these findings, I argue that minimal contrast needs to be included in the phonological representation. A *contrast-coindexing function* is developed in order to mark elements that are minimally contrastive for some property. This function is a concrete proposal about how phonological minimal contrasts are represented.

The significance of contrast in phonology has been a recurrent focus of attention in the phonological literature (e.g. Archangeli 1984, 1988, Steriade 1987, 1995, Pulleyblank 1988, Mester & Ito 1989, Dresher, Piggott & Rice 1994, Flemming 1995, 2004, Padgett 1997, 2003b, Dresher 1998a, b, Ní Chiosáin & Padgett 2001, Lubowicz 2003, Sanders 2003, among others). The present study contributes to this line of research by concentrating on the role of *minimal contrast*. Minimally contrastive segments are pairs of segments that differ in one property or dimension of contrast (Jakobson, Fant & Halle 1952). For example, /iː/ and /i/ are minimally contrastive for length because they only differ in terms of this property.

The main issues addressed in this study are given in (1). Each of these issues is discussed in turn in the following sections.

(1) Main issues addressed in this study

(i) the influence of minimal contrast on phonetic patterns

(ii) the role of minimal contrast in phonology

(iii) the representation of minimal contrast

- A new approach to phonemic length

(iv) a model of the phonology-phonetics interaction

1.1.1 The influence of minimal contrast on phonetic patterns

Phonological contrast has been shown to affect certain phonetic patterns. One of the most studied cases is that of coarticulation (Manuel 1999, see section 2.2 for an overview). The main insight from the literature on the topic is that the presence of phonological contrast limits the degree of coarticulation between different gestures. Previous work argues that this limit occurs in those cases where a high degree of coarticulation would decrease the saliency of the relevant contrast (Manuel & Krakow 1984, Engstrand 1988, Manuel 1999). Hayes (1995) puts forward the same functional motivation for languages where the presence of phonemic length limits the use of duration as a cue to stress.

In this study, the relationship between contrast and phonetics is further explored by looking at cases where minimal length contrast interacts with phonetic patterns that modify duration. More precisely, I present experimental data from Lithuanian showing that the presence of a minimal vowel length contrast attenuates the effects of a phonetic pattern, namely the voicing effect. The voicing effect refers to the tendency for vowels to be longer before voiced obstruents than before voiceless ones (Chen 1970). The Lithuanian vowel system is asymmetrical. High and low vowels each have short/long counterparts. On the other hand, mid vowels are always (phonologically and phonetically) long. Mid vowels are not minimally contrastive for length. In the experiment reported in this dissertation, I measure the degree of the voicing effect by comparing the duration of the first vowel in nonsense words such as [t**i**kʃa] vs. [t**i**gʒa], where the relevant vowel could be any of the Lithuanian monophthongs. The results show that the voicing effect is significantly stronger for the mid vowels than for the rest, i.e., it has strongest effect for the Lithuanian vowels that are not minimally contrastive for length. This means that the voicing effect is attenuated when the relevant vowel has a minimally different long/short counterpart. I argue that this result stems from the functional motivation to maintain distinct contrasts.

The conclusion from the experimental study is that minimal contrast can affect the outcome of a phonetic pattern (cf. Kingston & Diehl 1994). In view of this influence of minimal contrast, I argue that the phonological representation directly encodes information about this kind of contrast. My proposal is that the phonological representation incorporates contrast by establishing a coindexing relationship between segments that are minimally contrastive. Then, the phonetics has access to whether a given segment is specified for a contrast-coindex or not. This follows the assumption that phonetics acts upon the phonological representation and has access to all the information included in it.

1.1.2 The role of minimal contrast in phonology

The claim that minimal contrast should be part of the phonological representation receives further support from phonological phenomena that are sensitive to this kind of contrast. Evidence comes from vowel height harmony in the Romance variety of Lena. In Lena, a stressed vowel assimilates in height to a following inflectional vowel, as the examples in (2) illustrate (e.g. Neira 1955, 1982, Hualde 1989, 1992, Dyck 1995, Walker 2004, 2005). The first element in each pair undergoes raising of the stressed vowel.

(2) Vowel harmony in Lena[1]

[g**é**tu]	'cat.masc.sg.'	vs.	[g**á**ta]	'cat.fem.sg.'
[kord**í**ru]	'lamb.masc.sg.'	vs.	[kord**é**ros]	'lamb.masc.pl.'
[fl**ú**ʃu]	'lazy.masc.sg.'	vs.	[fl**ó**ʃos]	'lazy.masc.pl.'

[1] An accent mark over a vowel indicates stress.

The crucial observation about Lena harmony is that only inflectional vowels that are minimally contrastive for height can trigger the process. The Lena inflectional inventory includes /e, a, o, u/, which is realized as [i/e, a, o, u], where [i/e] indicates that the realization varies from [i] to [e]. This system does not have a height contrast among its front vowels. Interestingly, an inflectional front vowel realized as [i] never triggers harmony. I argue that this derives from the fact that front vowels are not minimally contrastive for height (cf. Dyck 1995 for related observations implemented in a different framework). Moreover, data from other varieties related to Lena reinforce the conclusion drawn from Lena harmony. The typology derived from these Romance varieties suggests that height harmony in these systems is triggered only by high vowels that are minimally contrastive for height.

The proposal that minimal contrast is part of the phonological representation predicts more cases like that found in Lena. I present additional evidence for the role of minimal contrast in phonology from a harmony process in the Australian language, Gaagudju. In relation to this case, the contrast-coindexing analysis of minimal contrast is compared against Underspecification Theories (Archangeli 1984, 1988, Steriade 1987, Pulleyblank 1988, Dresher, Piggott & Rice 1994, Dresher 1998a, b). Underspecification has been used before to account for cases where some phonological features are apparently inactive. I present arguments against underspecified representations drawn from the literature and, also from the Lena facts.

1.1.3 Representation of minimal contrast

This dissertation formalizes the phonological representation of minimal contrast as a *contrast-coindexing* function. *Contrast-coindexing* applies to minimally contrastive segments capable of distinguishing pairs of words. Minimal contrast is assessed at the word level, taking the language's entire set of phonologically well-formed words into consideration. This work adopts a systemic approach to minimal contrast so that that the candidates in the phonological evaluation are candidate languages (e.g. Flemming 1995, Ito & Mester in press, Padgett 1997, Ní Chiosáin & Padgett (to appear), cf. Lubowicz 2003). In preview, the contrast-coindexing function compares every possible pair of word forms within a candidate language and establishes whether they constitute a minimal pair. Each time a minimal pair is identified, the differing segments are compared for their dimensions of contrast. If they share all dimensions except for one, then they are *contrast-coindexed* for this dimension. Let us illustrate how the contrast-coindexing function works with a language that has a small vowel inventory, for example the Australian language Djaru (Tsunoda 1981). Djaru's vowel inventory is given in Table 1.[2]

Table 1. Djaru vowel inventory

	Front	Central	Back
High	i		u
Low		a aː	

[2] I come back to Djaru in section 3.3.2.1.

For the sake of illustration, I focus on length contrast in Djaru's system. Table 1 shows that length is contrastive only for low vowels in this Australian language. High vowels are always short. This means that minimal pairs can be found where the differing segments are low and they are distinct only in terms of their length. On the other hand, there are no minimal pairs where the differing segments are high and contrast in length. The forms in (3) include some possible and impossible hypothetical words in Djaru, illustrating the presence and absence of the relevant minimal pairs. (3)a) shows a pair of words that are different only in the length of the first vowel. Thus, this vowel gets a contrast-coindex for length (d-subscript stands for duration). (3)b) and (3)c) show that there are no two words that would differ only in the length of the first vowel, if this vowel is high. Accordingly, the phonologically well-formed words in (3)b) ([iru]) and (3)c) ([uru]) lack a length contrast-coindex for their first vowel.

(3) Possible and impossible minimal pairs in Djaru

(a) [$\mathbf{a}_{\mathbf{d}}$ru] *vs.* [$\mathbf{aː}_{\mathbf{d}}$ru]

(b) [**i**ru] *vs.* *[**iː**ru]

(c) [**u**ru] *vs.* *[**uː**ru]

Contrast-coindexing is couched within the framework of Dispersion Theory as developed by Flemming (1995) with further developments by Padgett (1997) and Ní Chiosáin & Padgett (2001) in Optimality Theory (OT; Prince & Smolensky

1993). Framed within OT, the *contrast-coindexing* function is argued to apply after GEN generates the candidates and before EVAL operates over them. The proposed architecture is schematically shown in Figure 1. This architecture is further developed in section 3.3.2.4.

Figure 1. Proposed architecture with contrast-coindexing function

GEN	=>	**Contrast-coindexing**	=>	**EVAL**
Candidate generation		Minimal contrast is marked		Constraint ranking selects optimal candidate

In the present study, special attention is paid to length contrasts in an effort to advance our understanding of how length differences should be represented. This thesis introduces a new approach to the representation of length that captures the behavior of minimal length contrast. More precisely, contrast-coindexing applies to phonemic length distinctions. Thus, length is treated as any other dimension of contrast, and its contrastive value arises through the same mechanism as for other properties. This implies that moras are not necessary to represent length contrasts. In fact, the traditional moraic account of length is shown not to be adequate to capture the effect of length contrast on phonetic patterns. Note that I argue only against moras in relation to the encoding of contrastive duration. Moras have other functions as units of weight that are not considered in this study.

1.1.4 A model of the phonology-phonetics interaction

This dissertation adopts the approach according to which phonetics and phonology are two different components of the grammar (Cohn 1993, Zsiga 1995, 1997). I argue that some phonological aspects, namely minimal contrast, influence phonetic patterns (cf. Kingston & Diehl 1994). Figure 2 represents this view of phonology, phonetics and their interaction.

Figure 2. Phonology-phonetics interaction

Phonology – Featural representation with contrast-coindices

↓ *Mapping of phonological representation*

Phonetics – Windows for acoustic, articulatory and intergestural timing targets

Phonetic detail can also affect the phonology and influence certain phenomena that take place at this level. Under one view, phonetic pressures can shape phonological processes in language change due to the phenomenon of 'innocent misapprehension' (e.g. Ohala 1981, 1993, Blevins & Garrett 1998, 2004, Hume & Johnson 2001, Hyman 2001, Blevins 2004, Hayes & Steriade 2004). The current study concentrates on the influence of phonology in phonetics, more concretely on the effect of minimal contrast on phonetic patterns, as well the role of minimal contrast on phonological processes. For this reason, the focus is on modeling the transition from the phonological component into the phonetics.

In Figure 2, the phonetic component consists of windows for acoustic, articulatory, and intergestural timing targets. Keating (1990) proposes the window model of articulation. According to this framework, acoustic and articulatory targets are defined in terms of acceptable ranges or windows. The window model explicitly relates contrast with coarticulation so that contrastive elements have narrower target ranges than elements that are not contrastive for that same property. Thus, the claim made in this thesis that minimal contrast limits phonetic patterns can be captured within this phonetic model. Furthermore, Keating's proposal and developments by Guenther (1995) state that the phonological, featural representation can be mapped into acoustic and/or articulatory targets in the phonetic component. This is in accordance with the approach adopted here.

The phase window model (Byrd 1996, Saltzman & Byrd 2000) extends the window idea to intergestural timing, i.e., the timing between different gestures. Phase windows of intergestural timing capture the observation that the relative phasing among articulatory gestures is not fixed but rather, it can be affected by linguistic and extra-linguistic factors. Those factors are called influencers (Byrd 1996). Focusing on contrast-coindices for length, I hypothesize that these coindices representing minimal length contrasts can act as influencers of intergestural timing. This proposal contributes to the phase window model by exploring what factors can function as influencers on the relative timing among gestures.

1.2 Theoretical background

1.2.1 Distinction between phonology and phonetics

This dissertation assumes a distinction between phonology and phonetics, in accordance with proposals made by Cohn (1993) and Zsiga (1995, 1997).[3] However, these two components do not act entirely independently of each other. There is an interaction between both systems, so that phonological elements and information become relevant for phonetic patterns and similarly, explanation for different phonological phenomena lies in the phonetics. Here, I introduce the main differences between phonetic patterns and phonological processes in order to clarify the basic distinction espoused in this work.

The effects of phonological phenomena are categorical. For instance at the segmental level, they involve changes that affect a whole segment (or sequence of segments), and the changes occur throughout that segment. On the other hand, phonetic processes are gradient and they might affect a segment only partially, rather than during its entire duration. Note that the distinction between phonology and phonetics is not always straight-forward. Whether a given process is categorical or gradient could become evident by looking at phonetic data (Cohn 1993, Steriade 1993, Zsiga 1995, 1997). For example, Zsiga (1995) claims that the palatalization of /s/ before /j/ in English is categorical when it takes place within a word, for instance in *permission* (derived [ʃ]). However, palatalization is gradient when it takes the

[3] See for example Keating (1984, 1990), Hale and Reiss (2000), Hyman (2001) among others for more arguments in favor of the distinction assumed here. Other researchers, on the other hand, assume no distinction (e.g. Browman & Goldstein 1986, 1989, 1992).

form of an external sandhi effect, for example across the words *miss you* (/s#j/). Zsiga reaches this conclusion after finding that derived [ʃ] shows the same acoustic and articulatory patterns as underlying /ʃ/. This is in contrast with /s#j/ which starts off behaving like an underlying /s/, i.e., at the onset the consonant shows phonetic properties of [s], and changes during its production into a [ʃ], so that its final portion resembles acoustically and articulatorily an underlying /ʃ/.

Phonological processes, and not phonetic effects, can apply 'cyclically', giving rise to cases of opacity. In Sundanese (Cohn 1993), [+nasal] spreads progressively from a nasal consonant until it is blocked by a supralaryngeal consonant. The examples in (4)a) show [+nasal] spreading. The forms in (4)b) include a supralaryngeal consonant (/l, r/), which blocks the spreading.

(4) Nasal spreading in Sundanese (Cohn 1993)

a. /ɲiar/ → [ɲĩãr] 'seek'

/mahal/ → [mãhãl] 'expensive'

b. /marios/ → [mã**r**ios] 'examine'

/ŋuliat/ → [ŋũ**l**iat] 'stretch'

However, the sonorant consonants in the plural infixes [-al-] and [-ar-] do not block [+nasal] spread into a following vowel. In these cases, under a serial analysis, the cyclic application of nasal spreading obtains these results. It seems that nasal spreading occurs before and also after infixation, resulting in nasalization of the infix vowel and any following material that might be subject to nasal spreading. This is illustrated in (5).

(5) Nasal spreading across /l, r/ in plural infixes

/ɲ-al-iar/ → [ɲã**l**ĩãr] 'seek'

/m-ar-ahal/ → [mã**r**ãhãl] 'expensive'

Phonological phenomena also show the special behavior of applying only in derived environments. These are processes that take place only in the context of affixation and not within a morpheme (see Lubowicz 2002 and references cited therein for examples). Another trait of phonological processes is that they might be subject to morphological restrictions and might have lexical exceptions. Igbo [ATR] vowel harmony (Zsiga 1997) takes place within non-compound words and across inflectional affixes. Within compound words and across most aspectual suffixes [ATR] harmony does not apply. However, there are some lexical exceptions formed by disharmonic morphemes and some aspectual suffixes that undergo the harmony.

The current study devotes its attention to the role of phonological contrast in phonetics and phonology, so it is relevant to explain how the two components react when perception of a given contrast is threatened by contextual modification. Under these circumstances, the phonology takes categorical measures. These might result in certain inventory distributions and neutralization patterns. In all of these cases, the contrast is maintained only in forms that are sufficiently distinct. Otherwise the contrast is neutralized. On the other hand, phonetics reacts differently: a compromise is reached between the aim to maintain a distinct contrast and the endangering effects of a given phonetic pattern. The result is that the phonetic pattern applies to a lesser degree, so that the contrast is undermined less than it would be if the pattern was to exert its whole force. The results from the Lithuanian experiment illustrate this point. In this language, when a phonetic pattern modifying duration endangers the realization of a length contrast, the phonetic effect is present to a lesser extent than when there is no contrast. Crucially, the effect is still present. It is not altogether suppressed; it reaches a compromise.

1.2.2 Optimality Theory

The phonological analyses in this dissertation are couched within the framework of Optimality Theory (Prince & Smolensky 1993).[4] The main insight of Optimality Theory (OT) is that grammar is a system of forces in conflict that can be represented as competing constraints. Thus, an optimality-theoretic grammar is a hierarchy of rankable and violable constraints that evaluate the well-formedness of output forms. One important characteristic of OT that sets it apart from previous generative frameworks is that the evaluation takes place in parallel. Parallel evaluation selects

[4] Prince & Smolensky's (1993) seminal paper has been recently published as Prince & Smolensky (2004). For general introductions to Optimality Theory, refer to Archangeli and Langendoen (1997), Kager (1999) and McCarthy (2002). Here, I focus on an optimality-theoretic approach to phonology.

from a set of candidate output forms that which is most harmonic, i.e., the optimal output, with respect to the constraint ranking.

There are three components in an OT grammar: GEN, CON and EVAL. GEN is the generator function, which takes some input as its argument and produces a set of candidates for evaluation. CON is the set of universal constraints that make up grammars. The constraints in CON are fixed across languages. However, individual languages impose different rankings on the elements of CON.[5] These rankings are always language-specific. EVAL is the evaluator function, which selects the optimal candidate from the forms given by GEN. EVAL contains the set of ranked constraints, which evaluates output candidates. The basic architecture of OT is illustrated in Figure 3 (McCarthy 2002).

Figure 3. Basic OT architecture

input → [GEN] → candidates → [EVAL] → output

An essential property of GEN is that it can generate an unlimited number of candidates. This property is called Freedom of Analysis. As a result, the set of candidates is infinite, with the only limitation that the candidates be made up of the elements from the universal vocabularies of phonological representation (e.g. segmental and prosodic structure). EVAL has the responsibility of accounting for all the regularities and patterns in surface forms of a given language. It has the crucial

[5] Some universal fixed rankings have been proposed (e.g. in Prince & Smolensky 1993, McCarthy & Prince 1995, Anttila 1997, Gnanadesikan 1997, de Lacy 1999, Walker 2000, Crosswhite 2001).

role of discriminating among all the candidates posited by GEN by assessing their harmony with respect to the constraint ranking. The OT grammatical organization is represented in Figure 4.

Figure 4. Schema for the input-output mechanism in an OT grammar

GEN (input) → {$cand_1$, $cand_2$... $cand_n$}

EVAL {$cand_1$, $cand_2$... $cand_n$} → output

The constraints in CON are of two main types: markedness and faithfulness. Markedness constraints evaluate the well-formedness conditions on outputs. Faithfulness constraints militate for the identity between the input and the output. McCarthy & Prince (1995) introduce the notion of correspondence. Under correspondence theory, faithfulness constraints demand identity between elements in correspondence, for instance the input and the output. Correspondence is defined as in (6), where S_1 could be the input and S_1 the output. GEN specifies the correspondence relations between different structures.

(6) Correspondence

Given two strings S_1 and S_2, correspondence is a relation R from the elements of S_1 to those of S_2. Elements $\alpha \in S_1$ and $\beta \in S_2$ are referred to as correspondents of one another when α R β.

As an illustration of the evaluation mechanism in Optimality Theory, consider a hypothetical grammar consisting of three constraints C_1, C_2 and C_3 in CON, ranked such that C_1 dominates C_2 and C_2 dominates C_3. Then, by transitivity C_1 dominates C_3 (C_1>> C_2>> C_3). The candidate set is made up of three possible candidate outputs ($cand_1$, $cand_2$, $cand_3$) obtained by the application of GEN to an input. OT evaluations are represented in a tableau, where the optimal candidate is signaled with a pointing hand. The tableau in Table 2 illustrates this simple grammar. The three relevant constraints are arranged from left to right according to their order in the constraint ranking. Constraint violations are indicated by asterisks, while exclamation marks indicate fatal violations. Note that the violations are hypothetical and they cannot be read off of the candidates here. Shading of the tableau cells indicates that these are irrelevant for the evaluation.

Table 2. Tableau 1 C_1>> C_2>> C_3

	C_1	C_2	C_3
a. $Cand_1$		*!	*
☞ b. $Cand_2$			*
c. $Cand_3$	*!		

Tableau 1 shows that candidate (c) fatally violates the top-ranked constraint C_1 and consequently, it needs not be further considered in the evaluation. Candidate (a) violates constraint C_2. This constraint is not top-ranked. However, candidate (b) does better with respect to C_2. Candidate (a) incurs a violation of C_3 too, although this is not decisive in the evaluation. Therefore, candidate (b) emerges as the optimal output for this grammar, even though it violates the low-ranked constraint C_3. The fact that candidate (b) violates a bottom-ranked constraint (C_3) does not prevent it from becoming the winner, as long as it satisfies the higher ranked C_1 and C_2, which are violated by either one of the two competitor candidates.

To conclude this section, it is worth discussing two other elements of the OT machinery, namely Richness of the Base and Lexicon Optimization (Prince & Smolensky 1993). According to Richness of the Base (ROTB), no constraints hold at the level of the input. An OT grammar is expressed as the interaction of constraints at the level of the output or on input-output correspondence, never at the input level alone. Also, there are no language-particular restrictions on the input. Consequently, the result of the ROTB principle is that the set of inputs is universal. All languages share the same inputs. However, a distinction can be made between inputs and underlying forms. It has been proposed that the learner posits a single underlying representation for each optimal output, i.e., the input that corresponds to the lexical item. In OT, the process of selecting the underlying representation from the set of possible inputs is done through the Lexicon Optimization (LO) process (Prince & Smolensky 1993, Inkelas 1994, Ito, Mester & Padgett 1995). A definition of LO is given in (7), following Ito, Mester & Padgett (1995).

(7) Lexicon Optimization

Of several potential inputs whose outputs all converge on the same surface form, choose as the underlying representation the input whose output is the most harmonic.

LO chooses the underlying representation that gives the most harmonic mapping with respect to the constraint ranking of the language. As a result, the underlying representation will be the input that most closely resembles the output (but see Inkelas 1994 for discussion of cases where there are alternations).

1.3 Organization of the thesis

The organization of the thesis is as follows. Chapter 2 focuses on the effects of phonological minimal contrast on phonetics. First, it gives an overview of previous work on the influence of contrast on phonetic patterns. Next, it introduces a phonetic experiment on Lithuanian that tests the interaction between minimal vowel length contrast and the voicing effect. The results show that the presence of minimal contrast limits the degree of the voicing effect.

Based on the experimental findings, chapter 3 develops an optimality-theoretic analysis of the vowel inventory in Lithuanian, extending Dispersion Theory to account for length contrasts. Following this analysis, the contrast-coindexing function is introduced, together with a discussion of minimal pair identification and a detailed description of the proposed architecture. Next, the dimensions of contrast are described in detail in section 3.4. Padgett's (2002) Feature Class Theory is adopted to capture the notion of dimension as a space along which contrasts are established, rather than specific features. Section 3.5 develops a model of the phonology-phonetics interaction, focusing on the influence of phonology in phonetics. First, based on the literature, I argue that phonetic patterns are sensitive only to contrasts along which they operate. For example, contextual duration modifications are influenced by length contrasts. Finally, following Keating (1990) and Guenther (1995a, b), I assume that the phonological presentation is mapped into a series of window targets for different acoustic and articulatory dimensions. Contrast-coindices, being part of the phonological representations, are also mapped into the phonetics as determiners of the window size. Byrd (1996) & Saltzman & Byrd (2000)'s phase windows are adopted to account for the influence of minimal length contrast on the voicing effect. I propose that contrast-coindices act as determiners of intergestural timing specifications within the phase window model. To conclude chapter 3, I show that the moraic representation is not able to capture the behavior of minimal length contrast

Chapter 4 explores a prediction of contrast-coindexing, namely that phonological phenomena can be sensitive to the presence of minimal contrast in the representation. I present and analyze the facts about Lena harmony, taking into account the contrast-coindices in the language. The typology drawn from other varieties related to Lena bring more support for the role of minimal contrast. Next, Underspecification Theory is discussed in relation to the role of minimal contrast in phonology. This theory is rejected due to its lack of empirical coverage and formal challenges. The chapter concludes with a case from Gaagudju further illustrating the role of minimal contrast in phonology. Contrast-coindexing allows for a successful analysis of these languages.

Chapter 5 states further extensions of the proposal and directions for future research. Finally, the conclusions from the dissertation are summarized.

CHAPTER 2

MINIMAL CONTRAST AND PHONETIC PATTERNS

2.1. Introduction

This chapter investigates the influence of phonological minimal contrast on phonetic patterns. The focus is on the relationship between phonemic vowel length and a phonetic effect that modifies vowel duration. More precisely, I present experimental results showing that the presence of minimal vowel length contrast in the system limits the amount of phonetic modification. Phonological contrast has been shown to affect certain phonetic patterns. One of the most studied cases is that of coarticulation and contrast (Manuel 1999, see section 2.2 for an overview and more references). The presence of phonological contrast can limit coarticulation between different gestures, in those cases where a high degree of coarticulation would blur perception of the relevant contrast. This chapter further explores this relationship by looking at cases where a length contrast affects some durational phonetic tendency. Experimental data are analyzed and show that the presence of phonological vowel length attenuates the effects of a phonetic pattern, namely the obstruent voicing effect, i.e., the tendency of vowels to be longer before voiced obstruents than before voiceless ones.

The structure of the chapter is the following. Section 2.2 gives an overview of previous findings in relation to the influence of contrast on different phonetic patterns. Section 2.3 presents a phonetic experiment on Lithuanian, whose aim is to test the interaction between vowel length contrast and the voicing effect. First some background to the Lithuanian phonological system is given, followed by details of the experimental methodology. Next, the results are reported and discussed in relation to the relevant hypothesis.

2.2. Phonological contrast and phonetic effects: previous findings

2.2.1 Contrast and coarticulation

2.2.1.1 Overview

Previous studies about the influence of phonological contrast on phonetic patterns have looked mainly at coarticulation (see Manuel (1999) for a review of this body of work). The primary finding is that "while the articulatory commands for adjacent segments might overlap in time, the patterns of overlap are affected by speakers' efforts to maintain distinctions among segments" (Manuel 1999: 180). The presence of a phonological contrast might condition the effects of coarticulation, in most cases by inhibiting them but also by enhancing them (as in the case of anticipatory lip rounding; Lubker and Gay 1982). This interaction arises only in cases where the coarticulation modifies the dimension along which the contrast operates (e.g. nasalization, vowel formants). Here, I review some illustrative cases, namely contextual nasalization (section 2.2.1.2) and C-to-V coarticulation in languages with and without a front-back vowel contrast (section 2.2.1.3). I choose these examples because they involve contrast along different dimensions (nasality and backness), and because the last two cases are complementary in the sense that they involve the same coarticulatory pattern, i.e., C-to-V, but in systems with different contrasts.

2.2.1.2 Nasal contrast and nasalization

Anticipatory contextual nasalization of vowels results when the velum lowering gesture for a nasal consonant starts before the oral closure is achieved. This leads to nasalization during the production of the vowel. In this case of coarticulation, the relevant endangered contrast is that between nasal and oral vowels. Thus, the prediction is that, all else being equal, a language with contrastive nasal vowels will restrict the amount of the velum lowering gesture during neighboring vowels more than a language without such a contrast. Cohn (1993) reports a greater degree of contextual vowel nasalization before a nasal consonant in English, which lacks a nasality contrast in vowels, than in French, a language with a nasal-oral vowel contrast. In order to avoid contextual nasalization of an adjacent vowel, the velum lowering gesture should be executed during the oral closure. This timing pattern would yield partially oral nasal consonants. Herbert (1986) reports that this pattern is only found in languages with phonemic nasal vowels indicating that partial denasalization of the stop is induced by the requirement to maintain a distinctive nasal-oral vowel contrast.

Interestingly, the French oral vs. nasal contrast for vowels is not present for all its vowel qualities. The high vowels /i, y, u/ do not have a nasal pair. Previous studies on French nasalization have considered only oral vowels that have nasal counterparts (Clumeck 1967, Cohn 1993, Rochet & Rochet 1991). However, Spears (2006) and Delvaux (2000) compared the degree of nasalization in French for vowels with a nasal vs. oral contrast and for vowels without such a contrast. Spears (2006) examined the amount of nasalization for the high vowel /i/, which lacks a nasal counterpart. The oral high vowel is expected to show more coarticulation for nasalization than vowels that contrast for nasality, given the assumption that coarticulation is suppressed to preserve the oral/nasal contrast. Spears measured the amount of nasalization in the oral vowels /i, ɛ/ when followed by a nasal consonant and an oral stop, and in the nasal vowel /ɛ̃/ word-finally. Taking a formant-like bandwidth between F1 and F2 as an indicator of nasalization, Spears' study obtained the following statistically significant results: (i) more /i/+nasal tokens show signs of nasalization than /ɛ/+nasal tokens, and (ii) the duration of nasalization is longer and present in a greater percentage of the vowel for the /i/+nasal tokens than in the /ɛ/+nasal tokens. These results indicate that /i/ undergoes nasalization to a greater extent than /ɛ/. But note Spears found that /ɛ/+nasal tokens do get some nasalization, i.e., nasalization is not totally suppressed for this vowel. Delvaux (2000) measured the amount of proportional nasal airflow, defined as the mean proportion of nasal to total airflow and volume, during the production of all the French vowels before a nasal consonant. She found that the amount of nasalization was significantly greater for those vowels that do not have a nasal counterpart than for those that have such a counterpart.

To recapitulate, French shows an asymmetry with respect to its contrast in nasality for vowels. All oral vowels except for /i, y, u/, have a nasal counterpart. French has traditionally been described as a language with a very restricted amount of contextual vowel nasalization. The presence of a nasal/oral contrast for vowels in the system is generally assumed to be responsible for this restriction. However, as Spears and Delvaux show, nasal coarticulation is greater for those vowels that do not have a paired nasal vowel. More precisely, vowels that are not minimally contrastive for nasality show a higher degree of contextual nasalization. Thus, within the system, vowels behave differently with respect to nasality depending on their contrastive status. In section 2.3, I show that this state of affairs is comparable to the findings from Lithuanian.

2.2.1.3 C-to-V coarticulation and back-front contrast

C-to-V coarticulation can result in undershoot of the vowel affecting, especially, the front vs. back contrast. This contrast is related to F2 values for which back vowels tend to have a lower frequency than front vowels. Thus, if a back vowel occurs after a consonant with a high F2 locus, such as a coronal, then the vowel might be undershot and be realized with a higher F2, i.e., more front. Flemming (1997) explores the effects of this type of undershoot in four different languages. Two of these languages, Finnish and German, have a contrast between the back round vowel /u/ and the front round vowel /y/. The other two, English and Farsi, lack this contrast. The prediction of contrast-sensitive coarticulation is that in those languages with a

/u/-/y/ contrast, F2 raising of /u/ due to coarticulation with a preceding coronal consonant will be more restricted than in those languages without the contrast. This follows from the fact that the main difference between /u/ and /y/ is that the F2 values for the latter are higher. Contextual raising of F2 for /u/ will decrease the distinctiveness between these two vowels. Flemming's results confirm this prediction: Finnish and German show a smaller degree of F2 variation in the context of coronal consonants than English and Farsi. Contextual fronting is restricted in those languages where it would endanger a front vs. back contrast.

Choi (1992) investigated the vowel production patterns in Marshallese, a language that lacks a front vs. back vowel contrast. He found that the vowel qualities for backness and rounding are determined mainly by the surrounding consonants. That is, the F2 trajectories for the Marshallese vowels depend on the F2 target values for their neighboring consonants. This situation is opposite to what Flemming found for Finnish and German, where there is a back vs. front contrast in the vowel system. In Marshallese, the absence of a vowel contrast along the F2 dimension allows for a greater degree of C-to-V coarticulation.

2.2.2 Cues to stress and phonemic vowel length

Another example of the interaction between contrast and phonetic patterns is found in the realization of stress. The main phonetic correlates of stress are changes in the fundamental frequency, duration and amplitude (Lehiste 1970). These cues seem to be employed on a language-particular basis. Berinstein (1979) conducted an experiment testing the hypothesis that for a language with phonemic vowel length, duration will be the least important cue to stress. She found that in the Mayan language, K'ekchi, where vowel length is phonemic, production of stress is primarily cued by changes in F_0, increase in intensity and changes in duration, with changes in fundamental frequency being the strongest correlate with stress. Furthermore, Berinstein's results show that duration does not have any effect on the perception of stress. On the other hand, a related language to K’ekchi, Cakchiquel, which does not have phonemic vowel length, uses duration as its primary cue to stress.

Ondráčkova’s (1962) results for Czech, a language with contrastive vowel length, are similar to those for K’ekchi. Czech does not make use of duration changes as the main phonetic marking of stress. Hayes (1995) further notes that languages with contrastive vowel length tend to avoid using duration as a cue to stress. As Hayes points out, these facts are obtained because the use of duration to cue stress would ‘obscure’ contrastive vowel length. This means that phonetic modification of vowel duration to mark stress would interfere with phonemic vowel length in that this contrast would become less distinct. This is related to the fact that length contrasts rely on duration to signal the difference between long and short elements.

In the next section, I examine a phonetic effect, namely the obstruent voicing effect, which modifies the durational pattern of vowels. This process is relevant because it is triggered by a segmental feature, i.e., voicing, and not by suprasegmental material like in the case of stress cues. Furthermore, the claim that phonemic vowel length limits this voicing effect is present in the literature, although there appear to be no published reports of experiments testing this claim. Thus, examining the relationship between length contrast and the voicing effect allows us to broaden the understanding of the general pattern of interaction between contrast and phonetic details, and also to contribute to previous work on the voicing effect.

2.3. Case Study: Lithuanian phonemic vowel length and the voicing effect

2.3.1 Introduction

The obstruent voicing effect on vowel duration makes reference to a phonetic pattern by which vowel duration tends to be shorter before voiceless obstruents than before voiced ones. The voicing effect has been found in numerous languages, such as Bengali, Dutch, English, French, German, Hindi, Hungarian, Icelandic, Italian, Korean, Marathi, Norwegian, Russian, Spanish and Swedish (Chen 1970, Maddieson 1977, Maddieson and Gandour 1976, Crystal and House 1988, Laeufer 1992, among many others; see Hussein 1994 for an overview of previous studies). Word size, inherent vowel duration, place of articulation of adjacent consonant, syllabic affiliation of following consonant, stress, speech rate, and position of the word in the utterance are some of the factors that have been identified as influencing the degree of voicing effect within a given language (Klatt 1973, De Jong and Zawaydeh 2002, Hussein 1994, Laeufer 1992, Port 1981, and references therein). As Laeufer (1992) points out the voicing effect can be masked if all the above factors are not controlled for.

Furthermore, there is another group of factors that, being language-specific, contribute to the cross-linguistic differences of the voicing effect. This group includes the precise way in which the voicing contrast is realized (Keating 1984, Kohler 1984), the language rhythm (Port et al. 1980) and the presence or absence of phonemic vowel length in the language (Keating 1985). Given the purpose of the present study, I focus on this last factor, namely phonemic vowel length, and its interaction with the voicing effect. There are claims in the literature that the presence of contrastive vowel length in the language attenuates the voicing effect (Keating (1985) for Czech and Saudi Arabic, Buder and Stoel-Gammon (2002) for Swedish), but there appear to be no published reports of experiments testing this claim. In order to test the hypothesis about the interaction between phonemic vowel length and the voicing effect, it is necessary to isolate phonemic vowel length from other possible conditioning factors. A way to do this is to measure the degree of the voicing effect in a language where vowel length is contrastive but only for a subset of its vowel qualities, i.e., a language that has some *unpaired* vowel along the long vs. short contrast. Then, according to the view presented above, i.e., that the presence of contrastive vowel length attenuates the voicing effect, the vowel without a short (or long) counterpart would exhibit a stronger voicing effect than the vowels in a long vs. short contrast relationship. The Baltic language Lithuanian presents such an asymmetrical system for contrastive vowel length.

It is relevant to notice that here, the voicing effect is viewed as a phonetic pattern. This effect does not influence phonological phenomena such as stress or weight, i.e. the voicing effect is not relevant in stress assignment or other weight-sensitive processes. Hyman (1977) notes that there are no languages where vowels before voiced consonants attract stress and vowels before voiceless obstruents do not. Gordon (2002) presents a typological survey of different weight systems. He does not list any system in which vowels before voiced obstruents count as heavy and vowels before voiceless obstruents behave as light. Given these facts, I argue that the contextual difference in duration due to the voicing effect is not phonological and does not interact with phonological processes.

2.3.2 Lithuanian background and hypothesis

According to descriptions of the language, Lithuanian has a vowel length contrast for all of its vowel qualities except for one[6] (Klimas 1970, Mathiassen 1996, Tekorienė 1990). Table 3 shows the phonemic vowel inventory for Lithuanian (a), together with its canonical realization (b).

[6] This exception can be argued to include a second vowel quality, namely the mid back vowel, as I discuss later in the chapter.

Table 3. Vowel inventory in Lithuanian.

(a) Phonemic inventory

	Front	Back
High	/i/ /iː/	/u/ /uː/
Mid	/**e**ː/	(/o/) /oː/
Low	/æ/ /æː/	/ɑ/ /ɑː/

(b) Realization

	Front	Back
High	[ɪ] [iː]	[ʊ] [uː]
Mid	[**e**ː]	([ɔ]) [oː]
Low	[ɛ] [æː]	[a] [ɑː]

As can be seen in Table 3, the mid front vowel /**e**ː/ lacks a short counterpart, unlike the high and low vowels, which all contrast in length. /eː/ is not minimally contrastive for length because there is not any element in the system that differs from it only in terms of its length. This unpaired vowel /eː/ is of special interest since it is expected to behave differently with respect to the voicing effect compared to the other vowels. The parentheses around the mid back short vowel (/o/) indicate that this vowel is marginal in the language as it only appears in recent loanwords. Thus, some descriptions of Lithuanian include this vowel in the phonemic inventory, while others choose to exclude it and only make reference to its borrowed origin. If the short mid back vowel is not phonemic, its long counterpart /oː/ might be expected to behave like an unpaired vowel for length.

Here a note about the difference in quality between the short-long pairs is necessary, since one might wonder whether those pairs contrast in duration or whether it is mainly a difference in quality. Balšaitytė (2004) finds a significant difference in duration between the members of each pair in Table 3. Furthermore, there are morphological alternations between the long and short vowels. For example, [æː] and [ɑː] may result from the lengthening of [a] and **[ɛ]**, respectively, in stressed positions (Ambrazas 1997, Mathiassen 1996). The following example pairs in (8) illustrate this lengthening process (data taken from Mathiassen 1996).

(8) Alternations under stress shift in Lithuanian

[ˈn**ɑː**mas]	'house.nom.sg.'	*vs.*	[n**a**ˈmʊs]	'house.acc.pl.'
[ˈgʲ**æː**ras]	'good.nom.sg.masc.'	*vs.*	[gʲ**ɛ**ˈrʊs]	'good.acc.pl.'

Further morphological alternations among the short-long paired vowels are found in the language. (9) includes some examples (data taken from Matthiassen 1996 and Ambrazas 1997).

(9) Alternations between long and short vowels in Lithuanian

[ˈb**a**ltɪ]	'to get white'	*vs.*	[ˈb**ɑː**la]	'becomes white'
[ˈb**ɪ**rtɪ]	'to fall'	*vs.*	[ˈb**iː**ra]	'falls'
[ˈs**ʊ**ntʃɛ]	'send'	*vs.*	[ˈs**uː**stɪ]	'to send'
[ˈspr**ɛ**ndʒa]	'decides'	*vs.*	[ˈspr**æː**stɪ]	'to decide'

The forms in (8) and (9) show that long and short vowels alternate with each other in morphologically related words. Crucially, [a, ɪ, ʊ, ɛ] alternate with [ɑː, iː, uː, æː], respectively. These alternations indicate that when a short vowel lengthens or a long vowel shortens, the quality of the resulting vowel also changes to that of the corresponding short or long vowel, showing that changes in length also result in minor differences in quality. This is evidence that at the phonological level, the vowel pairs under question, namely /i/-/iː/, /u/-/uː/, /æ/-/æː/, /ɑ/-/ɑː/, differ only in phonemic length. Thus, length differences represent a phonological contrast, which is accompanied by quality differences in its phonetic realization.

Furthermore, numerous studies report that vowel length contrasts tend to be accompanied by differences in quality cross-linguistically (e.g. Abramson 1962, Abramson & Ren 1990, Catford 1977, Lehiste 1970, Rosner & Pickering 1994). The main quality difference between long and short vowels is that the former are usually associated with more extreme formant values than the latter. This results in short vowels occupying a reduced area of the vowel space compared to their long counterparts (Lehiste 1970). This seems to be related to the fact that the greater amount of duration characteristic of long vowel allows for a more extreme articulation (Behne et al. 1999). In fact, the acoustic study of Lithuanian vowels by Balšaityte (2004) presents a vowel space for this language very similar to that reported by Lehiste (1970) for the long/short vowels in Czech. High long vowels are higher than their short counterparts. Also, long low vowels are lower than the short low ones. The same applies to the back/front distinction. This means that long vowels in Lithuanian have more extreme values than short vowels, in accordance with previous reports on other languages with phonemic vowel length.

Finally, it is worth pointing out that the IPA symbols used to represent the phonetic realization of the Lithuanian vowels, especially for the low front vowels, do not correspond in formant values to the ones typically used for American English. In Balšaityte (2004), the difference in height between [ɛ]-[æː] is smaller than the difference between American English [ɛ]-[æ] (Ladefoged 2001). That is, the difference in F1 between Lithuanian [ɛ] and [æː] is lesser than the difference between English [ɛ] and [æː]. Thus, it might be the case that the symbols traditionally used for the Lithuanian vowels suggest a greater quality difference than actually exists.

There is also evidence that the mid vowels /eː, oː/ are in fact long. First, these vowels have been reported in the literature as long in duration (Balšaityte 2004). Second, phonologically, /eː, oː/ behave like the long vowels in the Lithuanian system with respect to stress assignment (Tekorienė 1990) and word minimality requirements (Steriade 1991). For instance, Steriade (1991) points out that monosyllabic roots in Lithuanian can take the form of a closed syllable or an open syllable with a long vowel or diphthong. Open syllables with short vowels are not found as roots. In this case, /eː/ patterns with other long vowels and it is possible to find forms such /s**e**ː/ 'to sow', which satisfies the Lithuanian minimality condition on roots. The same applies to /oː/.

As for the consonants, Table 4 shows the Lithuanian consonant inventory (see Klimas (1970) for discussion).

Table 4. Lithuanian consonant inventory

	labial	labiodental	alveolar	postalveolar	palatal	velar	glottal
stop	p b		t d			k g	
fricative		f	s z	ʃ ʒ		x	h
affricate			ts dz	tʃ dʒ			
nasal	m		n				
trill			r				
approximant		ʋ	l		j		

Palatalization is contrastive in Lithuanian and all the consonants from Table 4, except the palatal /j/, have a palatalized version. In addition, it is relevant to mention two processes that Lithuanian consonants undergo, since they are relevant for the set-up of the experiment. First, word final obstruents undergo devoicing. Second, there is regressive voicing assimilation in obstruent clusters, such that the voicing of the last member of any such cluster determines the voice realization of any preceding obstruents. Sonorants do not participate in this process, i.e., they do not trigger or undergo voice assimilation. These two processes must be taken into account when constructing the stimuli since the experiment tests the effect of obstruent voicing, and any context-dependent change in the voicing status of this consonant should be avoided.

Before moving on into the methodology description, let us state the hypothesis that the Lithuanian experimental study will test. This is given in (10).

(10) HYPOTHESIS TO BE TESTED

The voicing effect will be greater for /**eː**/ than for the other vowels.

/**eː**/ is the only vowel that does not participate in a long vs. short contrast, i.e., it is not minimally contrastive for length. For this reason, this vowel is expected to show greater variation in its duration depending on the following obstruent voicing when compared with the other Lithuanian vowels, which show a minimal contrast for length. Note that /oː/ might also show the same behavior as /eː/, given that its short counterpart /ɔ/ might not be phonemic. The results of the experiment reported here bear on the interaction between phonemic vowel length and the voicing effect, and as the next sections show, verify the claim that the presence of contrastive vowel length in the system inhibits the magnitude of the voicing effect.

2.3.3 Methodology

2.3.3.1 Stimuli

A series of nonsense words were constructed according to Lithuanian phonotactics. A native speaker of Lithuanian helped as a consultant and overviewed the creation of these nonsense words. The following criteria were controlled for: syllabic structure, vowel quality and voicing of consonants. Each stimulus consisted of a bisyllabic word of the form $CV_1C_1C_2V$, where the first syllable bears the stress. The interest lies in the duration of V_1, so this vowel could be any of the monophthongs from the Lithuanian inventory (see Table 3). Standard Lithuanian orthographical representations were employed to mark the short vs. long contrasts. The short vowel graphemes used are <ì, è, à, ò, ù> (< > indicate graphemes) and they correspond to the phonemes /i, æ, ɑ, o, u/ and the phonetic realization [ɪ, ɛ, a, ɔ, ʊ]. Note that the acute stress mark <`> can only appear with short vowels. As for the long vowels, the graphemes <ỹ, **ė̃**, ę̃, ą̃, õ, ū̃> correspond to the phonemes /iː, **e**ː, æː, ɑː, oː, uː/ and the phonetic realization [iː, eː, æː, ɑː, oː, uː]. The circumflex accent mark <˜> can only appear with long vowels.

It was decided to locate the relevant vowel and the following consonant in the same syllable because previous studies have reported a greater voicing effect in cases where the vowel and the consonant are tautosyllabic (Laeufer 1992). Thus, the word medial consonant cluster C_1C_2 was formed either by a voiced velar stop [g] followed by a voiced post-alveolar fricative (<ž>=[ʒ]), i.e., [gʒ] for the voiced condition, or by a voiceless velar stop [k] followed by a voiceless post-alveolar fricative (<š>=[ʃ]), i.e., [kʃ] for the voiceless condition. Given the phonotactics of the language, these are environments where the coda consonants in question retain their voicing specification since they would undergo voicing assimilation vacuously, i.e., without producing a change.[7]

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[7] Another reason for choosing a fricative as C_2 is that I wanted to compare this non-neutralizing context with neutralizing environments where the stop would assimilate to a following fricative bearing a different voice specification. Those data are not reported here.

The first consonant and the last vowel in the stimuli were consistently [t] and [a], respectively. Table 5 shows the 22 stimuli used in the experiment that conform to the criteria just described.

Table 5. Stimuli used in experiment

	Voiced condition	**Voiceless condition**
Long vowels	<tỹkša> [tiːkʃa]	<tỹgža> [tiːgʒa]
	<tė̃kša> [teːkʃa]	<tė̃gža> [teːgʒa]
	<tę̃kša> [tæːkʃa]	<tę̃gža> [tæːgʒa]
	<tū̃kša> [tuːkʃa]	<tū̃gža> [tuːgʒa]
	<tõkša> [toːkʃa]	<tõgža> [toːgʒa]
	<tą̃kša> [tɑːkʃa]	<tą̃gža> [tɑːgʒa]
Short vowels	<tìkša> [tɪkʃa]	<tìgža> [tɪgʒa]
	<tèkša> [tɛkʃa]	<tègža> [tɛgʒa]
	<tùkša> [tʊkʃa]	<tùgža> [tʊgʒa]
	<tòkša> [tɔkʃa]	<tògža> [tɔgʒa]
	<tàkša> [takʃa]	<tàgža> [tagʒa]

The relevant words were inserted in the carrier sentence in (11), allowing for control of syntactic and prosodic structure.

(11) Sakyti ______________ negalima 'To say _________ is not allowed'

Each stimulus was repeated 8 times, so that the total number of tokens per speaker was 176. Each block of 22 sentences was randomized with a constraint that the last and first sentence of each block were not the same.

2.3.3.2 Subjects and recording

Five native speakers of Lithuanian, one male and four females, were recorded. They all come from the eastern region of Lithuania (from the cities of Kaunas or Vilnius) and they all speak the standard variety of Lithuanian. They all had formal instruction in Lithuanian up to the college level. The speakers have been in the United States for 5 to 10 years. They use Lithuanian everyday with their family and friends, and some of them at work. They often read and write in Lithuanian. The speakers were financially compensated for their participation in the experiment.

A program was created that displayed the sentences on a computer screen for the speakers to read. The experimenter controlled the computer. This program allowed for repetition of any sentence in cases where the speakers felt they had made a mistake or the experimenter noticed a misread token. The speakers were given oral instructions in English and were asked to read each sentence in a colloquial style. They were cued for each sentence in order to keep the rhythm constant. The recordings were conducted in a room with minimal noise using a laptop computer and a Plantronics head-mount microphone with USB DSP audio interface, at a sampling rate of 16,000 Hz. Before beginning the actual experiment, the speakers were allowed to practice on a couple of tokens, which were not included in the analysis, in order to help them get familiar with the nature of the sentences. These practice tokens were the same as some of the nonsense words used in the experiment.

2.3.3.3 Analysis

The data was analyzed using the Wavesurfer program, which displayed the synchronized waveforms and spectrograms used to measure the duration of the relevant segment, i.e., the first vowel in the token words. The vowel was measured from the onset of the first glottal pulse (the upward zero crossing) to the offset of the last one in the waveform, before voiceless stops. Preceding voiced stops, the end of the vowel was determined by a drop in amplitude and a change in waveform shape. In some of these cases, the spectrogram was also examined to find the point where the formant structure ended, which was considered the end of the vowel in those tokens where the waveform did not provide a clear ending point.

2.3.4 Results

The statistical analysis aims at answering the following three questions shown in (12), which need to be addressed in order to find if the data confirm by the hypothesis.

(12) Questions about the data to be answered by statistical analysis

1- Are long vowels different in duration from short vowels?

2- Is there a stop voicing effect?

3- Is the stop voicing effect greater for /eː/ than for the other vowels?

The first question relates to the presence of phonemic vowel length in the language. According to the description of Lithuanian in section 2.3.2, an effect of length should be found on the vowel durations. However, it is necessary to confirm if the speakers show this contrast in the set of data collected. The second question addresses the existence of a voicing effect for the data as a whole. Finally, the third one reflects the hypothesis of the study. If the answers to the first and second questions are positive, then it will be possible to test this third question, since for it to hold, phonemic vowel length and a stop voicing effect must be present in the language.

In order to answer these three questions, a series of one- and two-way factor full-interaction ANOVAs were carried out to test the effect of length, vowel quality and stop voicing on the vowel duration, plus a Fisher's PLSD post-hoc vowel-to-vowel comparison for vowel quality and a means comparison for vowel quality by stop voicing. Also, a possible speaker effect was considered. Next, the differences in duration between voiced and voiceless tokens and vice versa were calculated, and the effect of vowel quality on these differences was tested through a two-way factor full interaction ANOVA and a further Fisher's PLSD post-hoc vowel-to-vowel comparison for vowel quality. For all the statistical tests, the significance level was set at $p<.05$.

In the next sections, I report the results according to the effect being tested: length (two possibilities: long or short), vowel quality (eleven possibilities: [iː, eː, æː,

ɑː, oː, uː, ɪ, ɛ, a, ɔ, ʊ]), stop voicing (two possibilities: voiced or voiceless), and vowel quality and stop voicing interaction.

2.3.4.1 Length effect

The result of a two-factor ANOVA with vowel duration as dependent variable and speaker and length as independent variables shows that length has a significant effect on vowel duration ($F(1, 862)=465.833$, $p<.0001$), such that long vowels have a greater duration than short vowels. Also, the speaker effect ($F(4, 862)=129.356$, $p<.0001$) and the interaction between length and speaker ($F(4, 862)=37.961$, $p<.0001$) were statistically significant. In view of this interaction, a one-factor ANOVA for the length effect split by speaker was necessary. The results of this test show that length is significant for all the speakers ($p<.0001$) except for LV, who did not present a significant difference in duration between long and short vowels.

2.3.4.2 Vowel quality effect

The previous section showed that length has a general effect on vowel duration. However, it is necessary to test whether the relevant vowel pairs ([iː-ɪ, æː-ɛ, ɑː-a oː-ɔ, uː-ʊ]), are significantly different in their duration. First, the results of a two-factor ANOVA with speaker and vowel quality as independent variables show that vowel quality ($F(10, 817)=195.076$, $p<.0001$), speaker ($F(4, 817)=277.569$, $p<.0001$) and their interaction ($F(40, 817)=11.463$, $p<.0001$) have a significant effect on vowel duration. Second, a post-hoc Fisher's PLSD test for vowel duration gave a vowel-to-vowel comparison for vowel quality. The present study is just interested in the comparison between the members of the long-short pairs, although the results for the [eː- æː] and [eː-ɛ]comparisons are also reported, in order to test the behavior of unpaired /eː/ with respect to duration. Table 6 reports the results of this post-hoc test. Furthermore, in view of the significant interaction between vowel quality and speaker, an ANOVA was carried out with vowel quality as the independent variable and a corresponding Fisher's PLSD test for each speaker to see whether all the speakers make a significant difference in duration between the relevant vowels. These results are also included in Table 6. Figure 5 shows the duration (ms.) of each vowel for all the speakers pooled together. This figure gives an idea of each vowel's average duration.

Table 6. Results of Fisher's PLSD test on vowel duration for vowel quality effect.

	All speakers	*AV*	*JG*	*LV*	*RK*	*VP*
ɑː-a	*	*	*	**n.s.**	* p=.0006	*
æː-ɛ	*	*	*	**n.s.**	* p=.015	*
oː-ɔ	*	*	*	**n.s.**	**n.s.**	*
iː-ɪ	*	*	*	**n.s.**	*	*
uː-ʊ	*	*	*	* p=.043	*	*
eː-ɛ	*	*	*	n.s.	n.s.	*
eː- æː	*	*	n.s.	* p=.001	n.s.	n.s.

*=statistically significant (p<.0001, unless otherwise indicated)
n.s.=statistically non-significant

Figure 5. Vowel duration (ms.) for all speakers pooled together

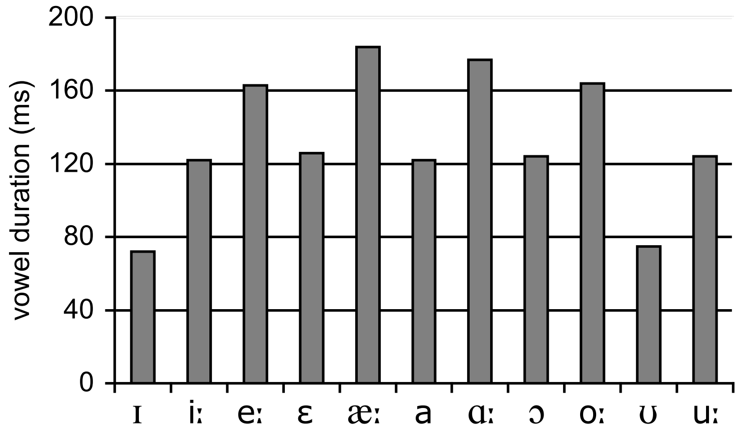
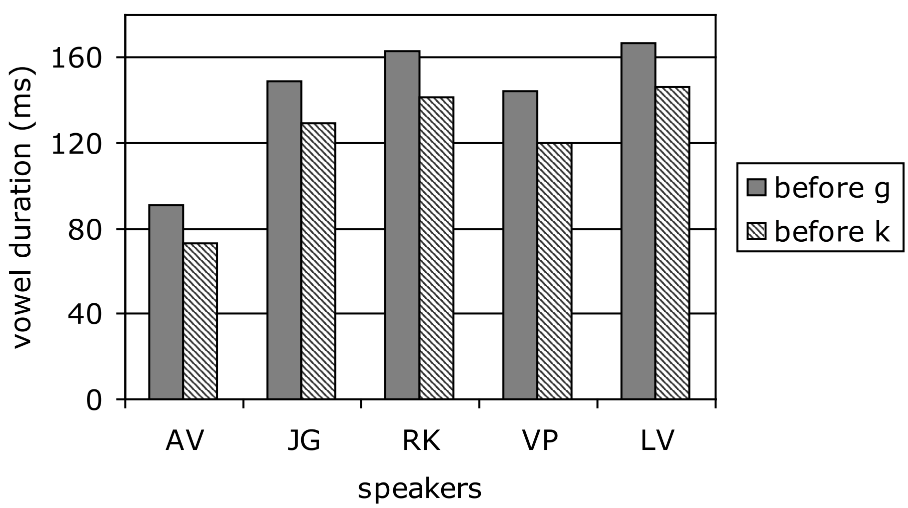


Table 6 shows that speaker LV behaves differently. For most of the long-short vowel pairs, the difference in vowel duration is not significant indicating that she does not make a length distinction for these pairs. These reflect the results from the length effect, which indicated that for LV length was not a significant factor for vowel duration. Also notice that another speaker, RK, does not make a difference in duration for the pair [oː-ɔ]. Remember that in the description of Lithuanian I pointed to the debate about the phonemic status of the short mid back vowel. Finally, it is worth mentioning that the vowel [eː] lies inbetween [ɛ] and [æː] as far as duration is concerned. For all the speakers except LV, the value of the mean duration for [ɛ] is less than for [eː] and in turn the value of the mean duration for [eː] is less than [æː], although the difference in these values does not always reach statistical significance.

2.3.4.3 Stop voicing effect

The results of a two-factor ANOVA with stop voicing and speaker as independent variables show that stop voicing ($F(1, 862)=45.778$, $p<.0001$) and speaker ($F(4, 862)=78.227$, $p<.0001$) have a significant effect on vowel duration. The interaction between stop voicing and speaker is not significant, indicating that all the speakers behave similarly with respect to the stop voicing effect. Figure 6 shows that vowels before the voiced stop [g] are longer than before the voiceless stop [k]. This is true for all five speakers.

Figure 6. Vowel duration (ms.) before [g] and before [k] for all speakers



2.3.4.4 Vowel quality and stop interaction

In this section I report the results of the statistical analyses performed in order to determine whether the stop voicing has a different effect depending on the vowel.

Ultimately, what is necessary to find out is whether the stop voicing effect is greater for /eː/ than for the other vowels. Given that speaker LV did not present a significant distinction in duration between long and short vowels, this speaker is excluded from the rest of the analyses.

First, taking vowel duration as the dependent variable, a three-factor full interaction ANOVA for vowel quality, stop and speaker as independent variables shows that, as seen before, these three factors have a significant effect on vowel duration ($p<.0001$ for all). As for the different interactions among the independent variables, only the interaction between vowel quality and speaker proved to be significant. However, this analysis did not establish the magnitude of the stop voicing effect for each of the eleven relevant vowels, and this information is necessary in order to determine whether the voicing effect is stronger for [eː] compared to the other vowels. For this purpose, a planned comparison of vowel duration means was conducted with respect to vowel quality and stop voicing, including the data from all the speakers (except LV) since they did not behave differently according to the previous three-factor ANOVA. This test compares the duration means for each vowel before [g] with the means before [k], providing information about the voicing effect for each individual vowel. The result of the means comparisons shows that the stop voicing effect was significant for [iː, ɪ, eː, æː, ɑː, oː, ɔ] and non-significant for [ɛ, a, uː, ʊ].[8] However, it is crucial to find out not

[8] Here, I do not attempt at explaining why vowels might behave differently with respect to the voicing effect. However, it is worth noting that vowel frequency does not seem to be the cause for the lack of

only which vowels are affected by the voicing effect, but also for which vowel the stop voicing has the strongest effect. In order to obtain the latter, the F-values obtained from the means comparisons were ranked. The F-value is a correlate of the effect's strength, i.e., the higher the F-value, the stronger the effect. This means that a ranking from lower to higher F-value correlates with a ranking from vowels less affected by the following obstruent's voicing to vowels more affected by this voicing. Table 7 reports this ranking.

Table 7. Ranking from lower to higher of F-values from means comparison

Vowel	ɛ	ʊ	uː	a	ɔ	æː	ɪ	iː	ɑː	oː	**eː**
F-value	2.889	3.103	3.618	3.784	4.131	4.132	4.319	4.978	6.373	9.298	13.428

The ranking in Table 7 shows that **[eː]** has the highest F-value, i.e., the stop voicing has the strongest effect for this vowel. But it is necessary to find out if the difference in the stop voicing effect among the vowels, more precisely between [eː] and the other ten vowels, is statistically significant. The tests conducted so far cannot answer this question, since they just indicate that the stop voicing effect varies depending on the vowel and that this effect is greater for [eː], but is this statistically significant? In order to answer this question, two new variables were created: First,

---

voicing effect for [ɛ, a, uː, ʊ]. Ambrazas (1997) provides phoneme frequency counts in Lithuanian, based on a corpus that contains over 100,000 phonemes occurrences. Regarding their frequency of occurrence, vowels are ranked as follows from most frequent to least frequent: **a** > ɪ > oː > **ɛ** > **ʊ** > eː > iː > ɑː > **uː** > æː > ɔ. The group of vowels that do not show a voicing effect (in bold) is neither the most nor the least frequent in Lithuanian.

the difference in the mean vowel duration before the voiced stop minus each vowel duration before the voiceless stop (i.e. the voiced–voiceless vowel duration difference); second, the difference in the mean vowel duration before the voiceless stop minus each vowel duration before the voiced stop (i.e. the voiceless–voiced vowel duration difference).

It should be mentioned that both variables, i.e., the voiced–voiceless vowel duration difference and the voiceless–voiced vowel duration difference, were included in separate analyses in order to control for any possible divergence depending on whether the voicing effect is seen as lengthening or shortening. In what follows, the results for the voiced–voiceless difference are reported. Both variables behaved similarly.

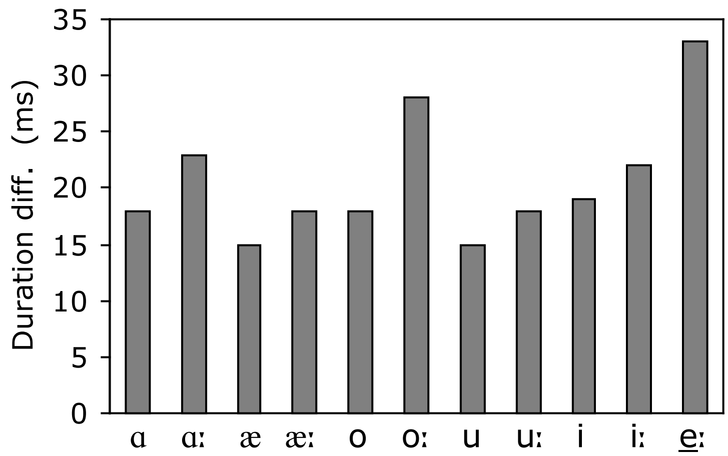
These two variables let us examine whether the variation in duration for each vowel due to the following obstruent's voicing is statistically significant. By subtracting the mean vowel duration before voiced stops from each vowel's duration before voiceless stops, the amount of variation in duration for each vowel is obtained. Now, it is possible to test whether this amount of variation is greater for [eː] than for the other vowels. Table 8 shows the means of the voiced–voiceless difference for all the speakers.

Table 8. Means (ms.) for voiced-voiceless vowel duration difference

Vowel	ɛ	ʊ	uː	a	ɔ	æː	ɪ	iː	ɑː	oː	**eː**
Mean	15	15	18	18	18	18	19	22	23	28	33

Figure 7 offers a more visual representation of the mean difference before voiced [g] and before voiceless [k] for each vowel.

Figure 7. Difference in duration (ms.) before [g] and before [k] for each vowel



Note that [eː] has the greatest mean, indicating that this vowel shows the highest amount of durational variation due to the voicing of the following obstruent. Also, it is worth noting that in the short-long pairs, the long vowel tends to have a higher mean, indicating that the variation due to the voicing effect is stronger for long vowels in terms of duration difference This is expected given previous reports in the literature (e.g. Laeufer 1992).

Taking the voiced–voiceless difference as the dependent variable, a two-factor ANOVA was carried out with vowel quality and speaker as the independent variables. The results show that vowel quality has a significant effect on the voiced-voiceless difference ($F(10, 304)=2.800$, $p=.0025$). On the other hand, speaker and the vowel quality and speaker interaction do not have a significant effect. This indicates than all the speakers behave similarly with respect to the vowel quality effect on the voiced–voiceless difference. The next step was to test whether there was a significant difference in the voiced-voiceless difference between **[eː]** and the other vowels. A post-hoc Fisher's PLSD test for the voiced-voiceless difference performed a vowel-to-vowel comparison to determine whether the mean for this variable is statistically distinct from one vowel to another. Table 9 reports the relevant results, which are those from the comparisons of [eː] with the other vowels.

Table 9. Results from Fisher's PLSD test on voiced–voiceless difference for vowel quality effect.

Vowels compared	**Statistical significance**	**Mean difference (ms.)**
eː-a	* (p=.0012)	15
eː- ɑː	* (p=.0271)	10
eː- ɛ	* (p=.0001)	18
eː- æː	* (p=.0015)	15
eː- ɪ	* (p=.0027)	14
eː-iː	* (p=.0170)	11
eː- ɔ	* (p=.0015)	15
eː-oː	n.s.	5
eː- ʊ	* (p=.0001)	18
eː-uː	* (p=.0017)	14

As seen in Table 9, there is a statistically significant difference between [eː] and all the other vowels except [oː]. This exception is discussed in section 2.3.5. Remember that the ranking of the F-values from the stop voicing effect for each vowel (Table 7) showed that **[eː]** had the strongest effect. So, in view of this and the results from Table 9, we can conclude that the stop voicing has the statistically strongest effect on **[eː]**.

The same analyses where conducted for the voiceless-voiced difference dependent variable. The results replicate those obtained for the voiced-voiceless difference and for this reason, no further details are given.

2.3.5 Discussion

In this section, the results from the statistical analysis are discussed in relation to the hypothesis in (10) and the questions raised in (12) above. Let us first answer the questions one by one in light of the experiment results.

Q: Are long vowels different in duration from short vowels?

A: Yes, as the results from the length and vowel quality effect show, long vowels are significantly longer than short vowels for all the vowel pairs, i.e, [iː-ɪ, æː-ɛ, ɑː-a oː-ɔ, uː-ʊ] for all the speakers except LV.

Q: Is there a stop voicing effect?

A: Yes, as the stop voicing effect results show, vowels are significantly longer before voiced stops than before voiceless ones for all of the speakers.

Q: Is the voicing effect greater for /eː/ than for the other vowels?

A: Yes, as the results from the vowel quality and stop interaction show, the stop voicing effect is greater for /eː/ than for the other vowels. This difference is statistically significant for all the vowels compared to /eː/, except /oː/. This fact might be related to the phonemic status of the /ɔ/-/oː/ opposition. As mentioned before, some descriptions of Lithuanian challenge the phonemic status of /ɔ/, saying that it is only present in borrowed words. If this is the case, it might be argued that the vowel /oː/ is not part of a short vs. long contrast. Thus, the voicing effect would be expected to be stronger for this vowel than for the rest. Bearing on this issue, the results in section 2.3.4.2 showed that two of speakers did not make a difference in duration between /ɔ/ and /oː/.

Clearly, the hypothesis is borne out by the experimental results: the voicing effect is greater for /eː/ than for the other vowels. This means that the voicing effect is maximally strong for the vowel that is not part of a short-long contrast, i.e., /eː/ in the case on Lithuanian. On the other hand, those vowels that have a short or long pair seem to be less affected by the stop voicing. These facts support the claim that I set out to examine through this experiment, namely that phonemic vowel length interacts with the voicing effect, in that the presence of such a length contrast in a language inhibits or attenuates this effect.

2.4 Summary

This chapter has explored the interaction between phonology and phonetics, focusing on the role of phonological minimal contrast in the outcome of phonetic patterns. The focus was on the influence of phonemic vowel length in the obstruent voicing effect, a phonetic pattern that affects vowel duration. I hypothesized that the presence of such a contrast in a language will inhibit the degree of contextual modification due to the voicing effect. Experimental results from Lithuanian confirm this hypothesis. More precisely, the data show that the voicing effect is sensitive to whether a given segment is minimally contrastive for length or not. When the relevant vowel is minimally contrastive, the durational modification due to obstruent voicing is attenuated. On the other hand, this modification is greater for a vowel that does not minimally contrast length.

The next step is to provide a phonological analysis of the Lithuanian vowel inventory. In chapter 3, working within the framework of Optimality Theory (Prince & Smolensky 1993), I adopt the Dispersion Theory of contrast (Flemming 1995 with developments by Padgett 1997 and Ní Chiosáin & Padgett 2001) and present an account for this vowel inventory. I argue that the phonetic component operates on the output of phonology, i.e., the vowel inventory from the Dispersion Theory analysis. Consequently, I claim, it is necessary to encode in the phonological representation the minimal length contrast for the vowels that are part of a contrastive pair (/i/ vs. /iː/, /u/ vs. /uː/, /æ/ vs. /æː/, /ɑ/ vs. /ɑː/) but not for those vowels that are not minimally contrastive for this property (/eː/, /oː/). In order to incorporate this information, I develop a *contrast-coindexing* function based on minimal contrast, which will be present in the output of the phonology, and thus, will carry into the phonetic component.

CHAPTER 3

REPRESENTATION OF MINIMAL CONTRAST AND THE PHONOLOGY-PHONETICS INTERACTION

3.1 Introduction

This chapter develops a new phonological representation for minimal contrast. In view of the experimental results reported in chapter 2, I argue that length as a dimension of contrast should be represented using the same mechanism as for other contrasts, rather than making use of the notion of moras. A formal system is proposed to represent minimal contrast through *contrast-coindexing* for those segments that are minimally contrastive for some property.

Given the influence of contrast on phonetic patterns, this chapter addresses the question of how the phonetics comes to be sensitive to this aspect of phonology. I argue that the phonological representation directly encodes contrast by establishing a coindexing relationship between segments that minimally contrast, i.e., that minimally differ in one dimension, for example length. Then, the phonetics has access to whether a given segment is contrast-coindexed, under the assumption that the phonetic component acts upon the output of the phonology and has access to all the information included in this representation.

The discussion of minimal contrast representation shows that the traditional moraic approach to duration is insufficient to capture the effect of length contrasts on the phonetics. I claim that a length contrast between two segments is not based on their moraic specification since a monomoraic segment might or might not be contrastive, depending on the presence of a minimally different bimoraic segment. In fact, under the approach developed here, length contrasts are represented by the same system that represents other minimal contrasts in a language, namely contrast-coindexing. Note that I only argue against moras in relation to the encoding of contrastive duration. Moras seem to have other functions as units of weight that are not considered here.

The organization of the chapter is as follows. In section 3.2, I develop an Optimality Theoretic analysis of the vowel inventory in Lithuanian coached within the Dispersion Theory of Contrast (Flemming 1995), and in section 3.3, I introduce a new approach to representing contrast, namely the *contrast-coindexing* function. Section 3.4 discusses the notion of dimension of contrast, which is an important concept in the contrast-coindexing function. Next, section 3.5 presents a model for the phonology-phonetics interaction taking the contrast-coindexing proposal into account. Finally, Section 3.6 considers an alternative approach to length, namely moraic theory, and shows how this kind of representation fails to capture the observed patterns.

3.2. Analysis of Lithuanian inventory

3.2.1 Dispersion Theory of Contrast

The Dispersion Theory of Contrast (DT; Flemming 1995 et seq. and further developments by Padgett 1997 et seq., Ní Chiosáin & Padgett 2001) is based on the functionalist principles of the Theory of Adaptive Dispersion (Lindblom 1986). This section focuses on DT and its power to analyze sound inventories. However, it should be noticed that DT is developed as a full theory of phonology and phonological processes, not just as an account of consonant and vowel inventories (cf. work on contrast preservation by Lubowicz 2003). DT takes Martinet's (1952, et seq.) functionalist assumptions about the well-formedness of contrasts and incorporates them as active components of the phonology. According to these assumptions, the perceptual distinctiveness of contrasts should be maximized and the articulatory effort should be minimized. DT identifies three main forces given in (13), whose interaction is responsible for different patterns of contrast.

(13) a. Maximize the distinctiveness of contrasts

b. Maximize the number of contrasts

c. Minimize articulatory effort

The first force (13)a) is derived from the communicative function of language. The goal of achieving successful communication depends on the listener's ability to recover the signal. Therefore, it is desirable to avoid perceptually confusable contrasts. This preference is in conflict with the two other forces. (13)b) reflects the idea that a larger number of contrasts allows for a greater combinatorial power, so that words can be relatively short, without inducing homophony. Let us illustrate how these two forces (13)a) and (13)b) stand at odds with each other. The aim to maximize the number of contrasts prefers a large number of contrastive elements in the inventory. For instance, just looking at the height dimension, it will select an inventory such as /i, e, ɛ, a/ over a simpler /i, a/. On the other hand, the aim to maximize the distinctiveness of contrasts prefers that members of a contrast be as distinct as possible from each other. The amount of possible distinctiveness is limited by the auditory space[9], so that the more elements present in this space, the less distinct these elements will be from each other. So, coming back to the example of vowel height, this force will prefer the smaller inventory /i, a/ over the four-element one /i, e, ɛ, a/. The interaction of these two forces will be relevant for the analysis of the Lithuanian vowel inventory.

(13)c) denotes a preference for reducing effort in production. This goal conflicts with the desire to maximize the distinctiveness of contrast since the minimization of effort might reduce the space from which contrasts can be selected. This last force is not further developed here, since it is not crucial for the analysis of Lithuanian.[10]

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[9] DT does not refer to the articulatory space, but this space is relevant in constraining the auditory space.

[10] See Pouplier (2003) for a critique of articulatory effort and Kirchner (1998, 2001, 2004) for arguments in favor of the role of articulatory effort.

Dispersion Theory couches these forces within Optimality Theory (Prince and Smolensky 1993), i.e., a system where the ranking of conflicting constraints determines the output of the phonology. Thus, (13)a) and (13)b) are translated into OT constraints that interact with each other. These are further described in sections 3.2.1.2 and 3.2.1.3, respectively. (13)c) corresponds to markedness constraints based on articulatory ease. As mentioned earlier, these constraints will not be further developed in this study.

3.2.1.1 Systemic approach

In traditional OT, the object of evaluation is a set of candidates, where each candidate consists of just one form. Thus, the well-formedness of each form is assessed independently of the rest of other forms in the language. However, work on contrast shows the relevance of a systemic view in order to assess phonological contrast relationships. According to this systemic approach to contrast, the well-formedness of a form must be evaluated with respect to other forms with which it contrasts (Flemming 1995, 2004, Bradley 2001, Ní Chiosáin & Padgett 2001, to appear, Lubowicz 2003, Padgett a, b, c, Sanders 2003, Bradley & Delforge 2006, Ito & Mester to appear, Padgett & Zygis to appear). Under this view, the whole language needs to be assessed as a system where the behavior of one form could affect the output of another. This line of research capitalizes on the importance of referring to a system of contrasts when evaluating the optimal output for a given grammar. Accordingly, each candidate includes a group of word forms in contrast and not just individual forms. In fact, work within Dispersion Theory assumes that inputs and candidate outputs are entire languages, i.e., the objects of analysis are languages (Flemming 1999, Ní Chiosáin & Padgett 2001, to appear, Padgett 2003a, b, c).

The proposal developed in this thesis, namely, the contrast-coindexing function, follows this systemic approach. Consequently, the analyses presented in the following sections treat the candidates as languages composed of different word forms. Figure 8 illustrates the shape of the candidates under the systemic approach espoused in this study.

Figure 8. Shape of candidates in DT systemic analysis[11]

Input:	*Output:*	
I-word-form$_1$	Candidate$_a$:	O-word-form$_1$
I-word-form$_2$		O-word-form$_2$
I-word-form$_3$		O-word-form$_3$
…		…
	Candidate$_b$:	O-word-form$'_1$
		O-word-form$'_2$
		O-word-form$'_3$
		…
	Candidate$_c$:	O-word-form$''_1$
		O-word-form$''_2$
		O-word-form$''_3$
		…

Figure 8 shows that the input consists of a set of word forms that get mapped into different output candidates, which are sets of word forms. The subscript number

[11] Note that contrast neutralizations are possible so that a candidate output could lack a correspondent output for I-word-form$_3$, for example.

represents the correspondence relation between input and output forms. The usual array of phonological correspondence constraints still hold within corresponding word forms, such as MAX-SEG, IDENT, etc. Note that each candidate can contain infinite forms, similarly to standard OT.[12] Also, it is worth mentioning that, as is usual in OT, the winner candidate includes all possible word forms according to the constraint-ranking, not just existing or attested lexical items (Ní Chiosáin & Padgett to appear, cf. Lubowicz 2003). This means that the winner candidate set may contain lexical gaps, i.e., phonologically well-formed items that are not assigned meaning in a given language.

In the next two sections, I introduce the formalization in OT constraints of two main DT forces discussed earlier: maximization of the distinctiveness of contrasts and maximization of the number of contrasts.

3.2.1.2 Maximize number of contrasts

Following Flemming (1996) and Padgett (1997), the preference for a maximal number of contrasts is formalized as a family of **MaintainContrast** constraints, which require that a certain number of contrasts along a given dimension is maintained. Example (14) illustrates the fixed ranking of MainContrast constraints.

[12] The issue of infinity is considered in section 3.3.2.4 in relation to the contrast-coindexing function.

(14) **MaintainContrast** constraints regulating the number of contrasts

Main-2-way-contrast$_D$ >> Main-3-way-contrast$_D$ >>….>> Main-n-way-contrast$_D$

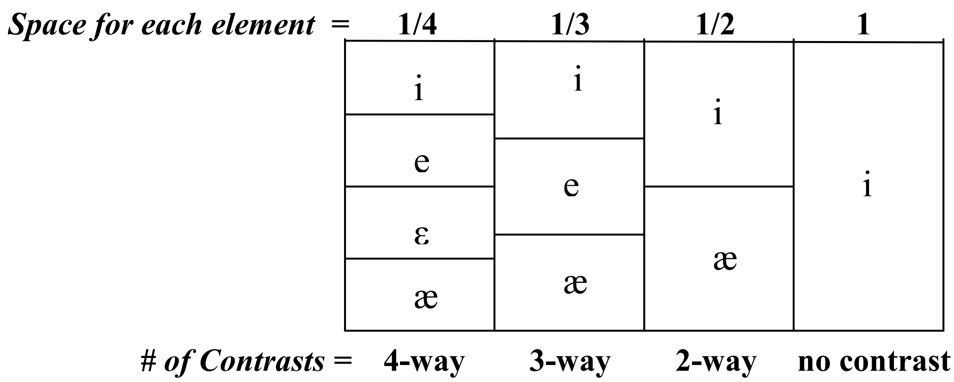
D stands for any dimension along which a contrast exists.[13] In this fixed ranking, the constraints demanding a smaller number of contrasts are higher ranked. Thus, violation of Main-n-way-contrast$_D$ implies violation of a Main-n+1-way-contrast$_D$, i.e., a lower ranked constraint. This captures the idea that candidates with larger number of contrasts are preferred.

3.2.1.3 Maximize distinctiveness of contrasts

Following Padgett (1997, 2003a, b, c) and Ní Chiosáin & Padgett (2001), the preference to maximize the distinctiveness of contrast is formalized as a family of SPACE constraints that require any given contrast to keep a certain amount of distinctiveness. These constraints regulate how distinct contrasts must be. SPACE constraints are parameterized for some acoustic dimension. This dimension is represented as a space, which is divided into intervals so that the distance along this space is represented by means of fractions of the entire range. Thus, any given SPACE constraint indicates the distance along that space which must separate any contrast in that dimension. Figure 9 illustrates the division of the height space into different fractions and how depending on the number of contrasts, the fraction corresponding to each segment varies.

[13] I elaborate on the notion of dimensions of contrast in section 3.4.

Figure 9. Division of height space into fractions depending on the number of contrasts



Examples (15) and (16) give the definition of the SPACE constraints and the fixed ranking among this type of constraints.

(15) Constraint regulating distinctiveness of contrasts

$\text{SPACE}_D \geq 1/n$: Potential minimal pairs differing in D must differ at least in 1/n of the full range.

(16) Fixed ranking among SPACE constraints

$\text{SPACE}_D \geq 1/n$ >> $\text{SPACE}_D \geq 1/n\text{-}1$ >>…>> $\text{SPACE}_D \geq 1/2$ >> $\text{SPACE}_D \geq 1$

The fixed ranking of SPACE constraints in (16) reflects the preference for maximally distinct contrasts. Less demanding constraints are ranked higher than constraints requiring greater distinctiveness, i.e., more space for each contrast. Thus, violation of $\text{SPACE}_D \geq 1/n$ implies violation of $\text{SPACE}_D \geq 1/n\text{-}1$. Note that since the SPACE constraints are in a stringent relation, the fixed ranking does not have to be stipulated.

According to the definition of SPACE constraints in (15), these constraints are evaluated against potential minimal pairs. Segments within different words are assumed to correspond with each other according to their order in the string (Padgett 2003a, b, c). Note that this involves a novel use of correspondence to mark order in the string, which is further discussed in section 3.3.2.2. Thus, a potential minimal pair is defined as a pair of words that have the same number and sequence of segments and that differ in just one of those corresponding segments. The formal definition of minimal pair is discussed in section 3.3.2.2. Recall that in Dispersion Theory, inputs to EVAL and candidates created by Gen are *sets* of word forms, rather than single words as in standard OT (see section 3.2.1.1). Therefore, the idea behind including minimal pairs in the definition of SPACE constraints is that the phonology evaluates whole word systems, not just vowel inventories. This means that EVAL assesses vowel (or consonant) contrasts placed within words, not as isolated segments. In the following analysis of Lithuanian, I assume this type of evaluation, but in order to restrict the attention to the relevant contrasts, candidates will be composed of sets of monosyllabic words formed by an open syllable. This idealization (Padgett 2003a, b, c, Ní Chiosáin & Padgett to appear) is possible given the fact that none of the Lithuanian vowel contrasts is dependent upon the environment where they occur, i.e., there is not contextual neutralization.

Bearing in mind Figure 9, let us illustrate how SPACE constraints for height are evaluated against some possible vowel inventories. Table 10 illustrates the assessment of three SPACE constraints with respect to these systems, which are included as different candidates.

Table 10. Evaluation of SPACE constraints

	$\text{S}\textsc{pace}_{height}\geq 1/3$	$\text{S}\textsc{pace}_{height}\geq 1/2$	$\text{S}\textsc{pace}_{height}\geq 1$
a. i e ɛ æ	*	*	*
b. i e æ		*	*
c. i æ			*
d. i			

As Table 10 shows, an inventory with a four-way contrast for height (candidate a) violates all three constraints, given that each of the elements gets 1/4 of the entire space and the constraints require these segments to have bigger fractions. A three-way contrast system (candidate b) only violates the constraints demanding 1/2 or more of the entire height range for each element. A two-way contrast inventory (candidate c) incurs a violation only of the lowest constraint, which basically requires that there be no contrast, i.e., the whole height space is reversed for a single element. Finally, this constraint and all the higher ranked ones are satisfied by a system with no contrast for height (candidate d).

Padgett (1997, 2003) addresses the issue that given the two families of constraints, MaintainContrast and SPACE, the interleaving among them might give rise to unattested patterns of contrast, for example six-way contrasts for height if Main-6-Contrast_{height} dominates $\text{S}\textsc{pace}_{height}\geq 1/5$. The lack of such systems reflects the fact that along the different dimensions, only a limited number of contrasts are possible cross-linguistically (a four-way contrast for height (Ladefoged and Maddieson 1996)[14]). Padgett's solution is to place the SPACE constraint that allows for the biggest possible contrast system in GEN. This means that for the height dimension $\text{SPACE}_{height} \geq 1/4$ is in GEN, so that only systems with one-, two-, three- or four-way contrast for height are generated. For most dimensions, the distinction usually involves a two-way contrast so the $\text{SPACE} \geq 1/2$ for those dimensions is in GEN. This approach parallels that of positing binary features in distinctive feature theory.

3.2.2 Dispersion Theory and Lithuanian inventory

This section develops a Dispersion Theory analysis for the Lithuanian vowel inventory. Previous work within DT for the analysis of vowels (Flemming 1995, Padgett 1997, 2003, Sanders 2003) has focused on the height and backness contrast dimensions. I contribute to DT by addressing length contrasts in vowels. Before moving into the details of the analysis, let us review the Lithuanian vowel inventory (Table 11), which was introduced in section 2.3.2.

[14] Ladefoged and Maddieson (1996) mention a potential five-way contrast in height found in the Bavarian dialect of Amstetten, Austria (Traunmüller 1982), but their discussion is not conclusive.

Table 11. Lithuanian phonemic vowel inventory

	Front	Back
High	/i/ /iː/	/u/ /uː/
Mid	/eː/	/oː/
Low	/æ/ /æː/	/ɑ/ /ɑː/

This inventory presents a two-way contrast in backness, a three-way contrast in height and a two-way length contrast for high and low vowels. This last feature makes the Lithuanian vowel system asymmetrical, in the sense that there are some unexpected gaps in the length dimension. Note that these gaps seem to have a historical reason.[15] However, I focus on a synchronic account of the Lithuanian inventory. First, I present an analysis for the height and backness facts, building on previous work by Flemming (1995), Padgett (1997 et seq.) and Ní Chiosáin & Padgett (2001). Next, I argue for an extension of DT in order to account for length contrasts.

As can be seen in Table 11, Lithuanian presents a three-way contrast along the height dimension. This means that the MaintainContrast constraint requiring a three-way contrast in height, i.e., Main-3-way-contrast$_{\text{Height}}$, is top-ranked and never violated. This occurs at the expense of a lower ranked SPACE constraint, SPACE$_{\text{Height}}\geq 1/2$, which requires any contrast in the height dimension to be at least 1/2 apart in the height space, i.e., each contrastive element should have at least 1/2 of the whole space. A three-way contrast does not satisfy this requirement since in this

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[15] The diachronic facts about Lithuanian vowels are not presented here, but several historical studies on Baltic seem to indicate that the lack of short mid vowels in Modern Lithuanian can be traced back to a series of mergers and diphthongization processes (see Schmalstieg 2005 for an overview).

case, the relevant contrasting elements would each get a 1/3 of the space. This implies that SPACE$_{Height}$≥1/3 is top-ranked and satisfied by the output inventory. The partial ranking so far in shown in (17).

(17) SPACE$_{Height}$≥1/3, Main-3-way-contrast$_{Height}$ >> SPACE$_{Height}$≥1/2

Other relevant constraints include SPACE$_{Height}$≥1 and Main-4-way-contrast$_{Height}$, which are low-ranked and violated in order to satisfy the higher ranked constraints requiring a three-way contrast and 1/3 of the space for each element in the contrast. Thus, the final complete ranking is that in (18).

(18) SPACE$_{Height}$≥1/3, Main-3-cont$_{Height}$ >> SPACE$_{Height}$≥1/2>> SPACE$_{Height}$≥1, Main-4-cont$_{Height}$

Let us exemplify how the interaction of these constraints selects a three-way contrast for height as the optimal output. Tableau 2 considers the height dimension only for back vowels, but note that the same analysis extends to front vowels. Candidates (b) and (c) with a two-way contrast and no contrast at all, respectively, are ruled out due to their violation of the high ranked constraint Main-3-contrast$_{height}$. Candidate (d) has four elements contrasting in height and consequently, violates SPACE$_{height}$ ≥1/3. Candidate (a) has a three-way contrast, satisfying the two top-ranked constraints.

Table 12. Tableau 2 Lithuanian three-way contrast for height

	SPACE$_{height}$ ≥⅓	Main-3$_{height}$	SPACE$_{height}$ ≥½	SPACE$_{height}$ ≥1	Main-4$_{height}$
☞ a. puː poː pɑː			*	*	*
b. puː pɑː		*!		*	*
c. puː		*!			*
d. puː poː pɔː pɑː	*!		*	*	

As for the back dimension, Lithuanian presents a two-way contrast for all heights and lengths. This indicates that Main-2-contrast$_{back}$ outranks SPACE$_{back}$≥1, which requires that any given segment gets the whole backness space, i.e., it disallows any contrast along this dimension. Given that a three-way contrast does not arise, Main-3-contrast$_{back}$ is dominated, crucially by SPACE$_{back}$≥1/2. This SPACE constraint allows for a maximum of two degrees of backness, and it is satisfied by the Lithuanian vowel inventory. The final ranking for the backness contrast is given in (19).

(19) SPACE$_{back}$ ≥ 1/2, Main-2-contrast$_{back}$ >> SPACE$_{back}$ ≥ 1, Main-3-contrast$_{back}$

Tableau 3 illustrates how this ranking works. Candidate (b) with a three-way contrast is ruled out by SPACE$_{back}$≥1/2, which is higher ranked than the MaintainContrast constraint that would prefer such a candidate, namely Main-3-

contrast$_{back}$. Candidate (c) presents an inventory with no contrast for backness. This inventory is ruled out since the ranking of Main-2-contrast$_{back}$ disfavors it. Note that Tableau 3 includes only high vowels for the sake of simplicity but Main-2-contrast$_{back}$ is enforced for each vowel quality as well as each vowel length.

Table 13. Tableau 3 Lithuanian two-way contrast for backness

	SPACE$_{back}$ ≥ 1/2	Main-2$_{back}$	SPACE$_{back}$ ≥ 1	Main-3$_{back}$
☞ a. pi pu			*	*
b. pi pɨ pu	*!		*	
c. pɨ		*!		*

Now, I turn to the analysis of the vowel length contrast distribution in Lithuanian. Building on previous work within DT, I introduce a fixed ranking of SPACE constraints along the vowel duration dimension, which regulate the distinctiveness of the length contrasts. This ranking is shown in (20), together with the definition of the SPACE constraint regulating duration in (21).

(20) SPACE$_{Vdur}$≥1/n >> …..>> SPACE$_{Vdur}$≥1/2>> SPACE$_{Vdur}$≥1

(21) SPACE$_{Vdur}$≥1/n : Potential minimal pairs differing in vowel duration must differ at least in 1/n of the full vowel duration range.

Length is understood to have two degrees of contrast[16], i.e., either long or short vowels. This is captured by the fact that only SPACE$_{Vdur}$≥1 seems to be violable in the phonology of a given language. Higher ranked SPACE constraints are in GEN,

[16] See Ladefoged and Maddieson (1996) for a potential case of a three-way contrast for length.

limiting the maximal distinctiveness of possible contrasts in length (cf. Padgett 1997, 2003). According to the analysis developed here, the interaction between SPACE$_{Vdur}$≥1 and Main-2-contrast$_{Vdur}$, i.e., maintain a two-way contrast along the vowel duration dimension, is responsible for the patterns of length contrast found cross-linguistically. In languages where the former dominates the latter, any given vowel must be assigned all the vowel duration space, so that no length contrast arises. On the other hand, the reverse ranking favors a two-way length contrast at the expense of minimizing the distinctiveness along the vowel duration dimension.

Lithuanian seems to illustrate this latter case. However, the facts are more complicated since only high and low, i.e., peripheral, vowels show a length contrast. Mid or non-peripheral vowels are always long. In order to account for this asymmetry, I propose to relativize the Main-2-contrast$_{Vdur}$ for vowel peripherality, so that the MaintainContrast constraints in (22) are derived (cf. Lubowicz 2003, ch. 3).

(22) a. Main-2-contrast$_{Vdur/peripheral}$: Maintain a two-way duration contrast for peripheral (high & low vowels)

b. Main-2-contrast$_{Vdur/non\text{-}peripheral}$: Maintain a two-way duration contrast for non-peripheral (mid) vowels

The constraint in (22)a) is satisfied by the presence of a two-way contrast for duration among peripheral vowels. (22)b) requires that the two-way contrast be maintained for non-peripheral vowels. These relativized constraints are necessary to obtain the asymmetries in the occurrence of length contrasts for peripheral and non-peripheral vowels in Lithuanian. The specific ranking of the constraints came about in language change, which is argued to be responsible for the synchronic shape of the Lithuanian vowel inventory (see footnote 13). Thus, the constraints responsible for selecting such a system have their grounding and motivation in the same factors that cause sound change, which I assume to be articulatory and acoustic, at least for changes in vowel inventories. In this case, the difference in length contrasts for peripheral and non-peripheral vowels might be related to the observation that mid or non-peripheral vowels constitute a perceptually-challenging natural class of vowels (Crosswhite 2001, 2004). This might explain why it is preferable to have a larger number of contrasts among peripheral vowels than among non-peripheral vowels. Adding a length contrast for mid vowels would increase the number of contrasts among these vowels. Here, it is also relevant to consider why the mid vowel is realized as long rather than short. I propose the markedness constraint in (23), which bans short non-peripheral, i.e., mid, vowels.

(23) *MidShortV

No mid short vowels

This markedness constraint captures the fact that mid vowels are realized as long /e:, o:/ in Lithuanian, i.e., short mid vowels are not allowed. This state of affairs in Lithuanian is the result of historical sound changes by which the short mid vowels were lost (merged with other short vowels) but the long mid vowels were retained. Crosswhite (2001, 2004) identifies a form of reduction that targets non-peripheral vowels, especially mid vowels. This relates to the idea of perceptually-challenging vowel qualities (Crosswhite 2004): short mid vowels are even more acoustically disadvantageous than long mid vowels in terms of perception of vowel quality given their reduced duration.

Let us turn now to the relevant ranking for length contrast distributions in Lithuanian. The fact that non-peripheral vowels do not show a vowel length contrast suggests that SPACE$_{Vdur}\geq 1$ dominates Main-2-contrast$_{Vdur/non\text{-}peri}$. However, SPACE$_{Vdur}\geq 1$ is dominated by the Main-2-contrast$_{Vdur/peri}$ constraints, given that peripheral vowels display length contrasts. This gives the partial ranking in (24).

(24) Main-2-contrast$_{Vdur/peri}$>> SPACE$_{Vdur}\geq 1$ >> Main-2-contrast$_{Vdur/non\text{-}peri}$

Note that the constraints responsible for the length contrasts in Lithuanian interact with the constraint regulating the number of height contrasts in this language. This stems from the fact that the height contrasts are different for long and short vowels. Main-2-contrast$_{Vdur/peri}$ dominates Main-3$_{height}$ since the Lithuanian vowel inventory shows a length contrast for peripheral vowels at the expense of not having a three-way height contrast for its short vowels. On the other hand, Main-3$_{height}$ is ranked higher than Main-2$_{Vdur/non\text{-}peri}$ because the actual system does have a three-way height contrast, even if that implies not having a short counterpart for its long non-peripheral vowels. These two ranking arguments give us the partial ordering in (25).

(25) Main-2-contrast$_{\text{Vdur/peri}}$ >> Main-3$_{\text{height}}$ >> Main-2$_{\text{Vdur/non-peri}}$

With respect to the markedness constraint *MidShortV, it is top-ranked in Lithuanian since it is never violated. Crucially, *MidShortV outranks Main-3$_{\text{height}}$. This accounts for the fact that the Lithuanian vowel system lacks a three-way height contrast for its short vowels due to the ban on short mid vowels. Finally, by transitivity and also because Lithuanian mid vowels cannot be short, Main-2$_{\text{Vdur/non-peri}}$ is dominated by *MidShortV. The final relevant ranking is given in (26).

(26) Main-2$_{\text{Vdur/peri}}$, *MidShortV >>SPACE$_{\text{Vdur}}$≥1, Main-3$_{\text{height}}$ >>Main-2$_{\text{Vdur/non-peri}}$

Tableau 4 exemplifies how the ranking in (26) selects the asymmetrical Lithuanian inventory. This tableau includes only front vowels but the same analysis applies to back vowels. Candidate (b) presents a system where vowel length is contrastive for all of the vowel qualities. This candidate satisfies low ranked Main-3$_{\text{height}}$ and Main-2-cont$_{\text{Vdur/nonperi}}$ but at the expense of violating top-ranked *MidShortV. Candidate (c), an inventory without a length contrast for its mid vowels, is ruled out by its violation of *MidShortV. Note that this is the only difference between this candidate and candidate (a), the optimal output. Candidates (d), (e) and (f), inventories with no length contrasts at all, fatally violate Main-2$_{\text{Vdur/peri}}$. Candidate (g), a system with a length contrast for its peripheral vowels and no mid vowels at all, is ruled out due to its multiple violations of Main-3_{height}. Note that the winner candidate (a) violates Main-3_{height} only once.

Table 14. Tableau 4 Lithuanian vowel length contrasts

	Main$2_{Vdur/per}$	*MidShortV	SPACE$_{Vdur}$≥1	Main3_{height}	Main$2_{Vdur/non\text{-}per}$
a. ☞ pi piː peː pæ pæː			**	*	*
b. pi piː pe peː pæ pæː		*!	***		
c. pi piː pe pæ pæː		*!	**	*	*
d. pi pe pæ	**!	*			*
e. pi pæ	**!			*	
f. piː peː pæː	**!				*
g. pi piː pæ pæː			**	**!	

To recapitulate, (27) shows a lattice which includes all the constraints and rankings relevant for the analysis of the Lithuanian vowel inventory.

(27) Ranking for Lithuanian inventory

Backness

$\text{SPACE}_{back} \geq 1/2$, Main-$2_{back}$

↓

$\text{SPACE}_{back} \geq 1$, Main-$3_{back}$

Height & Length

$\text{SPACE}_{height} \geq 1/3$, Main-$2_{Vdur/peri}$, *MidShortV

↓

$\text{SPACE}_{Vdur} \geq 1$, Main-$3_{height}$

↓

$\text{SPACE}_{height} \geq 1/2$, Main-$2_{Vdur/non\text{-}peri}$

↓

$\text{SPACE}_{height} \geq 1$, Main-$4_{height}$

The ranking illustrated in (27) selects the following set of minimal pairs containing the vowel inventory given in (28) as the optimal output of the Lithuanian phonology.

(28) Output of Lithuanian phonology

pi piː pu puː

peː poː

pæ pæː pɑ pɑː

3.3 Representation of minimal contrast

3.3.1 Introduction

The experimental results reported in chapter 2 indicate that contrastive vowel length influences the realization of a phonetic pattern that modifies duration, namely the voicing effect. This shows that phonological information, about contrast in this case, can impact the outcome of a phonetic pattern. But, what kind of contrast influences the voicing effect? The facts suggest that it is not length contrast as a property of the entire system, otherwise all vowel qualities would be behave alike with respect to the contextual modification. Lithuanian has an asymmetrical inventory since not all vowel qualities enter into a short vs. long contrast relationship. In fact, the results show that phonetics is sensitive to this asymmetry and treats vowels in contrasting pairs differently from the vowels that are not paired for length. This means that the phonetic pattern is different depending on the vowel.

The relevant notion here is that of minimal length contrast. Minimally contrastive segments are pairs of segments that differ just along one dimension of contrast, e.g. length (Jakobson et al. 1952). For instance, short /i/ and long /iː/ differ only in vowel length. Thus, these two segments are minimally contrastive for this property. On the other hand, short /i/ and long /eː/, differ in their length but also in height. These two segments do not minimally contrast for the length dimension. As discussed earlier, in Lithuanian the long mid vowel /eː/ is not minimally contrastive for length, and this is the vowel that behaves differently with respect to the voicing effect.[17] The importance of minimal contrast, as opposed to contrast in general, comes from the fact that Lithuanian /eː/ can be argued to contrast in length with short vowels, even if they have different qualities. However, the relevant contrast, the lack of which conditions the voicing effect, is that between long /eː/ and short */e/.

[17] /o:/ also patterns as unpaired with respect to the voicing effect.

Consequently, I argue that the phonological representation needs to include information about minimal contrast, which the phonetic component can access. However, returning to the output of the phonology in Lithuanian given in (28), this information is not usually included in the representation. I propose to formalize the representation of phonological contrast as a *Contrast-Coindexing of minimally contrastive segments*.

3.3.2 Contrast-Coindexing function

3.3.2.1 Definition

The proposal is to introduce a *contrast-coindexing* function into the phonological architecture in order to include minimal contrast in the phonological representation. Contrast-coindexing assesses minimal contrast at the word level within candidate languages, following the systemic evaluation of contrast (see section 3.2.1.1). For this reason, it is important to consider the definition of minimal pair, which is given in (29). Section 3.3.2.2 discusses the process of minimal pair identification in more detail. The definition of the contrast-coindexing function is shown in (30).

(29) Definition of minimal pair[18]

Let O be an output, a set of word forms, and $W_1 \in O$, $W_2 \in O$, and let W_1 and W_2 correspond to different word forms in the input[19],

and let S_1 be the set of segments in W_1 and S_2 be the set of segments in W_2:

If S_1 and S_2 are equal in number,

and intersect in all but one segment,

and all the shared segments are in the same order, and their non-shared segment is in the same position in the segment sequence,

then W_1 and W_2 form a minimal pair.

Note that in the definition of minimal pair, S_1 and S_2 intersect in all but one segment when all their segments, except for one, are phonologically identical.

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[18] Note that the definition of minimal pair in (29) assumes that contrast may arise only at the segmental level. However, floating elements such as tones might arguably also give rise to minimal contrast (see section 3.4). This possibility could be captured by modifying the definition of minimal pair so that the different element could be a segment or some other element such as floating tones. This means that not only segments but other phonological elements, i.e., floating tones, would be considered. In this case, the definition would encompass both sequenced elements, as above, and unordered floating elements.

[19] If W_1 and W_2 corresponded to the same input, they would be free variants.

(30) Contrast-Coindexing function

Let O be an output, a set of word forms.

For $W_1 \in O$ and $W_2 \in O$, and where W_1 and W_2 form a minimal pair:

Let α and β be two segments such that $\alpha \in W_1$ and $\beta \in W_2$,

let D_i be a given dimension of contrast,

if α and β have a SPACE<1 for D_i with respect to each other, and there is no other dimension D_j for which α and β have a SPACE<1 with respect to each other,

then α_{Di} and β_{Di} , i.e., α and β are contrast-coindexed for D_i.

Couched within Optimality Theory, the contrast-coindexing function is argued to take place after GEN generates all the candidates and before EVAL operates over them. Figure 10 illustrates the proposed architecture augmented with the contrast marking step. This architecture is further discussed in section 3.3.2.4.

Figure 10. Illustration of proposed architecture augmented with contrast marking step

GEN	=>	**Contrast-coindexing**	=>	**EVAL**
Candidate generation		Minimal contrast is marked		Constraint ranking selects optimal candidate

In a nutshell, contrast-coindexing applies to minimally contrastive segments that are able to distinguish minimal pairs of words. The notion of having a SPACE<1 for some dimension relates to the previous analysis of the vowel contrasts within DT. This means that SPACE<1 is assessed twice: one in the contrast-coindexing function and again in EVAL. Note that in the contrast-coindexing function SPACE is evaluated pairwise for word forms rather than for the whole system of forms. Let us explain the definition in (30) in some more detail. If any segment has SPACE<1 for any given dimension, this implies that it is sharing the space with some other element, i.e., there is a contrast along that dimension. Thus, two segments that have a common SPACE<1 for one and only one dimension are minimally contrastive and get a contrast-coindex for the relevant dimension. On the other hand, two segments that have a SPACE<1 for two or more common dimensions are not assigned a contrast-coindex by virtue of those distinctions. (However, those segments might minimally contrast with others and therefore be assigned a contrast-coindex). For example, Lithuanian short /i/ and long /iː/ have both a SPACE<1 for vowel duration. This is the only dimension for which both share this space. Thus, they are contrast-coindexed for vowel duration. However, there is no segment that shares with long /eː/ only a SPACE<1 for vowel duration. Short /i/ and long /eː/ have a SPACE<1 also for height so this pair does not cause them to be contrast-coindexed for vowel duration or height. Note that short /i/ is contrast-coindexed for vowel duration due to its relation with long /iː/. Also, long /eː/ gets contrast-coindexed for height through its opposition with long /iː/.[20] It is important to notice that contrast-coindexing produces

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[20] Some languages such as Italian or Icelandic seem to treat duration as a ratio over a span of segments (Saltarelli 2005). This treatment would necessitate evaluating duration contrasts over more

indexing on segments as a means of marking minimal contrast. This function does not produce a relation between minimally contrastive segments.

Let us further illustrate the contrast-coindexing proposal with a small inventory such as that of the Australian language Djaru (Tsunoda 1981), in Table 15.

Table 15. Vowel inventory for Djaru

	Front	Central	Back
High	i		u
Low		a aː	

Djaru has a front high vowel, a back high vowel and two central low vowels, one short and another long. For the Djaru system, three dimensions of contrast will be of relevance, namely backness, height and length. Section 3.4 discusses in detail the notion of dimension. For now, it will suffice to say that dimensions do not correspond to features but rather, they refer to the space along which contrasts occur. For instance height might be divide into two or three contrasts. Each of these contrasts would differ in height. Also, note that backness here would roughly equate with the more traditional term of color (Padgett 2002). Coming back to Djaru, first, /i/ and /u/ are compared. These two vowels both have a SPACE<1 for backness and they do not have any other common SPACE<1, since they only differ in backness. Therefore, /i/ and /u/ get a contrast-coindex for backness. Next, /a/ and /aː/ both have

than one segment. However, I take such cases to be in fact instances of length contrasts at the segmental level (e.g. consonants in the case of Italian), whose implementation affects the duration of more than one element (e.g. a VC sequence in Italian).

a SPACE<1 for vowel duration. This is their only common SPACE<1. Thus, they are assigned a contrast-coindex for vowel duration. If /i/ and /a/ are compared, it can be seen that these two vowels have a SPACE<1 for height and also for backness, given that these two segments have different values for these two dimensions. Then, this comparison does not contribute any contrast-coindex. The same is true for the rest of the comparisons, i.e., /u/ vs. /a/, /i/ vs. /aː/ and /i/ vs. /aː/, since these segments differ from each other in more than one dimension. This means that they have a SPACE<1 for more than one dimension of contrast. Example (31) illustrates the contrast-coindices assigned to the Djaru vowel inventory.

(31) Contrast-coindexed representation of Djaru vowels[21]
(b=backness, d=vowel duration)

$i_{\mathbf{b}}$ $u_{\mathbf{b}}$

$a_{\mathbf{d}}$ $\text{aː}_{\mathbf{d}}$

3.3.2.2 Minimal pair identification

Contrast-coindexing adopts a systemic approach to contrast, as described in section 3.2.1.1. It assesses minimal contrast at the word level, taking into consideration the language's entire set of phonologically well-formed words, in accordance with recent work on contrast within Optimality Theory (OT) (e.g. Flemming 1995, 2004, Ní Chiosáin & Padgett 2001, to appear, Padgett 1997, 2003, Sanders 2003, Ito & Mester

[21] Note that the Djaru low vowel /a/ might be treated as back. In that case, /a/ and /u/ would be minimally contrastive for height.

in press,; cf. Lubowicz 2003, Tessier 2004). The definition of contrast-coindexing in (30) reflects this systemic approach. The first clause in the definition states that it is necessary to consider *minimal pairs* of words in order to assess whether two segments are minimally contrastive or not. By looking at the word level during contrast evaluation, contrast-coindexing captures phonemic contrast, i.e., a segment is phonemic if there is a minimal pair that differs in this element. It also ties to the notion that phonology evaluates whole word-based systems of contrast, i.e., whole languages, rather than individual segments (see section 3.2.1.1).

Here, it is relevant to explain what it is meant by minimal pair within the contrast-coindexing proposal. A minimal pair is formed by two word forms that differ only in one segment in the same location. The rest of the segments must be phonologically identical with each identical pair in the same location. Location refers to the position within the order of segments in a word. This means that for two word forms to qualify as a minimal pair, they must differ in just one segment and this differing segment must occupy the same position within both words.

Padgett (2003a, b) addresses the issue of how to identify minimal pairs. He uses the notion of correspondence (McCarthy and Prince 1995) but in a novel way. Under his view, segments within a word form are indexed according to their order in the string. Therefore, the first segments of two different word forms correspond or are indexed for the same location in the order. Padgett's mechanism can be extended to the contrast-coindexing function and how it assesses minimal pairs. This function has to identify pairs of word forms that differ in just one of their corresponding segments. Let us illustrate this with the examples in (32), which show three word forms with the correspondence indices showing the relationship among their segments with respect to their order. Note that left to right sequencing is indicated by ascending integers.

(32) a. /$m_1a_2p_3e_4$/

b. /$m_1i_2p_3e_4$/

c. /$m_1e_2p_3i_4$/

(32)a) and (32)b) are identified by contrast-coindexing as a minimal pair since they differ only in one corresponding segment, i.e., the segment occupying the second position. All the other corresponding segments are identical. On the other hand, (32)a) and (32)c) are not identified as forming a minimal pair since, even if they differ in only one pair of segments, these segments do not correspond to each other within the order in the strings. Similarly, (32)b) and (32)c) do not form a minimal pair because, although they have the same segments, they differ in their order. Note that under this approach, given the correspondence relationships, only word forms with the same number of segments might be identified as minimal pairs. In (33), I revise the definition of minimal pair incorporating Padgett's proposal.

(33) Revised definition of minimal pair

Let O be an output, a set of word forms, and $W_1 \in O$, $W_2 \in O$, and let W_1 and W_2 correspond to different word forms in the input,

and let S_1 be the set of segments in W_1 and S_2 be the set of segments in W_2:

If all segments in S_1 and S_2 are in correspondence,

and S_1 and S_2 have identical corresponding segments except for one

then W_1 and W_2 form a minimal pair.

Minimal pairs are identified in the same way even when the contrasting segments show differences in more than one respect, e.g. in length and height. As explained above, a minimal pair is formed by two word forms that differ in just one segment in the same location. This definition does not specify in how many respects the two differing segments must contrast. They could differ in only one respect or in more than one. However, the number of contrasting aspects becomes important for the purposes of contrast-coindexing, since two contrasting segments must differ in just one property to be contrast-coindexed. The Lithuanian words in (34) illustrate how the number of differing aspects between two contrasting segments is irrelevant for minimal pair identification but it becomes crucial for contrast-coindexing.

(34)	a. /lɑːp**ɑː**/	‘leaf.acc.sg.’	*vs.*	/lɑːp**uː**/	‘leaf.gen.pl.’
	b. /lɑːp**ɑː**/	‘leaf.acc.sg.’	*vs.*	/lɑːp**eː**/	‘fox’

The two pairs of words in (34)a) and (34)b) are identified as minimal pairs. They both have the same number of segments and they differ in just one segment (/ɑː/ vs. /uː/ & /ɑː/ vs. /eː/) in the same location, i.e., the end of the word. Also, the other segments in the word forms are in the same order. However, contrast-coindexing does not apply equally to these contrasting segments. In (34)a), /ɑː/ and /uː/ contrast only for height and thus, they get contrast-coindexed for this property.[22] On the other hand, in (34)b) /ɑː/ and /eː/ contrast in height and backness, i.e., they differ in more than one respect. Therefore, they do not get contrast-coindexed.

3.3.2.3 Illustration

After explaining the definition of the contrast-coindexing function in detail, I illustrate how it applies to the vowel inventory of the case study language, Lithuanian. This can be seen in Table 16, where the nonsense words used in the experiment help illustrate the contrast-coindexing function. I focus on the three relevant dimensions of contrast for vowels, namely, height, backness and length. This illustration shows how the different segments are assigned their contrast-coindices by virtue of their comparison with other elements of the system. In Table 16, only comparison of segments differing along one dimension is included. These are the only relevant comparisons that lead to contrast-coindexing of their members. It should be clear that any other comparisons fail to fulfill the requirements of the contrast-coindexing function definition. The first column in Table 16 shows the word

[22] The reader should refer back to Table 3 for the Lithuanian vowel inventory.

forms in which segments are compared with respect to the different dimensions of contrast. The segments under comparison are the vowels in the first syllable. The next three columns indicate whether the segments being compared share the space for height, backness or vowel duration. If both segments have a SPACE<1 for any of these dimensions, then they get 'yes' in the corresponding cell. On the other hand, if these compared segments do not have a SPACE<1 for any of the three relevant dimensions, then a 'no' appears in the corresponding cell. The last column includes the contrast-coindexing that applies to the relevant pairs. Notice that each of these pairs gets a 'yes' only for one of the spaces. This is important because it shows that the pairs share only one common space, a requirement to be assigned a contrast-coindex. (35) presents the Lithuanian vowel inventory with its resulting contrast-coindices, illustrated with the words employed in the experiment.

Table 16. Illustration of contrast-coindexing for Lithuanian (d=vowel duration, h=height, b=backness)[23]

Compared forms	$\text{SPACE}_{\text{Vdur}}<1$	$\text{SPACE}_{\text{height}}<1$	$\text{SPACE}_{\text{back}}<1$	Contrast-coindexed representation
tɪkʃa *vs.* **tiː**ksa	***yes***	no	no	tɪ$_{\mathbf{d}}$ksa-tiː$_{\mathbf{d}}$ksa
t**ɛ**kʃa *vs.* t**æː**kʃa	***yes***	no	no	tɛ$_{\mathbf{d}}$kʃa-tæː$_{\mathbf{d}}$kʃa
t**ʊ**kʃa *vs.* t**uː**kʃa	***yes***	no	no	tʊ$_{\mathbf{d}}$kʃa-tuː$_{\mathbf{d}}$kʃa
t**a**kʃa *vs.* t**ɑː**kʃa	***yes***	no	no	ta$_{\mathbf{d}}$kʃa-tɑː$_{\mathbf{d}}$kʃa
tɪkʃa *vs.* t**ɛ**kʃa	no	***yes***	no	tɪ$_{\mathbf{h}}$kʃa-tɛ$_{\mathbf{h}}$kʃa
t**iː**kʃa *vs.* t**eː**kʃa	no	***yes***	no	tiː$_{\mathbf{h}}$kʃa-teː$_{\mathbf{h}}$kʃa
t**eː**kʃa *vs.* t**æː**kʃa	no	***yes***	no	teː$_{\mathbf{h}}$kʃa-tæː$_{\mathbf{h}}$kʃa
t**ʊ**kʃa *vs.* t**a**kʃa	no	***yes***	no	tʊ$_{\mathbf{h}}$kʃa-ta$_{\mathbf{h}}$kʃa
t**uː**kʃa *vs.* t**oː**kʃa	no	***yes***	no	tuː$_{\mathbf{h}}$kʃa-toː$_{\mathbf{h}}$kʃa
t**oː**kʃa *vs.* t**ɑː**kʃa	no	***yes***	no	toː$_{\mathbf{h}}$kʃa-tɑː$_{\mathbf{h}}$kʃa
tɪkʃa *vs.* t**ʊ**kʃa	no	no	***yes***	tɪ$_{\mathbf{b}}$kʃa-tʊ$_{\mathbf{b}}$kʃa
t**iː**kʃa *vs.* t**uː**kʃa	no	no	***yes***	tiː$_{\mathbf{b}}$kʃa-tuː$_{\mathbf{b}}$kʃa
t**eː**kʃa *vs.* t**oː**kʃa	no	no	***yes***	teː$_{\mathbf{b}}$kʃa-toː$_{\mathbf{b}}$kʃa
t**ɛ**kʃa *vs.* t**a**kʃa	no	no	***yes***	tɛ$_{\mathbf{b}}$kʃa-ta$_{\mathbf{b}}$kʃa
t**æː**kʃa *vs.* t**ɑː**kʃa	no	no	***yes***	tæː$_{\mathbf{b}}$kʃa-tɑː$_{\mathbf{b}}$kʃa

(35) Contrast-coindexed representation of Lithuanian

tɪ$_{\mathbf{d/h/b}}$kʃa	tiː$_{\mathbf{d/h/b}}$kʃa	tʊ$_{\mathbf{d/h/b}}$kʃa	tuː$_{\mathbf{d/h/b}}$kʃa
	teː$_{\mathbf{h/b}}$kʃa		toː$_{\mathbf{h/b}}$kʃa
tɛ$_{\mathbf{d/h/b}}$kʃa	tæː$_{\mathbf{d/h/b}}$kʃa	ta$_{\mathbf{d/h/b}}$kʃa	tɑː$_{\mathbf{d/h/b}}$kʃa

[23] Remember that backness is equated with the term *color* (Padgett 2002).

(35) shows a set of words illustrating the vowel inventory selected by the constraint ranking relevant for Lithuanian (see section 3.2.1, ranking (27)). This inventory includes the appropriate contrast-coindices for the segments that minimally contrast along a particular dimension.[24] Notice that /eː/ and /oː/ do not have a coindex for vowel duration. This is the expected result since, as seen earlier, these two segments do not minimally contrast for length, and consequently, they do not qualify for assignment of such a coindex. Therefore, /eː/ and /oː/ have the potential to behave differently with respect to the voicing effect because phonetics gets information that there is no minimal contrast for these segments.

3.3.2.4 Proposed architecture

In this section, I incorporate the contrast-coindexing function into the phonological architecture, focusing on the interaction between contrast-coindexing and the other components of the system, namely GEN and EVAL. Furthermore, I consider the mechanism of GEN within the framework adopted here (DT), together with the shape and size of the candidate set. The relevant question is whether the nature of GEN and the candidates is compatible with the contrast-coindexing operation.

I assume that minimal contrast is always assigned to those words that fulfill the requirements in the definition of the contrast-coindexing function. I propose that this coindexing takes place after GEN generates all the candidates, and before EVAL

[24] It is important to emphasize that the coindices do not result from the constraint ranking.

operates over them. The proposed architecture is illustrated in Figure 11 (repeated from Figure 10).

Figure 11. Illustration of proposed architecture augmented with contrast marking step

GEN	=>	**Contrast-coindexing**	=>	**EVAL**
Candidate generation		Minimal contrast is marked		Constraint ranking selects optimal candidate

The proposed architecture includes three different functions or components: GEN, contrast-coindexing and EVAL (cf. Sprouse's Enriched Inputs 1997[25]). Three topics need to be addressed in relation to this architecture: (i) contrast-coindexing and EVAL, (ii) contrast-coindexing and candidate generation, and (iii) lexical gaps.

First, situating contrast-coindexing before EVAL does not limit the power of this evaluator function and the constraint ranking. Under the current framework, contrast systems are the result of output-oriented constraints. Their ranking determines which contrasts surface in a language (see section 3.2.1). The contrast-coindexing proposal posits that different candidates come with different minimal contrasts and their respective contrast-coindexing, but whether one set of contrasts or another is chosen depends on the constraint ranking. Note that if contrast-coindexing was assigned due to some (violable) constraint and thus, was part of EVAL, there

[25] Sprouse (1997) presents an augmented version of Optimality Theory, in which there are two passes of generation. The first generator function, i.e. unification-GEN, can only add material to the underlying representation, not delete anything or change the feature specifications. Unification-GEN provides a set of Enriched Inputs. The second function, standard GEN, can apply other sorts of changes to the Enriched Inputs to provide a set of candidate outputs.

could be cases where a given ranking would favor an inappropriate coindexing due to high ranked constraints. By placing contrast-coindexing before EVAL, the selection of the optimal system of contrasts is still done by this evaluator and the correct coindexing for the members of the system is ensured. This means that minimally contrastive elements will always be contrast-coindexed.

Second, it is important to notice in the architecture developed here that GEN operates independently from the contrast-coindexing function. The latter does not impose any restrictions or conditions on the generator, nor does it limit the number of candidates. However, as shown below, the way the contrast-coindexing function works requires that the number of candidates be finite, rather than infinite as traditional OT assumes (Kager 1999, McCarthy 2002). In order to explain this, let us consider the shape of candidates and the process of candidate generation within the systemic framework adopted here.

As discussed in section 3.2.1.1, the framework developed here follows a systemic approach to contrast similar to that of Dispersion Theory (DT). This has implications for the shape of candidates generated by GEN. More precisely, the main difference from standard OT is that the candidates are candidate languages and they are potentially composed of many word forms. Each word form within a candidate is generated as an individual candidate in traditional OT. In that version of the theory, the generator function modifies the input in a number of different ways so that the result of each of these modifications constitute a candidate (McCarthy 2002).[26] Under a DT systemic approach, each of these modifications applies to a form within a candidate.[27] For example, given the input form /mad/, GEN generates forms such as {mat, mad, mada} and so on. Then, each of these forms will be part of different candidates, together with the forms resulting from other inputs. Thus, the number of word forms within each candidate is determined by the number of inputs. Assuming Richness of the Base (ROTB) (Prince & Smolensky 1993), the input is identical to the free combination of linguistic primitives, i.e., the universal vocabularies of segment structure, prosodic structure and morphology. This means that there are no language-particular restrictions on the input, so that all languages have the same set of potential inputs (McCarthy 2002). Note that this remains true under the contrast-coindexing proposal. The consequence of ROTB for the systemic approach adopted here is that the number of word forms within each candidate are the same for all languages given that the inputs are universal. Also, some candidates might have an infinite number of forms, given the unrestricted number of inputs. Other candidates will have a finite number of forms since some inputs may merge and map to the same output. Still some other candidate might map into a null output.

As for the number of candidates, in traditional OT, this is infinite given the freedom of analysis of GEN. Freedom of analysis refers to the fact that GEN

[26] In the traditional parallel version of OT, GEN generates candidates that may combine the effects of several distinct process, e.g. both a featural change and epenthesis. In certain other variants of OT, such as harmonic serialism (Prince & Smolensky 1993), GEN is limited to performing one change or operation at a time. Here, I follow the traditional parallel version.

[27] Some work on Dispersion Theory has suggested that inputs need not be assumed (Flemming 1995, Padgett 1997, Ní Chiosáin 2001). However, Padgett (2003a,b) indicate that inputs are in fact necessary.

provides very diverse candidate sets (McCarthy 2002). The generator function can modify the input by changing, for example, its featural content or by altering the number of segments. For example, for an input /bid/, GEN emits a set of candidates that include {bid, bit, bi, bide, etc}. If GEN incorporates a recursive operation such as epenthesis, then there is no limit on the size of a candidate, and consequently the number of possible candidates is infinite. The economy of epenthesis observed in different languages follows from constraint interaction rather than from restrictions on the number of candidates. In standard OT phonology, the restrictions on GEN's freedom of analysis stem from structural principles (Kager 1999, Smith [to appear]).[28] The DT systemic approach does not make any assumptions about the power of GEN and the number of possible forms generated by this function. In fact, this approach is consistent with ROTB and GEN's freedom of analysis (Padgett 2003).

The issue of infinity in OT has been addressed by previous work. Several researchers have shown how OT can be computationally implemented. These computational models do not require infinite time to execute (e.g. Ellison 1995, Tesar 1995, Walther 1996, Eisner 1997, Hammond 1997, Karttunen 1998, Heiberg 1999). This work focuses on the implementation of EVAL in relation to the process of candidate creation. This means, that the computational models make use of the

[28] Another type of restriction on GEN, called content-based restrictions, following Smith [to appear], excludes representations that are not well-formed according to the structural principles. Examples include limits on the possible patterns of syllabification and restrictions on the number of epenthetic segments (e.g. Lubowicz 2003).

language's constraint ranking in order to limit the number of candidates that need to be evaluated.

Contrast-coindexing, on the other hand, does not have access to the constraint ranking. Consequently, the issue of infinity within the contrast-coindexing function cannot be overcome by considering computational models like the ones mentioned above. Contrast-coindexing compares pairs of word forms within each candidate language. So, if the number of word forms and candidate languages is infinite, when does contrast-coindexing stop assessing different forms? Here, it should be noted that some work on contrast, namely Contrast Preservation Theory (PCT, Lubowicz 2003) does impose restrictions on the number of candidates. PCT adopts a systemic view so that each candidate has potentially a number of forms.[29] In this theory, each candidate is a scenario, which contains a number of input-to-output mappings. GEN generates the input-scenarios, which map into different outputs. Unlike in standard OT, PCT restricts the power of GEN by proposing bounded epenthesis, which limits the number of segments that can be added to the underlying form (Lubowicz 2003). Thus, only n+1 segments can be inserted by GEN, where *n* is the number of segments in the input to GEN. The result of bounded epenthesis is that the number of candidates is finite. PCT assumes that the number of mappings is finite due to the way in which contrast is evaluated within its system. PCT proposes new constraints that directly assess contrast and militate against neutralization. Some of these constraints require counting of the forms (mappings, input-scenarios or output-

[29] There will also be single form candidates and a null candidate.

scenarios) that violate them, and thus, a limit on the number of these forms is required.[30]

It is worth thinking about the PCT restrictions on the candidate set in relation to the contrast-coindexing function. PCT's proposal limits the number of candidates to a finite number. Contrast-coindexing applies for all candidates but most importantly, it compares word forms within each candidate, under the systemic view that candidates consist of different forms. This implies that infinity could arise not only in the number of candidates but also in the number of word forms in each candidate. Note that the PCT proposal to limit epenthesis is not sufficient to make the number of word forms finite, since infinity not only arises due to unbounded epenthesis but also due to faithful mapping to input forms with unlimited number of segments. Work by Samek-Lodovici and Prince (1999) becomes relevant here.[31] As McCarthy (2002: 218) notes, Samek-Lodovici and Prince "make considerable headway in bringing the infinity of candidates under formal control". Their work solves the infinity issue without requiring that the language's constraint ranking be examined. Their system relies on the difference between potential winners, candidates that are winners under some permutation of the constraints in CON, and perpetual losers, candidates that cannot be optimal under any permutation. With a

[30] Working within PCT, Tessier (2004) proposes an algorithm based on an OT-grammar to find the relevant forms for contrast evaluation. Tessier does not impose any restrictions on epenthesis but instead claims that the forms unnecessary to evaluate contrast can be ruled out by the already-existing OT machinery. Thus, her algorithm relies on the power of markedness and faithfulness constraints to derive the same results as bounded epenthesis. Note that this approach will not solve the infinity issue in relation to contrast-coindexing. Tessier's algorithm crucially depends on the language's specific constraint ranking.

[31] The following offers a simplified description of Samek-Lodovici and Prince (1999).

finite number of constraint rankings, the candidate set contains only finitely many potential winners. On the other hand, perpetual losers within the candidate set may come in infinite numbers, and often do: candidates may contain any number of epentheses and recursive expansions. Thus, Samek-Lodovici and Prince argue that if potential winners and perpetual losers can be separated in advance, then EVAL will never have to operate over an infinite set of candidates. Samek-Lodovici and Prince develop the necessary and sufficient conditions to establish whether a candidate is a winner or a loser just by applying the constraints in CON, without reference to the ranking. Their main idea is a generalization of the notion of harmonic bounding (Samek-Lodovici 1992, Prince & Smolensky 1993). I refer to their proposal as *Harmonic Bounding through CON*. A candidate $cand_1$ harmonically bounds $cand_2$ relative to some input, if $cand_1$ incurs a proper subset of $cand_2$'s violation marks. Regardless of the ranking, this makes $cand_2$ worse than $cand_1$. Any harmonically bounded candidate is a perpetual loser. Furthermore, several candidates may collectively harmonically bound another. Samek-Lodovici and Prince refer to this as the bounding set. Thus, a perpetual loser is defined as a candidate that has a non-null bounding set. A potential winner is a candidate that has only a null bounding set. The authors further show that bounding sets are limited in size. They need be no larger than the number of constraints in CON, and are typically smaller. This indicates that their system is able to identify in a finite and efficient way whether a candidate is a winner or a loser.

The crucial result is that perpetual losers can be identified by inspecting the candidates and the constraints without reference to ranking permutations.[32] Losers can be identified before the application of EVAL. With losers out of the set of candidates, EVAL now only considers the finite set of potential winners. This state of affairs, which derives from Samek-Lodovici and Prince's approach to infinity in OT, is compatible with the contrast-coindexing function. Following the system proposed by Samek-Lodovici and Prince, contrast-coindexing would apply once the perpetual losers have been removed from the set of potential winners. This implies that only potential winners, i.e., a finite set, would be assessed for minimal contrast. Samek-Lodovici and Prince's approach allows for contrast-coindexing to apply over a finite set of candidates and also over a finite set of word forms within each candidate. This results from the fact that *Harmonic Bounding through CON* can set limits on the number of segments of potential winner candidates. It can restrict not only the number of segments inserted by epenthesis but also, the number of surface segments that correspond or come from the input (i.e. not inserted segments). Outputs with infinite number of segments, whether inserted or already present in the input, will be ruled out before EVAL applies.[33]

Samek-Lodovici and Prince's proposal, *Harmonic Bounding through CON*, is incorporated into the architecture developed here as shown in Figure 12.

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[32] Samek-Lodovici and Prince make use of the Recursive Constraint Demotion algorithm (Tesar 1995, Tesar & Smolensky 1998) to identify perpetual losers from CON and a set of candidates.

[33] Ní Chiosáin & Padgett (to appear) suggest that the infinity issue can be solved by imposing an absolute upper limit on the length of the forms in the set of candidate outputs. This limit would take the form of a restriction on GEN. However, Ní Chiosáin & Padgett do not explain how this restriction would be implemented. Note that Samek-Lodovici & Prince reach the same result without imposing any restrictions on GEN.

Figure 12. Proposed architecture including Samek-Lodovici and Prince's proposal

GEN => **Harmonic Bounding through CON** => **Contrast-coindexing** => **EVAL**

Finally, another important aspect of the proposed architecture is that it assumes that the output of phonology is the set of possible (phonologically well-formed) words according to the language-specific constraint ranking, as explained in section 3.2.1.1. This set includes possible words that are not assigned meaning, i.e., lexical gaps (see also Lubowicz (2003), Padgett (2003a, b), Ní Chiosáin & Padgett (to appear) for a similar treatment of lexical gaps). I assume that lexical gaps are part of the optimal candidate for a given grammar and accordingly, these words are also taken into account for the assessment of minimal contrast through contrast-coindexing. Thus, the fact that a word lacks a minimal pair due to a lexical gap does not imply that the segments that would differentiate these two words do not minimally contrast for the relevant dimension of contrast. For instance, in Spanish a trill and a tap can occur intervocalically and give rise to lexical contrasts, e.g. [foro] 'liner' vs. [foɾo] 'forum'. But some words that contain an intervocalic trill, e.g. [gara] 'claw', do not have a minimal paired word that differs only in the rhotic, so there is not a word [gaɾa] in the Spanish vocabulary. However, this lexical gap does not block the assignment of a rhotic contrast-coindex for the trill in [gara], since its relevant minimal pair [gaɾa] is a possible word in the Spanish phonology. This treatment of lexical gaps is in accordance with the results from Lithuanian, where the minimal contrast effect was observed in nonsense words, i.e., words that could be part of the language but do not have any meaning.

Related to the treatment of lexical gaps, it is relevant to consider lexical frequency effects. These effects would potentially distinguish between lexical gaps and actual words of the language. For example, Scarborough (2006) tested the degree of nasalization of French vowels in *easy* words, i.e., words with high frequency and few, low-frequency phonological neighbors, and in *hard* words, i.e., words with low frequency and many, frequent phonological neighbors. She found that hard words exhibit more nasal coarticulation than easy ones. Scarborough relates these findings to the suggestion that speakers might produce additional coarticulation in order to increase the intelligibility of hard words. Interestingly, the effect of lexical confusability and coarticulation emerges only for vowels that have the phonemic nasal vs. oral contrast. These effects should be incorporated into any model of the phonology-phonetics interaction. However, due to the focus of this study, I leave this matter for future research. The relevant point here is that lexical frequency can have an impact on production. Lexical gaps are items with no frequency at all. Thus, they or forms with which they form minimal pairs might behave differently from items that do not have the status of lexical gaps.

3.3.2.5 Consequences of contrast-coindexing

This section explores some of the consequences of contrast-coindexing and the phonological architecture proposed in section 3.3.2.4. More concretely, the focus is on the implications for cases of contextual neutralization and free variation, cases where contrast plays a role. I show that, in fact, the system developed here makes the right predictions for these two patterns.

The consequences of contrast assessment at the word level seem to be in accordance with the result of contextual neutralization, by which a certain contrast is lost in a given environment. When a contrast is neutralized, there are no minimal pairs that contain that contrast in the neutralizing context. Then, according to the word-level assessment requirement, no contrast relation is established in that environment, and contrast-coindexing does not apply, even if in other contexts the contrast does exist. Neutralization of oral and nasal vowels illustrates this point. Some languages that contrast oral and nasal vowels do not show this opposition in the context of a following nasal consonant, where only nasal vowels occur (e.g. Brazilian Portuguese). Such a language would have the hypothetical words /pa/, /pã/ and /pãn/ but not */pan/. The presence of a nasal consonant leads to neutralization of the vowel contrast, and it is assumed that nasality is not contrastive for vowels in this environment. However, nasality is still minimally contrastive in other syllables or words without the neutralizing context. Therefore, the provision that minimally contrasting segments must appear in minimal pairs that differ in the relevant segments in order to be contrast-coindexed prevents vowels before nasal consonants from getting an index for contrastive nasality. For example, two words such as /papãn/ and /pãpãn/ that form a minimal pair get a nasal contrast-coindex for the first vowel (i.e., /pa_{n}pãn/ and /pã_{n}pãn/). The second vowel, which occurs in the neutralizing environment is not contrast-coindexed for nasality. The language does not have words such as */papan/ or */pãpan/ which would differ in the second vowel's nasality. Coming back to the monosyllabic words, the following contrast-coindices would be assign: pa_n , $pã_n$ and pãn, where subscript *n* stands for the contrast-coindex for nasality. Contrast-coindexing is able to identify neutralization cases and their lack of minimal contrast.

It is also worth noting that free variation will not pose a problem to the contrast-coindexing proposal. Free variation refers to cases where a given contrast in neutralized but the precise realization of the neutralized form varies among the merged segments. Gooniyandi (Steriade (1995) citing Hamilton (1993)) presents an instance of free variation in the realization of the alveolar and retroflex consonant contrast. In this Australian language, apico-alveolar and retroflexes contrast only after a vowel. Word-initially and after a consonant, there is free variation between the two articulations.[34] The data in (36) from Hamann (2003) and McGregor (1990) illustrates these facts. (36)a) shows the contrast in intervocalic position between the apical and the retroflex nasals. (36)b) includes two examples of neutralization and free variation between the alveolar and retroflex productions word-initially.

(36) Apico-alveolar and retroflex distribution in Gooniyandi

(a) [wi**l**a]	'OK, finish'	[wi**ɭ**a]	'back'
[ju**d**u]	'straight'	[ju**ɖ**u]	'dust'

[34] Here I abstract away from a process of consonant harmony triggered by alveolars and retroflexes.

(b) /laɲgija/ [**l**aɲgija~**ɭ**aɲgija] 'midday'

/duwu/ [**d**uwu~**ɖ**uwu] 'cave'

Within Optimality Theory, free variation has been analyzed as the result of constraint re-ranking due to partial ordering (Antilla 1997) or stochastically-ranked constraints (e.g. Boersma 1998, Boersma & Hayes 2001). According to this view of free variation, one single constraint ranking will not select the two variants as optimal outputs. Different rankings choose one variant or the other. Thus, free variation does not give rise to minimal pairs of words since the relevant contrast is neutralized and, even if the realization of the resulting form varies, it will never give rise to two distinct words, i.e., two different lexical items that differ in the neutralized segments. Thus, forms in free variation due to the neutralization of a given contrast do not fulfill the requirement to be assigned a contrast-coindex for that contrastive dimension.

3.4 Dimensions of contrast

So far, when talking about contrast and phonetic patterns, I have focused on cases where the dimensions of contrast are length or vowel feature-like properties. In this section, I discuss the notion of dimensions of contrast and consider what properties qualify as such and might, consequently, be subject to contrast-coindexing. Before continuing, recall that the relevant notion in this dissertation is that of minimal contrast. In Lithuanian, /eː, oː/ do not minimally contrast for length. However, length is still contrastive in the vowel system. In Section 2.3.2, I presented evidence showing that these unpaired vowels /eː, oː/ pattern with long vowels for different phonological processes. So, for those relevant phenomena /eː, oː/ are long and behave as the other long vowels to the exclusion of the short ones.

According to the definition of contrast-coindexing (see section 3.3.2.1), two segments must differ in just one dimension of contrast in order to be minimally contrastive and get a contrast-coindex for that dimension. The idea of dimension of contrast is taken from Dispersion Theory (Flemming 1995), where a dimension of contrast is defined as an acoustic dimension (vowel formants, nasality, VOT, etc). However, possibly articulatory parameters or dimensions are relevant for some other contrasts, for example, for place of articulation.[35] The main point is that these dimensions of contrast are defined in physical terms, whether acoustic or articulatory. Crucially, these dimensions have to be distinct to the human ear since they are relevant to language (Flemming 1995). Dimensions should be perceptually significant. Moreover, the possible dimensions of contrast are universal, but languages vary in the use they make of each dimension, i.e., whether they establish contrasts or not. Duration and sub-segmental feature-like properties, such as the vowel properties discussed for Lithuanian, fall under this notion of dimension of contrast. It is important to notice that the dimensions of contrast are not equivalent to features. This is a departure from the original conception of features in distinctive

[35] I do not develop further here how this idea would be implemented in the Dispersion Theory framework.

feature theory (cf. Jakobson et al. 1952, Chomsky & Halle 1968). In fact, dimensions of contrast are seen as the source of the interface between the symbolic phonological representation (e.g. through features) and phonetics (i.e., the physical implementation). This means that dimensions have a mediary or relational function between phonological features and the physical realization of sounds, and they serve as a means to relate both components.

I illustrate the difference between features and dimensions by examining vowel features and vowel dimensions of contrast. Let us focus first on vowel height. In a traditional featural analysis for this property, vowels are distinguished by their specification for the features [high] and [low]. For example, a high front vowel would be [+high, -low] and a low front vowel would be [-high, +low].[36] Notice that, if minimal contrast was based on features, the featural representations for these two front vowels would indicate that these vowels are not minimally contrastive because they differ in two features. This is not a desirable outcome since it misses the insight that these two vowels *only* differ, i.e., are minimally contrastive, in terms of their height. The dimensions of contrast in the contrast-coindexing proposal are able to capture the presence of minimal contrast between a high front vowel and a low front vowel. Under this approach, height conforms to a property, which correlates with F1 as the physical dimension, along which contrasts are assigned (cf. Clements 1991).[37] The vowel inventory of the Australian language, Maranungku, will serve as an

[36] These two vowels would also be specified as [-back].

[37] Clements (1991) views vowel height as a uniform phonetic dimension that can be repeatedly subdivided. Each division is implemented by a feature [$open_i$]. He bases this approach on phonetic and phonological grounds.

example to clarify this asymmetry between features and dimensions of contrast. The Maranungku vowel system together with the featural specification for [high] and [low] is given in Table 17, following Archangeli (1988).

Table 17. Maranungku vowel inventory and (partial) featural specification

	Front	Central	Back
High	i		u
Mid		ə	
Low	æ		ɑ

	High	Low
i, u	+	–
ə	–	–
æ, ɑ	–	+

In terms of features, the front vowels /i/ and /æ/ are distinct with respect to their specification for both [high] and [low]. These two pairs of vowels do not differ in any other feature. The consequence of the featural representation is that /i, æ/ would not be minimally distinct because they have different values for two features. Consequently, a system like that of Maranungku would lack a minimal contrast for height for its front vowels. This is because the language does not have a front mid vowel, which would differ from high and low vowels in only one feature.

On the other hand, the analysis of minimal contrast in terms of dimensions of contrast identifies the relevant vowel pairs from Maranungku, i.e., /i-æ/ and /u-ɑ/, as minimally contrastive for their F1 value, which corresponds with vowel height. The contrast-coindexing proposal treats height as a single dimension along which a number of contrasts might exist. For instance, Maranungku front vowels show two degrees of contrast within the height dimension, i.e., high and low, since there are no mid front vowels in this language. Consequently, high and low front vowels differ just in their height and are identified as minimally contrastive for this dimension by the contrast-coindexing function. The same applies to the back vowels. The result is that the Maranungku vowel system has a minimal contrast for height.

This illustration suggests that in a way, dimensions of contrast may correspond with groups of traditional features, e.g., height encompasses the group of features consisting of [high] and [low], rather than the individual features. This is reminiscent of work within the Feature Class Theory by Padgett (2002). Padgett develops a framework where features are grouped into sets that he calls feature classes. Phonological constraints make reference to these sets and affect the individual features directly.[38] These sets are not arbitrary lists of individual features but rather have a phonetic basis, an assumption carried over from traditional feature theory (Clements 1985, Sagey 1986). For example, he defines the feature class Height as the union of the [high] and [low] features. Padgett also proposes the feature class Color, which is composed of the features [back] and [round]. This class is similar to the backness dimension of contrast introduced in the analysis of Lithuanian. This dimension is further explained in a later section, after considering work by Flemming (2005).

Before moving on into other dimensions of contrast, it is worth noting that the approach to dimensions developed here share some ideas with work by

[38] Padgett's proposal differs from traditional feature classes in that for phonological processes that single out a feature class, it allows individual features' involvement to be violable. His Feature Class Theory is based on cases of partial class behavior and dissimilatory patterns.

Flemming (2005) on natural classes regarding the role of features. Flemming (2005) argues against the traditional account of natural classes based on feature theory (e.g. Kenstowicz & Kisseberth 1977). Natural classes refer to classes of sounds that undergo the same structural change in the same environments, or condition some change. Flemming develops a new analysis of natural classes in terms of Optimality Theory. He claims that classes that can be involved in some process are determined by and specified in the constraints. Under his view, all members of the class must be marked in the same environment, according to one or more constraints. Natural classes can be derived from sets of similar constraints. Flemming's conditions for natural classes refer only to the contents of the constraint set. They do not refer to feature specifications. Features play a minimal role in characterizing natural classes.

Coming back to the dimensions of contrast, in the analysis developed for Lithuanian in section 3.3, backness was considered as a relevant dimension for the vowels in this language. I argued that the Lithuanian high vowels /i/ and /u/ are minimally contrastive for backness.[39] On the other hand, as for their featural representation, these two high vowels are characterized as differing in terms of their values for [back] and [round], i.e., /i/ being [-back, -round] and /u/ being [+back, +round]. This means that /i, u/ differ in their values for two features. But note that this representation is compatible with the status of backness as a dimension of contrast since, as mentioned earlier, these dimensions do not necessarily correspond with features. Here, I assume that contrast along the backness dimension can be

[39] The low vowels /ε, a/ are also minimally contrastive for backness, as well as their long counterparts. I focus on the Lithuanian high vowel just for the sake of simplicity.

manifested in differences for the values of both [back] and [round]. In other words, following previous work on the Color feature class by Padgett 2002 and others (e.g. Mester 1986, van der Hulst and Smith 1987, Odden 1991), who view these two features as forming some kind of phonological constituent, I argue that contrasts along this dimension are based on differences in F2, which can be manipulated by modifying the tongue backness position or the lip rounding of the sounds (cf. Flemming 1995). The result is contrast along a single dimension that I have called backness but a more traditional term would be color.

Part of the motivation for this dimension is based on acoustic facts, which are summarized here.[40] Front and back vowels differ primarily in the frequency of the second formant. Front vowels have a high F2 and back vowels have a low F2. Lip rounding has the effect of lowering all formants (Stevens 1998). Thus, lip rounding during the production of a back vowel results in an even lower F2. Consequently, the maximally distinct F2 contrast is between front unrounded vowels, which have the highest F2, and back rounded vowels, which have the lowest F2 (Flemming 1995). Together backing and rounding contribute to enhancing the distinctiveness of contrasts based on their acoustic correlate F2 (Stevens, Keyser, and Kawasaki 1986). In fact, these articulatory dimensions are traded off in the pronunciation of vowels across dialects, speakers, and phonetic contexts (Perkell et al. 1993, de Jong 1995).

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[40] Padgett (2001) gives a comprehensive overview of these facts.

However, languages might have a contrast in rounding for vowels, independently of their backness/color. For instance, Turkish vowels contrast both in backness and rounding. The Turkish vowel inventory is given in Table 18.

Table 18. Vowel inventory in Turkish

	Front		Back	
	Unround	Round	Unround	Round
High	i	y	ɯ	u
Non-high	e	ø	a	o

According to the dimension of backness/color defined above, the elements of this system would be minimally contrastive for it. This would assume that this space is divided up into a four-way contrast. However, it might be desirable to capture the difference in rounding between /i, y/ on the one hand, and /ɯ, u/ on the other. Otherwise, /u/ in a system like that of Lithuanian and /u/ in a system like that of Turkish would have the same minimal contrast representation. This would fail to reflect that /u/ in Turkish further contrasts for rounding with /ɯ/. This distinction might be important for patterns of rounding harmony. Kaun (1995) notes that most systems with rounding harmony are those with contrasts such as /i/ vs. /y/ and /ɯ/ vs. /u/.

This suggests that rounding qualifies as another dimension of contrast for vowels, independently from backness/color. Rounding as a dimension of contrast seems to correlate with the articulatory property of lip rounding. A language like Lithuanian has contrast along the backness/color dimension only. Thus, /i, u/ in this language are not contrastive for the rounding dimension. On the other hand, a language like Turkish has contrasts along both backness/color and rounding. Remember that the use languages make of dimensions might vary and some may not have contrasts along some dimension (e.g. not all languages have contrasts in length). For example, there could be a language that has a two-way contrast for backness/color and a further two-way distinction for rounding, which would apply to both front and back vowels. This would give us a vowel system like that of Turkish. The minimal contrast representation would be /$i_{\mathbf{br}}$, $y_{\mathbf{br}}$, $ɯ_{\mathbf{br}}$, $u_{\mathbf{br}}$/, where b-subscript stands for backness/color and r-subscript stands for rounding.

Here, it is also important to consider vowel length contrast and duration as a dimension of contrast. The analysis of Lithuanian identifies duration as another dimension of contrast that might be employed by languages, giving rise to a contrastive distinction between short and long vowels. Duration is seen as a space along which languages might establish a two-way contrast.[41] Note that this dimension is defined in acoustic terms but it is not physical duration as measured in ms. Duration as a dimension of contrast relates long and short vowels, which are symbolically represented by their number of moras, with their phonetic implementation. Furthermore, minimal contrast in length is marked by a contrast-coindexing that is assigned after assessment of the duration dimension.

To recapitulate, four vocalic dimensions of contrast have been introduced so far, namely height, backness/color, rounding and length. At this point, it is important

[41] Remember that in the DT analysis developed in section 3.2.2, this limit is achieved by placing $SPACE_{Vdur}$ constraints higher ranked than $SPACE_{Vdur}\geq 1$ in GEN.

to emphasize that the dimensions of contrast relevant for contrast-coindexing correspond to the dimensions referred to in the Dispersion Theory analysis of vowel inventories. Consequently, when stating the dimensions relevant for minimal contrast, we are basically inquiring into the dimensions from which inventories, both vocalic and consonantal, draw their contrasts. Not all languages have the same contrasts and some dimensions might not be relevant in some cases. This suggests that although dimensions of contrast are universal, languages vary with respect to the use they make of these dimensions. As mentioned earlier, what all dimensions of contrast share is the possibility of giving rise to distinct contrasts, which can be captured by the human ear.

Other dimensions include those for which consonants can be contrastive. The notion of Feature Class from Padgett (2001) is useful to conceptualize these dimensions, which might correspond to sets of traditional sub-segmental features. But again, a dimension of contrast does not equate to each partition, i.e., each feature, but rather to the more general space that can be sub-divided. For example, as some of the data discussed in section 4.4 will show, apical consonants might contrast in their retroflexion, i.e., some might be apico-alveolar without any retroflexion, while some others might be apico-retroflex. For these two types of consonants the only contrastive difference is in terms of their retroflexion, which roughly corresponds with the orientation of the tongue tip during articulation. Under the analysis proposed here, apico-alveolar and apico-retroflex consonants are minimally contrastive for retroflexion and therefore, they are contrast-coindexed for this dimension.

However, dimensions of contrast may go beyond articulatory and acoustic features of vowels and consonants and include properties that might constitute a contrast at levels higher than the segmental one. In order to clarify this point, I discuss several 'supra-segmental'[42] potential candidates for dimensions of contrast, namely lexical accent (i.e. stress & lexical pitch-accent) and tone. First, I consider lexical accent, which includes stress and pitch-accent, as a possible dimension of contrast.

Oftentimes stress is defined as the linguistic manifestation of rhythmic structure rather than as a contrastive element (Hayes 1995). In these cases, stress is seen as having mainly an organizing function within the system. However, stress may also convey lexical contrast. For instance, in some languages, such as Russian, the position of stress is unpredictable and this brings about a contrast in words like *bágrit'* 'to spear fish' and *bagrít'* 'to paint crimson'. But stress is not lexically contrastive in all languages. In other languages such as Czech, French and Polish, stress is fixed and cannot constitute a lexical contrast (Lehiste 1970, Hayes 1995). Here, the focus is on instances of lexical stress, i.e., languages like Russian where stress is contrastive. Lexical stress systems together with pitch-accent systems, like that in Japanese, are usually cast together under the term *lexical accent* (Alderete

[42] The use of supra-segmental here merely refers to the fact that these properties are not sub-segmental features. This use should not be confused with the more traditional one that groups stress, tone and length together (e.g. Lehiste 1970).

1999). Similarly to stress in Russian, accent in Japanese is likewise contrastive and yields contrasts such as *hási* 'chopsticks' vs. *hasí* 'bridge', where the accent mark indicates the pitch accent. A further motivation for including systems such as those in Russian and Japanese under the same rubric of lexical accent is that they display phonological similarities. These similarities include edge effects, culminativity, and common and limited accentual processes (Alderete 1999 and references therein). While accent systems share a number of phonological properties, it is important to note that the phonetic correlates to accent may be different. That is, accent systems have similar phonological properties, but the phonetic cues to accent may differ from language to language. Thus, while amplitude and duration play an important role in the realization of accent in Russian (Jones & Ward 1969), the main cue for Japanese accent is changes in pitch (Beckman 1986).

The representation of accent is not a settled issue. The phonological similarities between stress and pitch-accent systems suggest a unified phonological representation allowing for direct comparison. On the other hand, the different phonetic correlates of accent support different phonological representations for accent, under the assumption that the phonological representation informs the phonetic realization. Consequently, the representation of accents varies in the literature on the topic. Some work gives non-stress accents an autosegmental representation with linked tones (e.g. Pulleyblank 1986, Poser 1986, Archangeli & Pulleyblank 1984), assuming a different analysis for stress-accent languages. Other approaches, especially those in the metrical literature, adopt a single phonological representation for both accents, for example as a prominence on the metrical grid (Alderete 1999). Despite the lack of a clear understanding of its representation, accent seems to constitute a dimension of contrast. However, whether accent corresponds to a single dimension or to different phonetic correlates cannot be determined at this point. If accent constitutes a dimension of contrast, then it is expected to potentially give rise to minimal contrast effects in phonetics.[43] This could be tested by looking at languages with lexical accent and analyzing the impact of this accent on phonetic patterns that modify its correlates (see above for Russian and Japanese). If accent behaves like other minimal contrasts, then the prediction is that effects similar to the one found in Lithuanian will be observed. I am not aware of any study testing this hypothesis. Note that Berinstein's (1979, see discussion in section 2.2.2) experiment on stress in different languages did not consider systems with contrastive stress. Stress in Kek'chi and Cakchiquel, the languages analyzed by Berinstein, does not constitute a contrast. All in all, further experimental research is needed to clarify the status of accent as a dimension of contrast and possibly, subject to contrast-coindexing.

As for tone, the interest lies in the use of this property to convey lexical contrasts. In tone languages, tone has a contrastive function in the sense that it can determine the identity of the lexical items. Examples of tonal distinctions are found in Mandarin Chinese [má:] 'mother', [mǎ] 'hemp', [mà] 'horse' and [mâ] 'scold'

[43] Chapter 4 shows that minimal contrast is also relevant for phonological processes, not only for phonetic patterns.

(Gussenhoven 2001).[44] The phonetic correlate of tone is pitch: tonal languages make use of changes in pitch to mark lexical dinstinctions. Tone involves linguistically relevant pitch events. This suggests that tone can be considered as a dimension of contrast and thus be subject to contrast-coindexing since it can be defined in acoustic/articulatory terms. The resulting prediction is that contrastive tone may influence a phonetic pattern that modifies pitch, in a similar fashion to how phonemic length limits the voicing effect in Lithuanian. Indeed, this prediction is borne out. Evidence comes from Yoruba, a language in which tone is phonemically contrastive. The relevant phonetic pattern is the tendency of a vowel's pitch to be lower before a voiced stop. Hombert, Ohala & Ewan (1979) report that this effect is present for English speakers. However, they show that in Yoruba this effect is substantially suppressed. The F_0-perturbing effect of prevocalic consonants is minimized in Yoruba. The pattern in Yoruba can be understood as resulting from the presence of contrastive tone in the language. That is, the fact that pitch is used in the system to mark contrasts limits the degree of the phonetic effect of voiced stops on pitch. The case of Yoruba thus supports the view of tone as a dimension of contrast.

3.5 The phonology-phonetics interaction

The contrast-coindexing proposal developed in this dissertation claims that the status of participating in a minimal contrast must be represented in the phonological representation. Further, phonetics has access to this aspect of representation and can

[44] Here I do not consider other uses of tone within the intonational system of a language, for example to indicate discourse meanings or mark prosodic phrasing (Gussenhoven 2001).

make use of this phonological information in determining the outcome of phonetic patterns. This claim was based on experimental results from Lithuanian that showed that the result of the phonetic voicing effect depends on the presence of minimal length contrast for each vowel.

With this claim in mind, this section elaborates on a possible way to understand the phonology-phonetics interaction that builds on the findings presented in chapter 2 and the proposal developed in the previous sections. First, I address the issue of whether all phonetic patterns are potentially sensitive to all contrastive properties. Based on previous literature, I draw the conclusion that phonetic patterns may be influenced only by properties that are affected or modified by the pattern in question. For example, duration in the case of Lithuanian. Next, I consider a phonetic model suitable for capturing the facts from Lithuanian, and the more general claim about the role of minimal contrast. The window model (Keating 1990) explicitly relates variability in coarticulation with contrast. I present revisions of this model (Guenther 1995a, Byrd 1996), which extend the original proposal to account for different patterns. I hypothesize that the effect of minimal contrast on the voicing effect results from differences in intergestural timing. Byrd (1996) and Saltzman & Byrd (2000) develop the idea of a phase window for intergestural timing. This model is presented together with the Task Dynamics framework within which the phase window model is developed.

3.5.1 Phonetic patterns and minimal contrast

Evidence from the literature on coarticulation suggests that a phonetic pattern is not sensitive to all dimensions of contrast, but only to those relevant to the given pattern. Before reviewing evidence for this claim, it is necessary to consider in more detail some of the characteristics that define a phonetic pattern.[45] First, phonetic patterns are not necessarily universal. Such patterns actually tend to be language-specific, including the voicing effect (Keating 1985). Second, phonetic patterns are gradient, given that the kind of elements that they manipulate are continuous and temporal. Third, phonetic patterns act along physical dimensions or parameters, articulatory or acoustic. For example, coproduction refers to the specific timing between different articulatory gestures that may lead to changes in some physical aspect of the sounds/gestures involved. Which aspects are affected depends on the gestures involved. Thus, coproduction of a nasal (i.e. velum) gesture and a tongue body gesture corresponding to a vowel may result in more or less nasality during the vowel. On the other hand, coproduction between a tongue tip or blade consonant gesture and a back vowel gesture causes the vowel's F2 to lower so the vowel is acoustically more front (Flemming 1997).

The main conclusion from the literature on contrast and coarticulation is that not all cases of coarticulation are sensitive to, i.e., influenced by, the same phonological contrasts. Coarticulation is restricted when it modifies the dimension along which the contrast operates. For example, coarticulation might affect nasality

[45] The term phonetic process is also used in the literature. Here, I choose to use the term phonetic pattern to differentiate these patterns from phonological processes.

or F2, which correlates, for instance, with vowel backness and rounding. Then, this phonetic timing pattern is concerned only with contrasts based on those dimensions, in this case oral vs. nasal vowels, and back vs. front and round vs. unround vowels. The pattern just described follows from the observation that the degree of coarticulation is restricted in those cases where a given contrast might be endangered, i.e., the contrast might not be distinct enough. The functional motivation for this articulatory behavior is to maximize the distinctiveness of contrasts, i.e., to ensure sufficient distinctiveness among them (cf. Engstrand 1988, Manuel & Krakow 1984, Manuel 1999). In what follows, I review the main studies on contrast and coarticulation that document the behavior just explained.

Flemming (1997) tests the influence of the presence of a back vs. front vowel contrast on C-to-V coarticulation. His study analyzes /t/ + /u/ sequences, where the coronal consonant has a high F2 locus and the back vowel has a low F2. Coarticulation between these two elements results in lowering of F2 for the vowel[46], i.e., the vowel becomes more front. Flemming examines the effect of /t-u/ coarticulation in two groups of languages: one group has a contrast between /u/ and /y/, which involves small differences in F2, and another group lacks this contrast. His results show that the C-V coarticulation is smaller in the first group of languages, where a change in the F2 value for the vowel could endanger the /u/-/y/ contrast. In this case, the vowel contrast operates along F2 (backness) and the phonetic pattern, namely C-V coarticulation, modifies this same dimension.

[46] The F2 locus for the consonant is potentially also affected by coarticulation with a back vowel.

Öhman (1966) analyzes V-to-V coarticulation in V_1CV_2 sequences. The two relevant vowels, V_1 and V_2, alternate in backness so coarticulation is equated with the behavior of the V_1-C and C-V_2 F2 transitions. Here, I focus on the results for the V_1-C transitions. Öhman tests three different languages: English, Swedish and Russian. For the first two languages, the V_1-C F2 transitions are dependent on the backness of the following vowel V_2. When V_2 is high, the F2 transition raises into the consonant, and when V_2 is low, the F2 transition falls into the consonant. However, Russian does not show this relationship between V_1-C F2 transitions and V_2 backness, i.e., there is no variation in the F2 transitions depending on V_2 backness. The answer to this asymmetry between Swedish and English on the one hand and Russian on the other is found in the consonantal contrast available in the languages. Russian, unlike the other two languages, contrasts palatalized and non-palatalized consonants. These consonants differ mainly in their F2 transitions, as a result of the different tongue gestures. Modification of the F2 transitions by V-to-V coarticulation would decrease the distinctiveness between palatalized and non-palatalized consonants in Russian. Thus, Öhman's study illustrates another case of the influence of contrast along the F2 dimension on coarticulation affecting this same dimension.

Cohn (1993) and Herbert (1986) report that contextual nasalization is more limited in languages with contrastive nasal vowels than in languages without such a contrast. Contextual nasalization occurs in the environment of nasal consonants as the result of a timing configuration by which the velum is open before or after the oral closure. As a consequence, the neighboring vowel is partially nasalized. Therefore, in cases where contrastive vowel nasalization restricts contextual nasalization, both the contrast and the phonetic pattern modify the same dimension, namely vowel nasality. Nasality results from the coordination between a vowel gesture and an open velum.

Further studies also show that the influence of contrast on coarticulation is limited to those cases where both operate along the same dimension (see Manuel 1999 for a review). Then, if this is the case, the prediction is that there will be no cases where a given contrast restricts a phonetic pattern that affects a dimension unrelated to the contrast. For example, a pattern modifying duration will not be restricted by a contrast in vowel backness. This implies that a phonetic pattern is precluded from being sensitive to properties that are irrelevant for the contrast to which it corresponds. Clearly, the phonetic model adopted and the interface between the phonological representation and the phonetics are crucial in allowing for this restriction or correlation between the phonetic pattern and phonological contrast. As for all contrasts in general, there must be some phonetic correlate for a particular *minimal* contrast. This correlate operates along the relevant dimension or has consequences for this dimension. In section 3.5.2, I develop this idea within an specific model and suggest possible extensions of the model to capture the facts just presented, namely that phonetic patterns may be influenced by contrast along specific dimensions.

3.5.2 A model for the phonology-phonetics interaction

This section develops a model of the phonology-phonetics interaction in light of the findings with respect to minimal contrast and the claim that this kind of contrast must be encoded in the phonological representation. This study adopts the view according to which phonology and phonetics are two independent, but interrelated, components of the grammar (see chapter 1 for a more detailed description). The focus here has been on the influence of phonology in phonetics. As argued earlier, I assume that this influence is mediated through the phonological representation that needs to explicitly include all of the phonological information relevant for the phonetics. The main finding of the experiment reported in chapter 2 is that minimal contrast can determine phonetic patterns, and thus, this contrast has to be incorporated into the representation. This is formalized as a contrast-coindexing function.

Given the focus of this study, I present a model for the interaction from the phonology to the phonetics. I do not assume that the same model accounts for the phonetic influence on phonology. The basic structure of the model developed here follows work within the window model as proposed by Keating (1990) and extended by Guenther (1995), among others. Furthermore, I argue that phase windows (Byrd 1996) as developed within Task Dynamics by Saltzman & Byrd (2000) appropriately capture the kind of timing variability observed for the voicing effect. I propose that contrast-coindices, among other factors, determine the size of windows, in general, and of phase windows, in particular.

Keating (1990) presents the window model, which has been further developed by Cohn (1993), Guenther (1995a, b) and Cho (2001), among others. The window model was developed to account for quantitative variability in coarticulation phenomena. It relates contrast with coarticulatory resistance and aggression.[47] Under this view, each segment feature projects a target window, i.e., a range of possible articulatory/acoustic values.[48] This window allows the featural realization to vary within a certain range. Thus, this range corresponds with contextual variability of a feature value. A narrow window allows for only small contextual variability, and a wide window reflects extreme contextual variability. The interpolation function finds the optimal path through a sequence of windows, so narrower windows impose stronger constraints on possible paths. Consequently, features that project narrower windows will have greater articulatory resistance and aggression. Features with wider windows will be more susceptible to coarticulation.

One shortcoming of the original window model is that it allows for one fixed size window and does not consider possible resizing due to linguistic and extra-linguistic factors (Keating 1996, Cho 2001). For example, Cho (2001) notes that prosodically-conditioned coarticulatory variations require a flexible window such that its size can vary depending on prosodic conditions. A possible solution to this problem has been presented by Guenther (1995a, b). Guenther (1995a, b) develops a

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[47] Coarticulatory aggression refers to the ability to affect neighboring segments.

[48] Work by Zsiga (1995, 1997) has proposed a mapping from phonological features into phonetic gestures. Her approach is restricted to articulatory dimensions. Under the contrast-coindexing proposal, dimensions of contrast might be defined in articulatory or acoustic terms. For this reason, Zsiga's model is too limited to capture the view pursued here.

neural net model of articulation that incorporates and expands the window concept.

In Guenther's model, the target for a speech sound consists of a range of acceptable values. These ranges function similarly to Keating's windows. More precisely, Guenther posits a convex region theory for speech targets. A convex region is a multidimensional region such that it can be defined in every orosensory dimension. Under this theory, targets for each speech sound are specified in the form of convex regions in orosensory space. In Guenther (1995a), the orosensory dimensions are quite closely related to the tract variables in the Task Dynamics model (Saltzman & Munhall 1989), including tongue body horizontal position, tongue body height, tongue tip horizontal positions, tongue tip height, lip aperture, etc. However, in subsequent versions of his model, Guenther includes acoustic targets (Guenther 1995b).

Each convex region target specifies a range of acceptable positions along that orosensory dimension, which allows variability that arises from constraints such as coarticulation effects in the spirit of Keating's window model. Large target ranges give rise to shorter movements and more contextual variation. An important development of Guenther's model compared to the original window model proposal is that it allows for resizing of the target range. In the former, the window-like range of targets can be resized as an implementation of Lindblom (1990)'s hyper-and hypo-articulation (Guenther 1995a, Keating 1996, Cho 2001). A small range or window is a kind of hyperarticulation because it requires more careful speech to attain the smaller target and limits coarticulation. Slow speech, phrasal prominence and other prosodic conditions, which result in a decrease of contextual variation, are modeled as involving hyperarticulation and decreasing the target range (Guenther 1995a, Keating 1996). Thus, Guenther's model provides the basis for modifying Keating's window model in a way that allows resizing of the window to accommodate influences from various linguistic and extra-linguistic factors, such as stress, prosody, and speech rate.

Let us examine the window model and its expanded versions in relation to the findings presented in chapter 2 regarding minimal contrast. The window model explicitly relates contrast and contextual variation, i.e., coarticulation in this case. Also, the windows are given for separate physical dimensions (articulatory and acoustic, Keating 1990, Guenther 1995b), and these seem to correlate with our dimensions of contrast. In fact, the window model seems useful to accommodate some of the coarticulation facts discussed in sections 2.2 and 3.5.1. According to the model, contrasting dimensions have narrower windows, i.e., less variability, than dimensions in segments not contrasting for that same dimension (Keating 1990, cf. Guenther 1995a). Thus, minimal contrast could be argued to determine the size of a window by restricting the possible values. The window model also captures the differences among segments. As seen for Lithuanian, not all segments might be minimally contrastive for the same dimensions. The contrast-coindices could be incorporated into the window model as determiners of a dimension's window size. In fact, the findings presented here with respect to the relevance of minimal contrast for phonetic patterns would shed light on the kind of elements that can determine window sizes. Furthermore, note that the window model accounts for the observation than phonetic patterns are influenced only by contrasts that operate along the same dimension the patterns modify. As mentioned above, minimal contrast is defined for dimensions of contrast, which correlate with the articulatory and acoustic windows of the model. Thus, minimal contrast along some dimension would determine the size of the window that corresponds to that dimension in question. Recall that the window size determines the amount of contextual modification for a given dimension.

However, one of the biggest challenges of the original window model and its subsequent modifications is that the windows are defined for articulatory and acoustic variation. The model does not include a component for temporal variation, and, more precisely, it is not able to account for variability in intergestural timing (Byrd 1996). It is important to understand the difference between two elements that relate to the temporal component. First, there is duration, which refers to time. Second, we have timing, i.e., coordination among gestures. The window model does not incorporate either time or timing.

Coming back to the Lithuanian results, these have to be accommodated in the temporal dimension and, as just mentioned, this challenges the window model since it does not provide a component for temporal variation. Clearly, the facts from Lithuanian call on the notion of time. The relevant phenomenon that needs to be modeled is the asymmetry resulting from minimal length contrast, where short and long vowels are involved. The dimension of time seems different from the spatial one. However, in her discussion of vowel reduction phenomena and non-moraic vowels, Crosswhite (2001) proposes to extend the window model to vowel duration. Crosswhite hypothesizes that phonological timing units (e.g. moras) are interpreted phonetically using durational windows. A durational window determines the range of temporal variation acceptable for a given segment. Crosswhite argues that these windows depend on the phonological durational category of the segment. Monomoraic segments have a window located towards the 'short' end of the durational continuum. Bimoraic segments will have windows near the 'long' end of the continuum. According to the author, non-moraic vowels also have durational windows. Following the original window model, Crosswhite states that the exact size and location of these durational windows will vary cross-linguistically. It should be pointed out that in Croswhite's proposal, only segments with a [+syllabic] root node are assigned a durational window. Segments that are not syllabic do not get a durational window. This means that consonants do not receive durational windows. Furthermore, even if durational windows are assumed, the notion of interpolation, which is an important component of the window model, does not seem to correspond to how duration patterns behave.

The Lithuanian findings, I argue, further call on intergestural timing. Although the literature on the voicing effect is not clear in offering an account of this pattern, previous research seems to agree that the difference in production between voiced and voiceless consonants, and the coordination between consonantal and vocalic gestures are relevant for describing and explaining the voicing effect (e.g.

Delattre 1962, Chen 1970, Kohler 1984, Lisker 1974, among others). The conclusion is that a satisfactory analysis of Lithuanian requires reference to the temporal dimension of gestures.

Byrd (1996)'s phase window model expands the window model to account for intergestural timing variability conditioned by linguistic and extra-linguistic factors. Further developments by Saltzman & Byrd (2000) implement the phase windows within Task Dynamics (Saltzman & Munhall 1989). In what follows, Task Dynamics is introduced, focusing on how it models time or duration differences. Next, I discuss the phase window model and its implementation in Task Dynamics, highlighting the advances it brings to the modeling of intergestural timing. I argue that this approach can capture the facts from Lithuanian and the relevance of minimal contrast.

Task Dynamics has been used to model different kinds of multi-articulator actions, including those involved in speaking (Saltzman & Munhall 1989). Research in speech production has examined kinematics of articulatory movements and suggested that they may be controlled by a particular dynamical setting in the framework of a mass-spring task dynamical model (e.g. Browman & Goldstein 1989, Saltzman 1995, Edwards et al. 1991, Beckman et al. 1992, Byrd et al. 2000, Cho 2001, among others). In the Task Dynamics model of speech production, articulatory movement patterns are conceived of as coordinated, goal-directed gestures that are dynamically defined (Saltzman & Munhall 1989). They have been modeled as critically damped oscillators that act as point attractors. Speech sounds are described by the parameter values of their component gestures and also, by how gestures are coordinated or phased with one another. This approach captures coproduction by allowing gestures to overlap in time. Thus, systematic articulatory variation is interpreted as consequences of dynamical parameter settings and of interactions among gestures.

The relevant dynamical parameters include target and stiffness.[49] The stiffness parameter is of interest here. In the task-dynamic model, there are (at least) two different articulatory maneuvers that can modify duration of a speech sound. First, the stiffness parameter value of a gesture may be decreased, resulting in longer activation time and making the gesture lower, and therefore longer for any given amplitude specification. Second, the gestures may be longer not because of their own intragestural dynamic specifications but because of intergestural timing of two gestures relative to each other.

Smith (1995) studied the articulatory behavior of geminate consonants and found that these consonants may differ in stiffness and consequently, in activation time values from singleton consonants. This illustrates how modifying the dynamical parameter of stiffness can capture different durational patterns. In view of Smith's results, it would be relevant to ask whether stiffness also differentiates short and long vowels. This means that long and short vowels could have different stiffness and activation time patterns. Hertrich & Ackermann (1997) conducted a kinematic study on German short and long vowels. They recorded and measured the compound lower

[49] Note that the damping ratio, another parameter in the Task Dynamics equation, is usually set to be constant.

lip/jaw opening and closing movements in a /pVp/ context, where the vowel could be either short or long. Hertrich & Ackermann found that the difference between German long and short vowels was performed by the adjustment of the correlation between peak velocity and amplitude, which corresponds to the stiffness parameter, and by the modification of the activation times of the opening and closing gestures. The results from this study indicate that differences in duration between long and short vowels can be modeled as changes in stiffness values and the activation patterns. In fact, the Task Dynamics model predicts that changes in time can be controlled solely by the adjustment of stiffness. For example, decrease of stiffness leads to prolonged gestures. This means that at least for those elements of the acoustic signal which depend on the duration of single articulatory gestures, explicit representation of time is not necessary in order to obtain duration modifications (Kelso et al. 1985, Vatikiotis-Bateson and Kelso 1993). Then, once the difference between long and short vowels is established, the influence of minimally contrastive long vowels on the voicing effect can be understood as the result of intergestural timing variability resulting from the presence or absence of this kind of contrast. This is developed within the phase window model.

Recall that one of the main challenges for the window model is that it cannot account for variation stemming from intergestural timing patterns. Byrd (1996) proposes the phase window model as a solution to this shortcoming of the original window formulation. This model develops the idea that intergestural timing displays variability conditioned by linguistic and extra-linguistic factors. It has been observed that the relative phasing among articulatory gestures is not fixed but rather it can be affected by linguistic factors such as prosody, stress, and syllabification (see Saltzman & Byrd 2000 and references therein). Thus, the phase window model hypothesizes that the target values are not invariant points but rather are constrained to fall within an acceptable range, i.e., a phase window. Byrd's proposal builds on Keating's model and applies the idea of window to the timing dimension. A phase window is a range of possible timing relationships specific to the types of gestures involved (V-to-C, V-to-V, C-to-C).

Recent developments in the task-dynamic model of speech production have related intergestural timing patterns to the behavior of coupled oscillators, i.e., intergestural patterns are seen as the result of coupling specifications among different articulators (e.g. Saltzman & Byrd 2000, Nam & Saltzman 2003). Saltzman & Byrd (2000) pursue the possibility of attractor states for intergestural timing that are characterized as ranges or phase windows following Byrd (1996), rather than points. Saltzman & Byrd's computational simulations present a method of flexibly controlling relative phasing among a pair of coupled oscillators to display stable phase windows in the steady-state. Saltzman & Byrd (2000) argue that the phase window approach for controlling the relative phasing of speech gestures is advantageous because windows provide appropriately constrained variability as a function of linguistic and extra-linguistic factors.

The question of interest here is what factors can influence intergestural variability. According to Byrd (1996), intergestural timing is physically and language-specifically constrained to fall within a certain phase window. Furthermore, where along the phase window a specific phasing will be realized is determined by linguistic and extra-linguistic factors or *influencers*. These are utterance-specific influencers that do not constrain the window but weigh it. There is an optimization process that weighs the effects of the different influencers. Each variable or influencer adds a certain weight to the probability of a certain phasing. The various influencers can be competing simultaneously, each contributing to the final intergestural phasing relation. In Byrd (1996), possible influencers include place of articulation and manner of segment, adjacent contexts, structural considerations such as syllable and boundary location, and speaking rate.

As mentioned earlier, I pursue the hypothesis that differences in the degree of acoustical duration variation due to voicing effect stem from differences in intergestural timing. Recall that the presence of minimal contrast for vowel duration limits the voicing effect, as shown by the Lithuanian results. This is interpreted as a result of minimal length contrast acting as an influencer on the timing or phasing between the relevant vowel and consonant gestures, which affects the vowel's duration. This proposal expands the possible influencers on intergestural timing by including minimal (length) contrast, which in the present study is represented as contrast-coindices. This means that a contrast-coindex for vowel duration functions as an influencer of a phase window and weighs in (together with other factors) to determine the exact phasing relation between a vowel and consonant gestures (V-to-C). It should also be mentioned that this account captures the observation that phonetic patterns are influenced by minimal contrast for properties (i.e. dimensions) relevant to that pattern. The connection between a contrast-coindex for duration and intergestural timing is made specific in the model adopted here, where modifications in duration may result from changes in intergestural timing or stiffness (see above). Thus, a contrast-contrast coindex for duration is an influencer of intergestural timing, which is directly correlated with contextual modifications of duration, which is the relevant dimension of contrast here. Finally, assuming the proposal that minimal contrast can condition phasing relations, then contrast-coindices allows us to include information about this kind of contrast in the model.

3.6 Alternative: Moraic representation of length

Having presented the contrast-coindexing proposal, I examine an alternative approach to the representation of length contrasts. More precisely, I consider moraic theory and the role of moraic specifications as a way to mark length contrasts. According to moraic theory, vowel length differences are reflected in the number of moras associated with each vowel (Hyman 1986, Hayes 1989). Short vowels are linked to one mora, as shown in Figure 13a, while long vowels are associated with two moras, Figure 13b.

Figure 13. Moraic representation of length in vowels

a. Short vowels b. Long vowels

However, this representation is not able to capture the behavior of vowels in Lithuanian. The problem arises when /eː, oː/, which are not minimally contrastive for length, enter the picture. The main finding of the experiment reported in section 2.3 was that /eː, oː/ behave different with respect to the voicing effect when compared with the other vowels in the Lithuanian system. Vowels that are minimally contrastive for length, whether they are short or long, pattern together in the sense that the voicing effect is attenuated in them. On the other hand, /eː, oː/ group together, separate from the other long vowels, and show a stronger impact of the voicing effect.

Under the moraic representation, /eː, oː/ would be associated with two moras. Remember that these two vowels are phonologically long. In section 2.3.2, evidence was presented pointing to the bimoraic status of long mid vowels. They behave like the other long vowels in Lithuanian with respect to stress assignment (Tekorienė 1990) and word minimality requirements (Steriade 1991). Consequently, if the contrast were based on the moraic specification, then the long mid vowels would be expected to pattern together with other bimoraic vowels. But this is not the case.

Another possibility could be to consider the vowels that are not minimally contrastive for length as unspecified for moraicity. This seems not to be an appropriate representation since, as I just mentioned, /eː, oː/ behave like two-mora vowels with respect to several phonological processes, suggesting that these two mid vowels are indeed specified as bimoraic in the phonology of Lithuanian. Furthermore, the term non-moraic is better understood to refer to vowels that present an impoverished duration due to their position, for example post-tonic syllables in Brazilian Portuguese (Crosswhite 2001, 2004). These durationally reduced vowels tend to be subject to neutralization. Clearly, Lithuanian /eː, oː/ do not have a reduced duration. In fact, according to the experimental results, these vowels tend to have a similar duration to other long vowels, such as /ɑː/ and /æː/ (see Figure 5 above). The evidence presented here points to the need for something independent from moraic specification to represent whether a given segment minimally contrasts for length or not. The contrast-coindexing proposal captures the asymmetrical behavior of /eː, oː/. Further assessment of the moraic approach to length contrasts in language is developed in chapter 5.

3.7 Summary

The importance of minimal contrast is clearly highlighted by the experimental results. Moreover, minimal contrast surfaces as a property of each segment rather than of the whole vowel system, although contrast itself must be assessed in the context of the whole system. Phonetics has access to information about the contrast relationships that each individual vowel is part of. This fact challenges traditional representations of vowel length contrast. Moraic Theory is not able to account for the behavior of an asymmetrical system for vowel length, such as that in Lithuanian. Moraic Theory is based on a basic binary distinction between mono-moraic and bi-moraic elements. However, the Lithuanian inventory makes a distinction between mono- and bi-moraic segments, and between vowels that are minimally and non-minimally contrastive for length. These four types of segments intersect and there is no one-to-one correspondence among them. Thus, a moraic analysis is not sufficient to capture asymmetries in vowel length contrasts within the same language.

This chapter proposed a new system to include minimal contrast in the phonological representation. The contrast-coindexing function developed in this thesis successfully accounts for the Lithuanian results. Contrast-coindexing is couched with Optimality Theory, as a function that applies to candidates generated by GEN. Contrast-coindexing relies on minimal pair comparison in order to assess minimal contrast. This ensures that minimal contrast will not be identified in cases of contrast neutralization. The result of contrast-coindexing is that minimal contrast will be represented whenever it is present in the surface forms.

Finally, this chapter presents a framework for the phonology-phonetics interaction, which considers contrast-coindexing and its dimensions of contrast as crucial elements in the interface between phonology and phonetics. The window model is expanded in order to incorporate the influence of minimal contrast in phonetic patterns. The account developed here is further shown to offer a direct connection between the phonetic model and the observed restrictions on the minimal contrast effects, namely that minimal contrast influences phonetic patterns that operate along the same dimension of contrast.

CHAPTER 4

MINIMAL CONTRAST AND PHONOLOGICAL PHENOMENA

4.1. Introduction

This chapter discusses the implications of the contrast-coindexing proposal in relation to phonological phenomena. Remember that the main claim put forth earlier in the dissertation is that the phonological representation must include information about minimal contrast. Under the present approach, this kind of contrast is captured through coindices that indicate whether a given element is minimally contrastive for a dimension or not. For example, in Lithuanian, mid vowels lack a contrast-coindex for length because these vowels are not minimally contrastive for this property.

This proposal predicts that minimal contrast might be active or relevant in the phonology. Minimal contrast encoded as contrast-coindices is part of the representational apparatus of phonology. This means that phenomena that take place in this component, i.e., phonological processes, can have access to these coindices and be sensitive to them. More precisely, phonological processes might single out segments with certain coindices, as opposed to other segments lacking the relevant minimal contrasts. The idea is that phonological process might target, be triggered or blocked only by segments that minimally differ for some dimension of contrast, i.e., segments that have a specific contrast-coindex. This idea is captured through the proposal that constraints driving phonological processes can make reference to contrast-coindices. I discuss data showing that coindices can be mentioned by both markedness and faithfulness.

Here, I present evidence supporting this prediction. Different phonological processes show that the presence or absence of minimal contrast may play a role in determining the observed patterns. The first case comes from vowel height harmony (i.e. metaphony) in Lena Asturian, a Romance variety spoken in northwestern Spain, where only vowels that are minimally contrastive for height can trigger the harmony process. Furthermore, the typology of vowel harmony illustrated by several varieties spoken in northwestern Spain lends further support to the claim that minimal contrast is active in the phonology.

The structure of the chapter is the following. Section 4.2 focuses on vowel height harmony in Romance varieties. Vowel harmony in Lena is discussed in detail in section 4.2.2. Next, section 4.2.3 presents a vowel harmony typology derived from several varieties from northwest Spain. Section 4.2.4 develops an analysis of Lena harmony adopting the contrast-coindexing proposal. In section 4.3, I consider an alternative approach to the Lena facts, namely Underspecification Theory. Finally, section 4.4 extends contrast-coindexing to the analysis of other phonological patterns.

4.2. Case studies: Vowel height harmony in Romance varieties

4.2.1 Introduction

Metaphony patterns in some Romance dialects offer an instance of a phonological process sensitive to minimal contrast. The term metaphony refers to a type of vowel height harmony by which post-tonic high vowels trigger assimilation in a stressed vowel, usually raising (Penny 1970, Calabrese 1985, 1988, 1998, Hualde 1989, 1998, Kaze 1989, 1991, Maiden 1991, Dyck 1995, Walker 2004, 2005). For example, compare the Lena forms [ts**ú**bu][50] 'wolf.masc.sg.' and [ts**ó**ba] 'wolf.fem.sg.'. These examples show alternation between [u-o] depending on the last vowel. In some varieties of Romance, the triggers of metaphony must not only be high but also minimally contrastive for height with some other vowel in the inventory. Thus, in these systems, high vowels show an asymmetrical behavior with respect to metaphony: those that minimally contrast for height are able to cause raising of a preceding vowel but those that do not minimally contrast for this dimension do not trigger the harmony pattern. A relevant variety includes one spoken in northwestern Spain, more precisely the dialect of Asturian spoken in Lena. In this variety, only back vowels contrast for height in the context where harmony triggers occur, and the high back vowel is the only trigger of metaphony.

The claim about the relationship between minimal contrast and metaphony in the varieties from northwestern Spain builds on Dyck's (1995) observation that metaphony is present only in those varieties with a mid vs. high vowel contrast. In

[50] An accent mark over a vowel indicates stress.

the absence of such a contrast, metaphony does not occur. Dyck further argues that vowel inventories in these varieties from Spain are divided into the inventory of vowels that can occur in stem and the inventory of vowels that can occur in desinences, i.e., inflections. She makes the observation that raising only takes place in dialects with a contrast between mid and high vowels in the desinence (or inflectional) inventory.[51]

In the rest of this section, I introduce the facts about Lena vowel harmony, focusing on the contrast relationships relevant for explaining the facts. I claim that the presence of minimal height contrast conditions the application of metaphony in Lena, and show how the contrast-coindexing proposal makes the correct prediction. Next, I analyze Lena's metaphony process following Walker (2005), i.e., as a case of licensing of a feature that belongs to a perceptually weak position. This analysis is expanded by including the notion of contrast-coindexing, which helps account for the facts observed in the variety under study. Finally, more data is presented from other varieties of northwestern Spain that provide further evidence for the role of minimal contrast. Many of the generalizations about these dialects are summarized in Dyck (1995), who offers a cross-linguistic study of metaphony. However, the current study presents additional data in relation to the realization of the inflectional high front vowel in Lena and some metaphony patterns in the verbal paradigm of the

[51] Dyck's (1995) analysis of metaphony in the varieties from northwestern Spain is discussed in section 4.3.2.3 on Modified Contrastive Specification, since her approach is developed within this framework.

Aller variety. These data further support the claim about the role of minimal contrast pursued here.

4.2.2 Lena vowel height harmony

4.2.2.1 Data and main facts

Lena is an Ibero-Romance variety spoken in the northwestern Spanish region of Asturias. More concretely, it is a central dialect of Asturian (i.e. Bable). Lena is not a Spanish dialect since it evolved directly from Vulgar Latin, like other varieties from northwestern Spain (Granda 1960). Most of the Lena data comes from original fieldwork by Neira (1955). When other sources have been used, references are provided.

In its stem inventory, Lena has a five vowel system, very similar to that of Spanish, as Table 19 shows.

Table 19. Lena vowel inventory in stem

	Front	Central	Back
High	i		u
Mid	e		o
Low		a	

Metaphony is one of the main phonological processes of Lena (Neira 1955). As mentioned before, Lena metaphony is a vowel height harmony process by which a post-tonic, unstressed high vowel triggers raising of the stressed vowel (e.g. Hualde

1989, 1992, Dyck 1995, Dillon 2003, Walker 2004, 2005, Finley 2006). Some examples of Lena metaphony are presented in (37).

(37) Examples of Lena metaphony (data from Neira 1982)

	masc. sg.	*fem. sg.*	*masc. pl.*	*gloss*
a.	t**ú**ntu	t**ó**nta	t**ó**ntos	'dumb'
b.	f**í**u	f**é**a	f**é**os	'ugly'
c.	s**é**ntu	s**á**nta	s**á**ntos	'holy'

The examples in (37) show three morphologically related forms, i.e., masculine singular, feminine singular, and masculine plural, for each gloss. The masculine singular examples show the vowel harmony pattern. A word final /u/ causes raising of the preceding stressed vowel. Examples (37)a, b, c) display raising of /o, e, a/ to [u, i, e], respectively.[52] On the other hand, the forms for the feminine singular and masculine plural do not undergo metaphony given that those forms do not contain a post-tonic high vowel. Stressed high vowels (/i, u/) do not change in the harmonizing environment, as can be seen in the examples in (38).

[52] Dyck (1995) argues that /a/ does not raise to /e/. Instead, this vowel undergoes a process of centralization under influence of a final unstressed high vowel and the resulting vowel is different from underlying /e/. Whether /a/ raises or centralizes is tangential to the present analysis since the interest lies on the possible triggers of the metaphony process and not so much in the targets.

(38) High vowels stay the same in the harmonizing environment (Hualde 1989)

	masc. sg.	*fem. sg.*	*masc. pl.*	*gloss*
	fr**í**u	fr**í**a	fr**í**os	‘cold’
	m**ú**ntʃu	m**ú**ntʃa	m**ú**ntʃos	‘much/many’

It should also be noted that the target of the harmony is always and only the stressed vowel in the word. Any vowel that intervenes between the trigger and the target is not affected by the raising process. Similarly, harmony does not persist beyond the stressed vowel. In the examples in (39)a), the intervening unstressed /a/ stays the same, while stressed /a/ raises to [é]. The forms in (39)b) show that the vowel /a/ preceding the stressed one does not undergo raising, whereas stressed /e/ raises to [í].

(39) Intervening unstressed vowels are unaffected by harmony

	masc. sg.	*fem. sg.*	*masc. pl.*	*gloss*
(a)	p**é**ʃ**a**ru	páʃara	páʃaros	‘bird’
	s**é**b**a**nu[53]	sábana	sábanos	‘sheet’
(a)	g**a**mb**í**ru	gambéra	gambéros	‘hooligan’

A final relevant fact about Lena metaphony is that the trigger of the harmony is always a word-final inflectional suffix or desinence[54] (Hualde 1992, Dyck 1995, Walker 2005). The forms in (40) show that a post-tonic high vowel in the stem does not trigger the harmony. In this example, the feminine and plural forms have a post-tonic /i/ (in italics), which is part of the stem. However, the stressed vowel does not raise to /i/, indicating that only inflectional suffixes may cause the stressed vowel to raise.

(40) Only inflectional suffixes may trigger the harmony

masc. sg.	*fem. sg.*	*masc. pl.*	*gloss*
silik**<u>ú</u>**t*i*ko	silik**ó**t*i*ka	silik**ó**t*i*kos	'suffering from silicosis'

More evidence that the trigger is always an inflectional suffix comes from forms that lack an inflectional suffix and do not show harmony, even though the word-final element is a high back vowel. These are forms that cannot be inflected, either because they are adverbs or because they refer to objects that do not allow for the mass/count distinction. The examples in (41) illustrate these facts. For instance, the word corresponding to the adverb 'down' [abáxu] surfaces with a low stressed vowel, suggesting that it has not raised, despite the presence of a word-final /u/. This shows that only inflectional vowels can trigger the metaphony.

[53] The masculine form of inanimates indicates a smaller object than the feminine (Hualde 1992).
[54] Many studies on Romance dialects use the term desinence to refer to inflectional suffixes.

(41) Forms that lack an inflectional vowel do not show harmony (Neira 1982)

[ab**á**x**u**]	'down'	
[j**é**ls**u**]	'plaster'	(cf. Castilian [jeso])
[fj**é**r**u**]	'iron'	(cf. Castilian [jero])

These facts suggest that the inflectional (i.e. desinential) vowel inventory is the relevant set that has the potential to trigger metaphony (cf. Dyck 1995). For this reason, I focus on the inflectional inventory in Lena and show how the contrast relationships that are established among the different vowels are responsible for selecting the trigger of metaphony. More precisely, I argue that the presence of minimal contrast is crucial in determining which vowels can act as triggers. Only those vowels that are minimally contrastive for height can activate the harmony.

4.2.2.2 Lena inflectional vowel inventory

In this section, the Lena inflectional vowel inventory is discussed, paying special attention to the presence or lack of contrasts among its different elements. Table 20 shows the phonemic inflectional vowel inventory (a) and its realization (b).

Table 20. Lena inflectional vowel inventory (a) and its realization (b)

(a) Inflectional vowel inventory

<table>
<tr><th>Front</th><th>Central</th><th>Back</th><th></th></tr>
<tr><td rowspan="2">/e/</td><td></td><td>/u/</td><td>High</td></tr>
<tr><td></td><td>/o/</td><td>Mid</td></tr>
<tr><td></td><td>/a/</td><td></td><td>Low</td></tr>
</table>

(b) Realization

<table>
<tr><th>Front</th><th>Central</th><th>Back</th><th></th></tr>
<tr><td rowspan="2">[i/e]</td><td></td><td>[u]</td><td>High</td></tr>
<tr><td></td><td>[o]</td><td>Mid</td></tr>
<tr><td></td><td>[a]</td><td></td><td>Low</td></tr>
</table>

The Lena inflectional system is asymmetrical. The back vowels /u, o/ differ in terms of their height, indicating that they are minimally contrastive for this property. On the other hand, production of the front vowel ranges from [i] to [e], but crucially, it lacks a height contrast (Granda 1960, Dyck 1995, Walker 2005). This means that only back vowels are minimally contrastive for height.

Evidence for the contrast between /u/ and /o/ in Lena comes from the distinction between masculine singular count forms, which take the suffix /-u/, and mass forms, which are formed with the suffix /-o/ (Penny 1970). This difference can be seen in nouns and adjectives that agree with their corresponding nouns. The morphological contrast between mass and count forms is robust in Lena, and new words and borrowings show the phonological alternation between a word-final suffix /-u/ and /-o/ to mark this grammatical difference (Neira 1978). The adjectives in (42) illustrate the contrast between the inflectional suffix /-u/ for masculine singular forms and the suffix /-o/ for mass ones.

(42) Inflectional /o/-/u/ contrast in Lena (data from Neira 1982)

masc. sg.	*mass*	*gloss*
frí**u**	frí**o**	‘cold’
múntʃ**u**	múntʃ**o**	‘much/many’
túnt**u**	tónt**o**	‘dumb’
fí**u**	fé**o**	‘ugly’
sént**u**	sánt**o**	‘holy’

On the other hand, the Latin distinction between inflectional /i/ and /e/ was lost in Lena. Both suffixes merged (Granda 1960). However, the precise realization of the front vowel is not totally undetermined, i.e., there is not free variation between [e] and [i]. Some forms always show an inflectional /-e/. The examples in (43) illustrate this pattern.

(43) Realization of inflectional [-e]

[pót**e**] 'pot.masc.sg.' (cf. [pot-a] 'wide pot.fem.sg.')

[fér**e**] 'type of hawk.masc.sg.' (cf. [feres] 'type of hawk.masc.pl.')

Some conditions tend to favor the production of this vowel as [i] Granda (1960). First, when there is a preceding (pre-)palatal sound, the word-final front vowel tends to be realized as [i]. The form in (44) shows production of a final [i] following a pre-palatal (or postalveolar) consonant.

(44) [i] realization after a pre-palatal sound

[jetʃ**i**] 'milk.fem.sg.' (cf. [jetʃ**es**] 'milk.pl.' *glasses of milk*)

Second, there is also a tendency to pronounce the vowel as [i] when there is a preceding stressed [í] in the stem. Example (45) illustrates this pattern. The word for 'push' has a word-medial stressed [i], which favors the production of the final vowel as high [i]. Comparison with the Castilian form [embíte] indicates that the stressed vowel is not the result of harmony, but rather is present underlyingly.

(45) [i] realization after a stressed [i]

[imbít**i**] ‘push.masc.sg.’ (cf. [imbít**es**] ‘push.pl.’, Castilian [emb**í**te])

Finally, [i] production may result from analogy to forms within the same semantic field that have a word-final [i] due to one of the preceding factors.

The conclusion from this discussion about the factors conditioning the realization of the final front vowel is that a word-final [i] has a fixed target for its production. Its realization is not variant or inbetween [i] and [e]. This implies that the high front vowel is in fact specified as [+high]. These facts about the phonological characterization of inflectional [i] are further discussed in section 4.3 where an alternative approach, namely underspecification, to the Lena data is considered.

To summarize this section, the relevant observation about the inflectional vowel system in Lena is that back vowels are minimally contrastive for height, whereas front vowels lack this minimal contrast. Section 4.2.2.3 shows that the distribution of minimal height contrasts determines which inflectional vowels are capable of triggering the harmony.

4.2.2.3 Possible triggers of harmony in Lena

The important fact to notice is that an inflectional front vowel realized as [i] never triggers metaphony. At first sight, it seems that this vowel should be able to initiate the process, given that it is a suffixal high vowel. As the preceding discussion (4.2.2.2) about the factors conditioning its realization suggest, [i] is specified [+high], which is the relevant feature triggering the metaphony. However, the examples in (46) show that forms with desinences realized as [i] fail to undergo raising of their stressed vowel (cf. Dyck 1995).

(46) Production of inflectional suffix as [i] but lack of harmony (Granda 1960)

[b**é**nt**i**]	'twenty'	(cf. [b**e**ntidós] 'twenty-two')
[p**á**dr**i**]	'father'	
[m**á**dr**i**]	'mother'	
[mat**é**st**i**s]	'you pl. killed'	(cf. [mat**é**mos] 'we kill', showing /e/ is underlying in stressed vowel)

The data from Lena indicate that only an inflectional /u/ can trigger the vowel harmony. Therefore, Lena illustrates a case of an asymmetrical system in so far as only the high vowel that contrasts with a mid vowel, i.e., /u/, triggers the metaphony. The high vowel that lacks a contrastive mid vowel, i.e., the front vowel, cannot initiate the harmony process. The generalization is that in Lena only a high vowel that is minimally contrastive for height can trigger the harmony.

Summarizing, this section has shown that the vowel harmony system in Lena crucially depends upon two main claims: First, the inflectional and stem vowel inventories must be considered separately in terms of phonological contrast. Second, the presence of minimal height contrast among the inflectional vowels determines the trigger of metaphony. In the next section, Lena metaphony is placed within the vowel harmony typology derived from several varieties from northwestern Spain. I present data from these dialects, and show that the notion of minimal contrast is crucial in explaining the observed typological pattern.

4.2.3 Vowel harmony in related varieties from northwestern Spain

4.2.3.1 Aller Asturian

Aller is a central dialect of Asturian, spoken in the region geographically adjacent to the Lena area. Aller and Lena are very closely related and show comparable phonological patterns (Dyck 1995).[55] However, we will see that there is a relevant difference between these two Asturian varieties. The main facts about Aller are taken from Neira (1963, 1982) and Granda (1960), who rely on the original source of Rodríguez-Castellano (1952).

Aller presents a metaphony pattern similar to that of Lena: an inflectional high vowel causes raising of a preceding stressed vowel. Example (47) illustrates this phenomenon in Aller masculine singular forms, where a suffixal /u/ triggers the raising.

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[55] Aller, like the rest of the varieties from Northwestern Spain presented here, has the same five vowel inventory in the stems as Lena (see Table 19).

(47) Examples of Aller metaphony

masc.sg.	*pl.*	*gloss*
kald**í̲**ru	kald**é**ros	'pot'
f**í̲**tʃu	f**é**tʃos	'fact'

Aller's inflectional vowel inventory has some similarities to that of Lena. Aller also displays a phonological difference between the mass and count grammatical categories, which is realized as a contrast between inflectional /u/ and /o/. Similarly to Lena, Aller nouns lack an inflectional distinction between /i/ and /e/, and forms that end in inflectional /i/ do not undergo metaphony. However, unlike Lena, Aller shows a limited inflectional contrast between /i/ and /e/ for the verbal paradigm. This contrast comes from the phonological difference between the second person singular imperative suffix /-i/ and the third person singular present suffix /-e/. The verbal forms in (48) exemplify this contrast.

(48) Aller contrast between inflectional /i/ and /e/

imperative	*present*	*gloss*
bíb**i**	bíb**e**	'to live'
kúbr**i**	kúbr**e**	'to cover'

Interestingly, Aller imperative forms undergo vowel harmony when the stressed vowel is non-high. These verbal forms follows the same pattern as the nominal forms in (47). The examples in (49) illustrate the verbal metaphony triggered by an inflectional /i/.

(49) Aller imperative forms show metaphony triggered by /i/

imperative	*present*	*gloss*
ébri	**á**bre	'to open'
k**ú**ri	k**ó**re	'to run'

The data from Aller offer further evidence about the role of minimal height contrast in metaphony. In this variety, inflectional vowels that have a minimal contrast for height can trigger the harmony. These vowels are /u/ in the nominal and adjectival forms and /i/ in the verbal paradigm. Correspondingly, harmony occurs only in those forms where these two minimally contrastive vowels occur.

4.2.3.2 Western Asturian

This section describes the metaphony pattern and inflectional vowel system found in the Western Asturian dialects. The data and generalizations are taken from Granda (1960) and Dyck (1995), who draw mainly from the results of fieldwork by Rodriguez-Castellano (1954).

The Western Asturian inflectional system is more simplified than that of Lena and Aller, as Table 21 shows.

Table 21. Western Asturian inflectional vowel inventory

<table>
<tr><th></th><th>Front</th><th>Central</th><th>Back</th></tr>
<tr><td>High</td><td rowspan="2">e</td><td rowspan="2"></td><td rowspan="2">o</td></tr>
<tr><td>Mid</td></tr>
<tr><td>Low</td><td></td><td>a</td><td></td></tr>
</table>

Western Asturian does not have a contrast between the suffixes /u/ and /o/. These varieties do not show the phonological distinction between mass and count nominal forms. Also, the /i/ vs. /e/ opposition is absent from the system. Dyck (1995) notes that the pronunciation of the non-high vowels varies from mid to high, i.e., [i/e] for the front vowel and [u/o] for the back vowel, depending on the particular dialect and the phonetic influence from adjacent segments.

Relevant for the metaphony typology, Western Asturian does not display vowel harmony at all. Even those forms that are realized with a final high vowel do not show harmony. The examples in (50) compare the same words in Western Asturian and in Lena in order to highlight the lack of metaphony in the Western dialects.

(50) Comparison between Western Asturian and Lena

Western Asturian	*Lena*	*gloss*
tʃ**ó**bu	tʃ**ú**bu	'wolf'
p**é**tʃu	p**í**tʃu	'breast'

4.2.3.3 Eastern Asturian

This section focuses on the inflectional system and metaphony observed in the Eastern Asturian varieties. Granda (1960) and Dyck (1995) are the main sources used here.

The inflectional vowel system of Eastern Asturian is very similar to the one found in Western Asturian (see Table 21). There is not a height contrast among front vowels. Back vowels also fail to show a height contrast like the one observed in Lena or Aller. A non-robust, archaic /u/ vs. /o/ distinction seems to exist for the accusative pronominal forms [lu] (masc.sg.) vs. [lo] (mass).

Penny (1970) reports that metaphony in Eastern Asturian is irregular, partial and rare. In fact, none of the sources offer an example where vowel harmony takes place. However, we do find non-harmonizing forms like the ones in (51), which compare the same words in Eastern Asturian and Lena.

(51) Comparison between Eastern Asturian and Lena

Eastern Asturian	*Lena*	*gloss*
s**á**ntu	s**<u>é</u>**ntu	'holy'
tʃ**ó**bu	tʃ**<u>ú</u>**bu	'wolf'

4.2.3.4 Cantabrian Montañes

Montañes is spoken in the province of Cantabria, which is adjacent to the Asturian region. Montañes is used as a cover term for the varieties spoken in the mountainous area of Cantabria, which include Tudanca and Pasiego. The data presented here are taken from Dyck (1995), who is informed by the original sources of Penny (1969, 1978).

In Montañes, there is an inflectional contrast between /u/ and /o/ used to mark the grammatical difference between mass and count forms. On the other hand, it has only one inflectional front vowel that is realized as a schwa and crucially, lacks a height contrast. Metaphony is active in Montañes, which shows vowel height harmony triggered only by inflectional /u/[56], as the examples in (52) illustrate.

(52) Examples of Montañes metaphony (Pasiego dialect)

msc.sg.	*mass*	*fem.sg.*	*gloss*
lix**í**ru	lix**é**ro	lix**é**ra	'light'
g**ú**rdu	g**ó**rdo	g**ó**rda	'fat'

4.2.3.5 Summary of vowel harmony typology

Table 22 shows the vowel harmony typology derived from the inflectional vowel systems and the metaphony patterns from the northwestern Spain varieties presented in the previous sections.

[56] The metaphony pattern found in Montañes is not exactly like that in Lena or Aller. For instance, in the Cantabrian varieties, the low vowel /a/ does not raise. For more details see McCarthy 1984, Hualde 1989 and Dyck (1995).

Table 22. Summary of vowel harmony typology from varieties spoken in northwestern Spain

	Harmony by /u/ & /i/	Harmony by /u/ only	Lack of harmony
/u-o/ & /i-e/ contrast	Aller		
/u-o/ but not /i-e/ contrast		Lena, Montañes	
No /u-o/ or /i-e/ contrast			Eastern, Western Asturian

The typology strongly suggests that the presence of minimal height contrast can play a determining role in whether harmony takes place in the system or not, as seen in the varieties of Northwestern Spain. In Lena and Montañes, only back vowels are minimally contrastive for this property and only /u/ can trigger the raising. On the other hand, Aller has a minimal height contrast for both its front and back inflectional vowels. Correspondingly, this variety shows metaphony triggered both by /u/ and /i/. Finally, Eastern and Western Asturian lack a minimal contrast for their inflectional vowel altogether. These are the dialects where vowel harmony does not take place.

In section 4.2.4, I develop an analysis of the Lena vowel harmony. I show how the contrast-coindexing proposal helps explain and formally account for the observed patterns with respect to minimal contrast and the possible triggers of metaphony. I adopt Walker's (2005) licensing approach to metaphony and extend it to the asymmetrical system of Lena, by incorporating contrast-coindices in the phonological representation.

4.2.4 Analysis of Lena vowel harmony

This section develops an analysis of Lena vowel harmony that accounts for the asymmetrical behavior among high vowels in terms of their capacity to trigger harmony. I show that contrast-coindexing can readily explain the difference between inflectional front high and back high vowels in this variety. The latter are contrast-coindexed for height, whereas the former lack such a coindex. After discussing the contrast-coindexed representation for Lena, I present an analysis of its metaphony system following Walker's (2005) proposal about licensing by strong positions of phonological elements in weak positions. Under this approach, vowel harmony patterns like the one in Lena take place in order to license elements that occur in perceptually weak positions by associating the relevant elements, i.e., features, with strong positions. In Lena, the phonological element in a weak position is a high vowel in a word-final unstressed syllable and the strong position is the stressed syllable. The challenge presented by Lena is how to explain the restriction on the possible triggers. I argue that contrast-coindexing should be incorporated into the licensing analysis so that only high vowels with a contrast-coindex for height can trigger the harmony.

The analysis developed here treats metaphony in Lena as a phonological process, triggered by the height feature in the inflectional vowel. However, certain other accounts have viewed Lena harmony as a morphological process, rather than a phonological one (see section 4.2.4.1 for references). I argue that a purely morphological approach to Lena is not suitable and fails to offer a unifying explanation for all the data. On the other hand, I show that my analysis combines a phonological approach to Lena with some morphological considerations.

Before introducing the details of the contrast-coindexed analysis, I first discuss evidence arguing against a solely morphological analysis of Lena harmony in order to motivate a phonological approach.

4.2.4.1 Arguments against a morphological analysis

Morphological conditions play a role in Lena vowel harmony. As seen in section 4.2.2, metaphony can only be triggered by inflectional vowels. Stem vowels do not initiate the process. Furthermore, in Lena only masculine singular count forms show metaphony. Remember that in Lena there is a count vs. mass distinction. This has led some to treat raising of the stressed vowel as marking count morphology (e.g. Dillon 2003, Finley 2006). More precisely, vowel-raising would be part of the phonological realization of the morpho-syntactic properties of mass and number. However, this morphological analysis is not substantiated by several facts. I present some of the arguments against a purely morphological treatment of metaphony in Lena.

Hualde (1992) sketches a possible morphological account of Lena metaphony, which treats the raising of both final and tonic vowels observed in the singular count forms as marking count morphology. Under this approach, the basic form for the word ‘dumb’ would be /tonto/. From this basic form, the singular count [túntu] would be obtained by adding the count morphology, which would consist of a vowel-raising feature-size morpheme. More precisely, Hualde states that the feature

[+high] would constitute the morphological marker of masculine singular count items. This feature would spread to the stressed vowel, giving rise to the observed patterns. However, Hualde argues that a morphological account of Lena metaphony is not substantiated by other facts of the language that are independent of metaphony. He gives three arguments against a morphological analysis like the one developed above.

First, a morphological account treats mass forms as morphologically unmarked. On the other hand, singular count and plural forms would contain some extra morphology. Hualde argues that there is some evidence indicating that count forms are in fact more basic than mass forms in Lena. Hualde notes that whether a given noun that admits a semantic mass interpretation will have a distinct mass form or not depends on the shape of the corresponding count form. Only masculine nouns whose count form end in /u/ have a distinct mass form. Feminine nouns or masculine nouns with an ending other than /u/ do not have a distinction between mass and count forms.

Second, related to the difference in markedness between mass and count morphology, Hualde argues that evidence against a morphological approach to metaphony comes from agreement facts involving mass nouns. According to Hualde, mass nouns show a pattern of agreement that is more complex than that of count nouns. Mass nouns trigger mass agreement with following adjectives within the noun phrase and with targets of agreement outside the noun phrase. With preceding elements in the noun phrase, they show gender agreement (masculine or feminine).

However, mass agreement does not affect elements to the left of the noun within the noun phrase. For example, adjectives that can either precede or follow the noun show mass agreement only if they follow the noun. If the adjective precedes the noun it will show only gender agreement. Hualde notes that mass agreement is suspended when the adjective is preposed. Hualde argues that the agreement facts indicate that mass forms have a more complex feature content than the corresponding count forms. According to Hualde's view, nouns are specified for gender, In addition, they may carry a mass feature. He further claims that the just mentioned facts show that in the count/mass opposition, mass morphology is marked and count morphology is unmarked.

Third and finally, Hualde mentions that the morphological analysis establishes a direct connection between metaphony and masculine singular count morphology. However, not all masculine singular count forms show metaphony. Forms ending in a non-high vowel or in a consonant do not undergo vowel harmony. For example, compare [fére] 'type of hawk.masc.sing.count' with [féres] 'type of hawk.plural', where the stressed vowel in the count form does not raise (i.e. *[fire]). These cases indicate that what conditions the metaphony is a final high vowel rather than simply being morphologically conditioned.

Adding to Hualde's arguments, I present two further pieces of evidence against a purely morphological account of Lena metaphony. First, a morphological analysis of metaphony predicts that only masculine singular count forms can show the harmony pattern. However, as section 4.2.3 shows, in the closely-related variety of Aller, verbal forms ending in a high vowel show exactly the same pattern as nominal forms ending in /-u/. This indicates that in Lena all forms ending in a high vowel are masculine singular count forms because these are the ones that have a word-final inflectional high vowel. But Aller has verbal forms ending in a high vowel and these also undergo metaphony. Furthermore, a purely morphological analysis would not able to capture the correlation between contrast and the existence of metaphony observed in the typology presented in section 4.2.3. Under a morphological approach, this correlation would be merely accidental.

In view of the limitations and problems of a purely morphological explanation, the next sections (4.2.4.2 and 4.2.4.3) present an analysis that takes into account both the phonological (i.e., triggered by a minimally contrastive high vowel) and the morphological (i.e., triggered by an inflectional vowel) conditionings of metaphony in Lena (cf. Maiden 1991[57]).

4.2.4.2. Contrast-coindexing and the Lena vowel inventory

The relevant observations from the vowel harmony pattern in Lena are the following: (i) only inflectional high vowels initiate the process, and (ii) the trigger needs to be minimally contrastive for height. More precisely, inflectional [i], which does not have a mid counterpart and thus, is not minimally contrastive for height, does not have the capacity to initiate metaphony. Here, I represent the asymmetry in the Lena inflectional vowel inventory making use of contrast-coindices (section 4.2.4.2.1).

[57] Maiden (1991) argues that metaphony in varieties of Italy is conditioned both by morphology and phonology.

Furthermore, the inflectional vs. stem difference in vowel qualities and minimal contrasts suggests that the contrast-coindexing specification varies depending on the morphological status of the vowel. This leads to a revision of the contrast-coindexing function in order to incorporate these morphological considerations (section 4.2.4.2.2).

4.2.4.2.1 Contrast-coindexed representation for height

First, let us relate the observations from Lena with the contrast-coindexing proposal introduced in chapter 3. Remember that contrast-coindexing marks elements that enter in a minimally contrastive relationship along some dimension. In the case of Lena, the relevant dimension is height. The generalization that only an inflectional high vowel that is minimally contrastive for height can initiate the harmony implies that the trigger must differ with at least one other vowel along the height dimension only. In Lena, as section 4.2.2.2 showed, only inflectional /u/ and /o/ are minimally contrastive for height. As for the front vowel, even though it can surface as a high vowel, this vowel does not minimally contrast for height since it does not differ from any vowel only along the height dimension.

The definition of contrast-coindexing (see section 3.3) incorporates the notion of minimal contrast, so that only those segments that minimally differ from another segment along one dimension get a coindex assigned. An important characteristic of the contrast-coindexing function is that it adopts a systemic approach to contrast. It operates at the word level, taking the language's entire system into consideration. This means that, in the case at hand, the vowels of the Lena inflectional inventory are assigned their contrast-coindices by virtue of comparison with other members of the system.

Example (53) shows the contrast-coindexed representation for the Lena inflectional vowel inventory. Note that this representation is included only for the height contrast and it is illustrated with hypothetical words.

(53) Contrast-coindexing representation for height in Lena (h-subscript=height)

pik-**i** pik-$\mathbf{u_h}$

pik-$\mathbf{o_h}$

pik-**a**

As mentioned above, elements are assigned their contrast-coindices as a result of comparison with other members of the system. In example (53), the relevant comparison, i.e., minimal pair, that lead to contrast-coindexing for height of the inflectional vowels is [pik**u**] vs. [pik**o**]. These two words constitute a minimal pair since they differ in just one element, i.e., the final vowels [u] and [o], and these vowels only contrast in their height. Consequently, the words [piku] and [piko] are contrast-coindexed for height (h). As for other comparisons or minimal pairs, for instance [pik**i**] vs. [pik**o**] or [pik**i**] vs. [pik**a**], they do not lead to contrast-coindexing for height because their differing segments do not contrast only in height.[58] For example, in [pik**i**] vs. [pik**a**], the final vowels have different height and backness. Crucially, [pik**i**] does not have a paired form that only differs in the height of the inflectional vowel. For this reason, front vowels lack a contrast-coindex for the height dimension. This corresponds with the fact that front vowels are not minimally contrastive for height.

4.2.4.2.2 Contrast-coindexing and morphological structure

As argued earlier, the system of contrasts for stems and inflections needs to be considered separately in order to analyze Lena vowel harmony. Relevant here is that these two systems are not identical. Stems show a minimal height contrast for front vowels given that /i/ and /e/ are contrastive for Lena stems (see Table 19 in this chapter). Compare /p**i**na/ 'wood wedge' and /p**e**na/ 'rock'. Inflectional vowels, on the other hand, lack such a contrast. The contrast-coindexing analysis presented in the previous section does not include any morphological considerations.

It should be noted that not all words in Lena end in an inflectional vowel. This means that just making reference to the word-final position is not sufficient to account for the asymmetry between stems and affixes. Remember that in section 4.2.2.3, I mentioned that some words, such as adverbs, cannot be inflected and therefore, lack a word-final inflectional vowel. Crucially, these words do not show

[58] The comparison [piko] vs. [pika], I argue, does not lead to indexation for height. The vowels [o] and [a] differ in terms of their height and backness. Dimensions of contrast do not correspond to features. See section 3.4 for a more detailed discussion.

vowel harmony even when they end in a high vowel. This fact suggests that there exists a distinction between inflectional and non-inflectional vowels that cannot be subsumed under the word final vs. non-final distinction.

The question then is how contrast-coindexing can take into account the relevant morphological information. Integrating morphological information into the contrast-coindexing function, I argue that this function applies over stems and over affixes separately. This means that, in words that contain concatenated stems and affixes, different morphological categories are evaluated for minimal contrast independently of each other. It is worth noting that different allomorphs are taken into account for the contrast-coindexing evaluation. For example, within the stems set, all allomorphs are considered when assessing minimal contrast, indicating that any phonological alternation for a given stem, including those alternations triggered by an affix, is part of the set. I claim that this approach makes the right predictions for Lena. Lena inflectional vowels will be assigned their contrast-coindices as a result of comparison among themselves, without taking the stems into consideration. Under this view, the adjective [tónt_{stem}+$\text{o}_{inflection}$] 'dumb.mass' will have a height coindex for its inflection because this vowel minimally contrasts in height with the suffix [-u] 'masc.sg.count'. Whether the form *[tónt_{stem}+$\text{u}_{inflection}$] exists or not is irrelevant for contrast-coindexing of the suffixal element because this element is assessed for minimal contrast by comparison with other suffixes, independently of the stems.

Furthermore, harmonized stems will not be assigned a height contrast-coindex for their stressed vowel. For example, consider the stem in [$\text{tú nt}_{\text{stem}}$+$\text{u}_{\text{inflection}}$] 'dumb.masc.sg.', i.e., [tunt-], which has undergone raising from /o/ to [u]. This stem cannot constitute a minimal pair with another of the form [$\text{tónt}_{\text{stem}}$] because, given that the former stem corresponds to the latter, they both have the same meaning, 'dumb' in this case. This means that both forms correspond to the same input. One of the requirements to identify a minimal pair is that the two words have different meanings, i.e., correspond to different inputs. This prediction implies that a raised (i.e. harmonized) high vowel in the stem does not minimally contrast for height. This corresponds with a view of vowel harmony as an instance of contextual neutralization (Hansson [to appear]).

4.2.4.3 Lena vowel harmony as licensing of elements in weak positions

In this section, I integrate the contrast-coindexed representation for Lena into an analysis of the vowel harmony pattern observed in this variety. Here, I build on Walker's (2005) proposal, which views metaphony as licensing by strong positions, and extend it by including the notion of contrast-coindexing. First, I introduce the main details of Walker's licensing proposal, focusing on the perceptual motivation for some vowel harmony systems. Next, I analyze Lena as an instance of licensing of elements in weak positions. I claim that the licensing constraint driving the harmony requires that only height features in high vowels that are minimally contrastive for height be licensed by association to a strong position.

4.2.4.3.1 Licensing of elements in weak positions[59]

Walker (2005) presents an analysis of vowel harmony patterns triggered by elements in weak positions, e.g. unstressed syllables, that target stronger positions, e.g. stressed syllables. Clearly, Lena metaphony follows this pattern. The relevant insight of Walker's study is that vowel harmony may take place to improve perceptibility of a weak feature or an element in a weak position. More precisely, focusing on Veneto metaphony, she claims that height features of a high vowel, which are perceptually weak given their shorter duration and lower amplitude, in a weak position, i.e., post-tonic, need to be associated to a strong position such as a stressed syllable.

The phonetic motivation for metaphony is captured by a formal constraint that operates over perceptually weak structure. More precisely, this constraint requires weak structure to be licensed by a strong position. The relevant constraint takes the shape of a positional markedness licensing constraint (Walker 2004, 2005). Its general version is given in (54).

(54) License (F, S-Pos)

Feature [F] is licensed by association to a strong position.

where F is a specification that is perceptually difficult,

and/or F belongs to a prosodically weak position,

and/or F occurs in a perceptually difficult feature combination.

[59] Some recent work on vowel harmony adopting the licensing approach includes Revithiadou et al. 2005, Downing 2006, Bonet et al. 2007 and Jiménez & Lloret 2007.

For cases of metaphony, Walker (2005) proposes the more specific constraint in (55), which requires the height features of a perceptually weak high vowel in a weak unstressed syllable to be licensed by a strong stressed syllable.

(55) LICENSE (Height features$_{\text{[+high] post-tonic V}}$, σ́)

“Height features of a [+high] vowel in a post-tonic syllable must be associated with a stressed syllable. “

Metaphony produces alternations in stressed syllables, depending on the height of the inflectional vowel. This indicates that the licensing constraint in (55) outranks the positional faithfulness constraint in (56), IDENT-σ́-IO(high) (Beckman 1998), which militates against changing a [high] specification in a stressed syllable. The licensing constraint also dominates the more general IDENT-IO(high) (McCarthy & Prince 1995), which requires faithfulness among correspondent segments with respect to their [high] specification. These two faithfulness constraints are violated whenever the stressed vowel raises as a result of metaphony.

(56) IDENT-σ́-IO(high)

Let β be an output segment in a stressed syllable and α the input correspondent of β. If β is [γhigh], then α is [γhigh].

The tableau in Table 23 illustrates how the LICENSE constraint in (55) interacts with the positional faithfulness constraint in (56) and the general faithfulness constraint IDENT-IO(high). When the former dominates the latter, vowel harmony takes place and the top-ranked LICENSE constraint is satisfied as candidate (b) shows.

Table 23. License >> Ident-σ́(high), Ident(high)

/tont-u/	LICENSE[height]	IDENT-σ́(high)	IDENT(high)
a. t**ó**ntu | [+high]	*!		
☞ b. t**ú**ntu ╲| [+high]		*	*

4.2.4.3.2 Weak positions in Lena

Here, I extend Walker's approach by incorporating the contrast-coindexing proposal into the licensing constraints driving the harmony. In a nutshell, harmony *may* be triggered only by minimally contrastive segments. More concretely, Lena metaphony can be triggered only by segments that show a minimal contrast for height. This section presents the details of the analysis and motivates the licensing constraint that I propose to account for the metaphony pattern under study.

In Lena, the weak structure that must be licensed involves a perceptually weak segment, i.e., a high vowel, and also a morphologically weak position, i.e., the inflection (cf. Walker 2005). Remember that in this variety only inflectional vowels can initiate the raising process: high vowels in the stem are not triggers. This suggests that in Lena both perceptually weak structure and morphologically weak properties need to be licensed by association with a strong position, namely the stressed syllable. Walker (2005) presents other languages similar to Lena, where structure in a morphologically weak position is licensed by a strong position. For instance, vowel harmony in the Bantu language Nzɛbi is triggered by the suffix high vowel /-i/, which is a verbal marker (Guthrie 1968, Clements 1991). This inflectional vowel causes raising in the radical. The trigger in Nzɛbi constitutes weak structure for two reasons. This vowel is high and furthermore, it occurs in an affix. Similarly, in Vata, a plural suffix /-i/ causes optional raising of the stem mid vowels (Kaye 1982). This illustrates another case of a weak element in a morphologically weak position triggering the harmony.

As for the elements that must be licensed in Lena, all height features of the relevant high vowel seem to need licensing. This high vowel triggers raising of /a/ to a mid vowel, indicating that its [-low] feature is active in this case (see also Walker 2005). Finally, the licensing analysis needs to capture the observation that Lena harmony singles out as triggers only high vowels that are minimally contrastive for height, i.e., ones that are contrast-coindexed for this property.

I propose the licensing constraint in (57), which states what kind of structure needs to be licensed. More precisely, this constraint requires the height features of a minimally contrastive inflectional high vowel to be licensed by association with a stressed syllable. This constraint applies only for minimally contrastive high vowels in weak position.

(57) Proposed licensing constraint for Lena vowel harmony

LICENSE (Height features $_{\text{[+high]inflectional Vh}}$, σ́)

Height features in a [+high] desinential V_h must be licensed by a stressed vowel, where V_h stands for a vowel contrast-coindexed for height.

The tableaux in Table 24 exemplify how the licensing constraint in (57) works, which is abbreviated to LICENSE[height] in the examples.

Table 24. Tableaux showing how the licensing constraint in (57) works

(a) Metaphony triggered by contrast-coindexed inflectional [u]

/tont-u/	LICENSE[height]	IDENT(high)	IDENT(low)
a. t**ó**ntu$_{\mathbf{h}}$ | [+high]	*!		
☞ b. t**ú**ntu$_{\mathbf{h}}$ \\\| [+high]		*	

(b) Lack of metaphony: inflectional high vowel [i] is not contrast-coindexed for height

/vent-i/	LICENSE[height]	IDENT(high)	IDENT(low)
☞ a. vénti | [+high]			
b. vínti ╲| [+high]		*!	

Note that the tableaux in Table 24 include a simplified version of the analysis. They do not show how the inflectional vowels get contrast-coindexed for height (see section 4.2.4.2 and chapter 3 for a discussion). Also, in these tableaux each candidate is a single word but under the systemic approach adopted in this study, in fact each candidate is formed by a set of possible words (see section 3.3). The aim of these sample tableaux is to illustrate how the licensing constraint is evaluated against some potential candidates, and they are relevant as far as they fulfill this function.

Tableau (a) shows a form that has an inflectional high back vowel. From the discussion of the Lena inflectional inventory, I concluded that this vowel /u/ is minimally contrastive for height, and consequently, it gets a contrast-coindex for this dimension. Note that the candidates in tableau (a) include a height coindex (h-subscript) for this vowel. The licensing constraint requires the height features of contrast-coindexed inflectional high vowels to be associated with the stressed syllable.[60] Thus, this constraint is active for the evaluation in tableau (a). Candidate (a) violates the licensing constraint because the height features of the contrast-coindexed inflectional vowel are not associated with the strong position. On the other hand, candidate (b) satisfies this constraint by linking the height features in the suffixal /u/ with the preceding stressed vowel, resulting in a violation of the lower ranked IDENT(high).

Tableau (b) gives the evaluation for a form that has an inflectional high front vowel. Front vowels do not contrast for height, as was shown earlier. This implies that an inflectional [i] is not minimally contrastive for height, and therefore lacks a contrast-coindex for this dimension. The candidates in tableau (b) do not have a height coindex. For this reason, the licensing constraint is vacuously satisfied by both candidates because neither has a contrast-coindexed inflectional high vowel, so the metaphony does not need to apply. The tie between candidate (a) and (b) is resolved by the low ranked constraint IDENT(high). This constraint favors the more faithful candidate (b) over the candidate that shows raising of the stressed vowel, because the latter incurs a gratuitous violation of this IDENT constraint.

For a complete analysis of metaphony, I refer the reader to Walker (2005).[61] Given that the interest of the present study lies in the nature of the triggering vowels, I do not further develop the analysis to account for all the details of the vowel

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[60] The tableaux in Table 24 only show the [+high] feature of the inflectional vowel. This is the relevant height feature for these examples because it causes the alternation. But note that [-low] would also be shared given that all height features need to be licensed.

[61] Walker (2004, 2005) gives a more detailed analysis of metaphony considering different issues such as transparency of intervening vowels, the chain shift effect, i.e., the fact that /a/ raises to /e/ rather than all the way to /i/, etc.

harmony pattern. The main aim of this section was to present a way in which contrast-coindexing can be incorporated into a constraint evaluation of a given phonological phenomenon. In the case under study, Lena metaphony is sensitive to the contrast-coindexing of the trigger, and this fact is reflected in the formulation of the constraint triggering the harmony process (57).

4.2.5 Conclusion

The contrast-coindexing proposal provides a formal representation for minimal contrast, which augments the phonological output. This chapter presents evidence for the prediction that minimal contrast as contrast-coindices can be active not only in phonetic processes, as chapter 2 shows, but also in phonological phenomena. Concretely, metaphony in Lena illustrates a case where the trigger of the relevant process, i.e., harmonic raising, must have a certain coindex, namely a contrast-coindex for height. The data from Lena together the vowel harmony typology derived from related varieties from northwestern Spain further support the relevance of minimal contrast and support the incorporation of contrast-coindexing into the phonological representation.

4.3. Alternative: Underspecification

4.3.1 Introduction

This section considers an alternative approach to the metaphony pattern observed in Lena, i.e., underspecification of predictable information. Underspecification theories argue that certain phonological material might be underspecified at some phonological level such us the input or the output. This can explain why some features are phonologically active while other features are inert. Here, I consider how the contrast-coindexing proposal compares with underspecification theory, focusing on how these two approaches differ and have distinct consequences for phonology.

First, I give an overview of the different theories of underspecification, including Radical and Contrastive Underspecification and Modified Contrastive Specification, and also Input and Output Underspecification. The main arguments against underspecification of feature values are presented in the section 4.3.3. The comparison between contrast-coindexing and underspecification is developed in section 4.3.4, where I consider the status of unspecified features in Optimality Theory and then explain the predictions made by each approach. Contrast-coindexing is shown to account for the different observed phenomena, while underspecification faces different challenges that render this theory as unsatisfactory for several cases.

4.3.2 Types of Underspecification

4.3.2.1 Radical Underspecification

Radical underspecification (e.g. Archangeli 1984, 1988, Pulleyblank 1988) eliminates from the underlying representation feature values predictable from both context-sensitive and context-free markedness statements. Context-sensitive markedness refers to feature co-occurrence restrictions that express conditions on the possible feature combinations within a segment. These restrictions can take the shape of filters or rules. Context-free markedness makes reference to the asymmetrical distribution of individual features, whose value can be either marked or unmarked. This is reflected in context-free redundancy rules.

Radical underspecification includes in the underlying representation only unpredictable features. Values are considered predictable if either a context-free or a context-dependent rule can be formulated to insert them. Redundant and unmarked features are left out. Features that are not distinctive and the unmarked value of those that are distinctive are left out. For example, in a system such as that of Spanish, sonorants, for which voicing is non-distinctive, would be underspecified for voicing. Likewise, voiceless obstruents, for which [-voiced] is the unmarked voicing value, would be underspecified for voicing. As for place of articulation, [Coronal] would be underspecified due to markedness considerations. In the case of liquids, it would be underspecified due to liquids' non-distinctiveness for place.

Predictable values are inserted by rule during the course of derivation. Within Lexical Phonology (Kiparsky 1982, 1985) it is assumed that the ordering between redundancy rules and phonological rules is irrelevant and not set by any principle. Work outside Lexical Phonology (Archangeli & Pulleyblank 1989) proposes a Redundancy Rule Ordering Constraint by which redundancy rules inserting certain feature values apply before any phonological rule that makes reference to that value.

4.3.2.2 Contrastive Underspecification

Contrastive Underspecification (e.g. Steriade 1987, Mester & Ito 1989) eliminates feature values that are predictable from feature co-occurrence restrictions. The hypothesis is that contrastive features, whether marked or unmarked, are always present underlyingly. This follows from the scarcity of cases showing distinctive underspecification, i.e., the possibility that distinctive but unmarked values are missing underlyingly. Contrastive Underspecification assigns values to a feature in the underlying representation only when that feature is being used to distinguish segments. On the other hand, non-contrastive features are left unspecified.

The notion of distinguishing segments refers to cases where the only difference between two segments is that feature. Redundant features are left out, i.e., features that are not distinctive in the system. For example, in a system such as Spanish, only sonorants would be underspecified for voicing. As for place of articulation, coronals would be underspecified only for liquids since place is not distinctive for these consonants.

4.3.2.3 Modified Contrastive Specification

The theory of Modified Contrastive Specification (MCS) was set out by Dresher, Piggott and Rice (1994), and further elaborated by Dresher (1998a, 1998b, 2003a, 2003b). In addition, there are numerous studies that have applied MCS (e.g. Dyck 1995, Zhang 1996, Barrie 2002, 2003, Mackenzie 2002, 2005, D'Arcy 2004). See

Hall (2007) for references to the primary works.[62] The contrastivist hypothesis adopted in MCS states that the phonology of a language operates only on those features which are necessary to distinguish the phonemes of that language from one another (Hall 2007). A further claim of MCS is that only those features that are contrastive are specified in the phonological representation. Redundant feature values are always absent. This sets MCS apart from Radical and Contrastive Underspecification where features may be available to some rules but not to others. Under MCS, non-contrastive feature values are never active in the phonology (e.g. Dresher & Zhang 2004, Hall 2007).

MCS posits that contrastive feature specifications derive from ordering features into a contrastive hierarchy (Dresher et al. 1994, Dresher 1998a, 1998b; 2003b). The hierarchy can vary from language to language both in the features relevant for contrast in the language and their hierarchical ordering. This proposal is implemented through the Successive Division Algorithm. The basic idea behind this algorithm is that contrastive feature specifications are established by splitting the inventory by means of successive divisions, governed by an ordering of features. Let us explain the Successive Division Algorithm (SDA) in more detail. The initial assumption is that all sounds in a given language form one phoneme. This 'allophonic soup' is divided into two sets by whichever distinctive/contrastive feature is selected first. The algorithm keeps dividing the inventory into sets, applying successive features in turn descending through the contrastive hierarchy,

[62] Also, the web page for the MCS project (www.chass.utoronto.ca/~contrast) offers a complete list of relevant references.

until every set has only one member. As an illustration, let us take the inventory /i, y, u/ and the contrastive hierarchy round>back, according to which privative [round] has scope over privative [back]. First, [round] divides the inventory into two sets /i/ and /y, u/, the latter being specified as [round]. Second, [back] divides the set of round vowels into /y/ and /u/, the latter being specified as [back]. The resulting specifications are the following: /y/ is specified as [round], /u/ as [round, back] and /i/ is unspecified. Reversing the example contrastive hierarchy to back>round, where [back] has scope over [round], changes the inventory specification. [back] divides the inventory into /i, y/ and /u/, the latter being specified [back]. Next, [round] splits the set of front vowels into /i/ and /y/, the latter being specified as [round]. This results in the following specifications: /y/ is [round], /u/ is [back] and /i/ is unspecified.

Note that the algorithm gives different results depending on the ordering of the features, i.e., the contrastive hierarchy. The SDA can produce underspecification for some contrastive features, and which feature or features are absent depends on the hierarchy. Also, all feature specifications assigned by the algorithm are contrastive. Finally, it should be noted that the algorithm proposed by MCS, as well as Contrastive and Radical underspecification, applies over inventories rather than over words as the contrast-coindexing proposal does.

Dyck (1995) applies MCS to the analysis of vowel height harmony in Lena and other varieties from northern Spain. Focusing on vowel height features, Dyck argues that the privative feature [low] distinguishes low vowels from non-low ones.

She further maintains that the feature [high] does not appear in the vowel representation unless required in order to mark height contrasts in more complex inventories, for example in three-height systems. Accordingly, Dyck claims that in the varieties from northern Spain, including Lena, the feature [high] implies the presence of a feature [low]. So, the algorithm for adding height contrast to these inventories follows the contrastive hierarchy low>high, where [low] has scope over [high]. In a two-height system, low vowels are specified as [low], while high, i.e., non-low, vowels are unspecified for height features. On the other hand, in a three-height system the feature [high] is specified for high vowels. This means that [high] can be active only if height contrasts exist among the non-low vowels in a given system. Otherwise, the feature [high] is unspecified and thus, inactive.

Coming back to Lena, its asymmetrical vowel inventory for desinences has a height contrast between mid and high vowels only for the back vowel space. In MCS, this means that there should be only one specified [high] vowel in the back region. Given the contrastive hierarchy low>high proposed by Dyck, the low vowel /a/ would be specified as [low] and only the back high vowel /u/ would be specified as [high]. Finally, given the MCS representation of height features, Dyck argues that in the asymmetrical Lena system, only the high back vowel should be a possible trigger for a rule referring to the [high] feature. Since the front vowel lacks this feature, it would not be a possible trigger. According to Dyck, this would explain the vowel harmony pattern observed in this variety. However, as section 4.3.4.2 will show, there is evidence indicating that the front vowel is specified as [+high] and in fact, this feature is active in the phonology of Lena, undermining Dyck's MCS analysis of Lena.

4.3.2.4 Input underspecification

Input Underspecification claims that a segment which surfaces with some phonological material M is not specified for M in the input and it remains unspecified up to some later phonological level. An underspecified input is supplied with its featural specifications at some stage during the derivation or mapping to an output form. Radical and Contrastive Underspecification are examples of input underspecification since most versions of these theories assume that the output of phonology is fully specified (or at least more fully specified), despite the presence of underspecification at some earlier stage in the derivation.

Within Optimality Theory (OT), Input Underspecification has been proposed as an available option resulting from optimization with respect to the grammar, rather than as resulting from restrictions imposed on the underlying representation. (Inkelas 1994, 2006, Inkelas, Orgun & Zoll 1997, cf. Harrison & Kaun 2000). In OT, Richness of the Base rules out systematic exclusion of featural specification from input representations, given that the input is unrestricted. Lexicon Optimization (LO, Prince & Smolensky 1993, Ito, Mester & Padgett 1995) guides the construction of lexical representations and it favors fully specified inputs, under the assumption that the speaker will choose the most harmonic input-output mapping. Some authors (see above) claim that the model, nevertheless, leaves room for some underspecification at the input level.

Inkelas (1994) claims that one of OT's advantages is that underspecification is unnecessary in the analysis of various phenomena. However, she argues that underspecification is necessary in some cases, where its motivation is to capture alternations in an optimal way. This kind of Input Underspecification is proposed to be present only when there are alternant surface forms all of which are predictable from context or grammatical defaults. The relevant data involve cases of three-way contrasts in a single feature (positive, negative & underspecified). Inkelas (1994) presents voicing alternation in Turkish as an instance of Input Underspecification through optimization. In Turkish, some root final plosives alternate between being voiceless in coda positions and voiced in onsets. Some other forms lack this alternation and are always either voiced or voiceless, regardless of the syllabic position. The examples in (58) illustrate this pattern.

(58) Voicing (non)alternation in Turkish

(a)	[kana**t**]	'wing'	[kana**d**a]	'wing.acc.'
(b)	[devle**t**]	'state'	[devle**t**i]	'state.acc.'
(c)	[ety**d**]	'study'	[ety**d**y]	'study.acc.'

(58)a) shows alternation between voiceless and voiced. (58)b) has a non-alternating voiceless plosive, and (58)c) contains a non-alternating voiced plosive. Inkelas argues that the plosives that alternate are underspecified for the [voice] feature in the input, while those that do not alternate are specified for [± voice].

Note that under this optimized view of Underspecification, the output specification is determined by the ranking of structure-filling constraints. The output of phonology and the phonetic representation are more fully specified than the input.

4.3.2.5 Output Underspecification

Output Underspecification (also known as perseverant or surface underspecification) claims that a segment might be underspecified for some feature at the output of the phonology, i.e., some forms are never fully specified and lack a phonetic target for the relevant specification (e.g. Ito, Mester & Padgett 1995[63], Rice 1995, Steriade 1997, Hale & Kissock 2007, see Myers 1998 for tone underspecification). If some material is absent from surface representation, then it cannot be a target for phonetic interpretation. Consequently, the realization of underspecified outputs is characterized by the absence of articulatory or acoustic targets for one or more features. This results in an articulation which is determined by context, rather than by some feature value or values, and the existence of alternating articulations and corresponding acoustic results.

[63] Ito, Mester and Padgett (1995) argue that the output of the grammar might be underspecified. They do not say anything about the phonetic characteristics of an underspecified output.

Keating (1988) discusses the difference between underspecified and specified outputs. Specified features are stable and non-transitional. For example, if a segment acquires a feature value (e.g. through a context-filling rule) from an adjacent segment, it will share a phonetic property with that segment across most or all of its duration. On the other hand, underspecified features are continuous and transitional. If a contour is built through a segment due to underspecification, it will have a more or less continuously changing, transitional quality from beginning to end that will depend on preceding and following context (Keating 1988, see also Cohn 1993).

4.3.3 Arguments against underspecification

Underspecification faces theoretical and empirical issues that have been discussed elsewhere in the literature (e.g., Kingston & Solnit 1989, Mohanan 1991, McCarthy & Taub 1992, Smolensky 1993, Steriade 1995, Inkelas 1994, Baković 2000, Pulleyblank 2003). The main principles proposed (to differing degrees) by most versions of (pre-OT) input underspecification are that unmarked material is underspecified, redundant feature values are underspecified, and predictable material is underspecified. Inkelas (1994) notes that counterexamples to these three principles have been presented in the literature.

Radical Underspecification, which underspecifies redundant and marked feature values, has been challenged by observations that markedness is not universal (e.g. Mohanan 1991). What is marked in one language could be unmarked in another and vice versa. For example, Radical Underspecification predicts that the epenthetic vowel should have an unmarked value. However, the epenthetic vowel varies from language to language, for example, from [i], [u], [ə] to [a] (Mohanan 1991). This type of underspecification has also been challenged by studies arguing that phonological well-formedness constraints rather than underspecified representations are the best means to handle markedness effects (Smolensky 1993). Relatedly, Rice (2007) shows that it might be impossible to identify a single feature or feature value of an opposition as unmarked cross-linguistically in terms of its phonological patterning. The feature which patterns as unmarked can differ from language to language. However, Rice (2007) notes that this cross-linguistic variation is constrained to a certain extent, with only certain features demonstrating unmarked patterning in a given set of contrasts.

Morpheme Structure Constraints have been presented as evidence against underspecification (Mester & Ito 1989, Mohanan 1991). These constraints may restrict the morpheme-internal segmental structure. For instance, some languages place restrictions on root consonantism, following the generalization that homorganic consonants cannot co-occur within the same root. According to Radical Underspecification such restrictions should not hold for unmarked place features, such as [Coronal]. The facts contradict this prediction since the homorganicity restrictions hold for all places of articulation. For instance, Arabic and Russian impose restrictions on their roots so that homorganic consonants, including coronals, cannot cooccur with the same root (see McCarthy (1988) for Arabic and Padgett (1995) for Russian). In these cases, the Morpheme Structure Constraint gives no special status to the unmarked place.[64] Thus, lexical presence of non-redundant unmarked features is required for an explanation of these restrictions.

Underspecification theories introduce a number of redundancy rules and cooccurrence filters that are ordered with respect to other phonology rules according to the Redundancy Rule Ordering Constraint (Archangeli & Pulleyblank 1989) or to different levels in Lexical Phonology. This results in a grammar with an overpredictive capacity. Steriade (1995) points out that attempts to impose universal limitations on the possible orderings of different rule types have met with only limited success. Furthermore, there is evidence that in some cases there is no single ordering among the different rules that will derive the correct output. These are cases where there is a stage at which the features in question are active that is earlier than one at which those features must be underspecified (inactive). This situation implies that the underspecified features might be active at some point, and inactive at a later stage, giving rise to what is known as an Underspecification paradox (Ito, Mester & Padgett 1995). English illustrates an instance of a paradox along these lines.

English presents a counterexample for an underspecification analysis. Previous work argues that English coronals, the unmarked place of articulation for consonants, are underspecified for place based on the following evidence. Coronals are not subject to a restriction that bans sC_1VC_2 sequences when C_1 and C_2 are hormorganic (Davis 1991). For example, */skig/ is not allowed but /stid/ is fine. Moreover, coronals act as unspecified for place with respect to a constraint

[64] Note that [Coronal] appears to show a special status with respect to some other phenomena as discussed in papers collected in Paradis & Prunet (1991).

prohibiting consonant clusters with more than one place of articulation (Yip 1991). For instance, the clusters /sk/ and /ft/ are permitted but */fk/ is not. Finally, English coronal nasals optionally assimilate to a following oral consonant in place of articulation. Non-coronal nasals do not assimilate (e.g. [tɛŋkɪŋz] *ten kings*, *[sʌŋkɪŋz] *some kings*).[65] Note that this assimilation occurs across words, indicating that this process is post-lexical. Underspecification would assume that coronals, being the unmarked place of articulation, are underspecified for place features. However, English has several phonological phenomena that take place at the lexical level (stratum 1, Mohanan 1991) that require alveolars to be specified for place. There are some syllable structure restrictions that disallow a sequence of two non-continuant coronals in the onset (e.g. */dl-/). Fricativization applies to alveolar stops, but not to labials or velars, in some derivational processes (e.g. [dɪvaɪd] *divide* vs. [dɪvaɪsɪv] *divisive*). Finally, the voiceless alveolar fricative undergoes voicing in certain environments (e.g. [sɑlv] *solve* vs. [dɪzɑlv] *dissolve*, see Myers 1999 for a detailed description). Thus, these phenomena call for the presence of the coronal place feature when they apply (see McCarthy & Taub 1992 for more evidence). But early coronal specification is incompatible with the claim that lexical underspecification persists at early stages of the derivation, and even into the post-lexical phonology. This is an underspecification paradox: coronals must be

[65] Morpheme internally both non-coronal and coronal nasals assimilate.

underspecified for later stages in the phonology of English but they are specified for several earlier patterns.[66]

Yoruba shows another problematic case for underspecification theory.[67] The pattern in question comes from a process of [ATR] harmony that is active in this Niger-Congo language. The vowel inventory for Yoruba is given in Table 25 (following Baković 2000).

Table 25. Yoruba vowel inventory

<table>
<tr><td></td><td>Front</td><td>Central</td><td>Back</td><td></td></tr>
<tr><td>High</td><td>i</td><td rowspan="3"></td><td>u</td><td rowspan="2">[+ATR]</td></tr>
<tr><td rowspan="2">Mid</td><td>e</td><td>o</td></tr>
<tr><td>ɛ</td><td>ɔ</td><td rowspan="2">[-ATR]</td></tr>
<tr><td>Low</td><td></td><td>a</td><td></td></tr>
</table>

In Yoruba, the segmental structure of bisyllabic stems[68] is determined by the following restrictions. In forms with mid vowels only, the two vowels must agree in their value for [ATR]; thus, the sequences [eCe] and [ɛCɛ,] are allowed while *[ɛCe] and *[eCɛ] are disallowed.[69] If the final root vowel is the low vowel [a], then the preceding vowel, if mid, must be [–ATR]. This rules out the sequence *[eCa] while

[66] Ito, Mester & Padgett (1995) discuss another underspecification paradox in Japanese. Voicing for sonorants is inactive for Rendaku and Lyman's Law. However, obstruent voicing is triggered by nasal consonants. The paradox comes from the fact that voicing in obstruents due to assimilation to an adjacent nasal are visible for Rendaku and Lyman's Law. A further paradox comes from the behavior of [i] in Yoruba. This case is explained in section 4.3.4.2.

[67] The argument against underspecification from Yoruba and Pulaar builds on the observation by Mohanan (1991) that underspecification rules out non-contrastive features as possible triggers.

[68] See Baković (2000: 138) for a discussion arguing that the bisyllabic stems displaying the [ATR] harmony are composed of two morphemes, i.e., a root and a prefix.

[69] The Yoruba restrictions are exemplified using mid front vowels but the same applies to mid back vowels.

allowing the sequence [ɛCa]. [a] can precede [+ATR] and [-ATR] mid vowels ([aCe], [aCɛ,]). High vowels may follow or precede any vowel. Sequences of the shape [iCe], [iCɛ], [eCi], [ɛCi], [iCa], [aCi], [iCi], [aCa] are permitted.

The generalization is that two vowels must agree in [ATR] except when the first vowel is low or high, and when the second vowel is high. This pattern has been analyzed as an instance of right-to-left spreading of the [ATR] feature. Relevant here is the behavior of [a]. This low vowel can trigger the harmony but it fails to undergo it, unlike high vowels, which both fail to trigger and undergo the harmony. Within an underspecification approach (radical or contrastive), [ATR] values for low and high vowels would be underspecified since they are not contrastive in terms of [ATR]. On the other hand, mid vowels would get an specification for [±ATR] because this feature if distinctive among these vowels. Consequently, underspecification predicts that low and high vowels should not be triggers of the [ATR] harmony process, given that segments underspecified for some feature value cannot trigger a process that manipulates that value. However, the data from Yoruba show that [a] does in fact trigger this harmony.

Pulaar presents an even more problematic case for the underspecification premise that predictable features cannot be active in the phonology. In this language, [ATR] harmony is triggered by all the vowels in its inventory, regardless of whether their [ATR] value is predictable or not (Paradis 1992, Krämer 2003). Table 26 shows the Pulaar vowel inventory.

Table 26. Pulaar vowel inventory

	front	cent	back	
High	i		u	[+ATR]
Mid	e		o	
	ɛ		ɔ	[-ATR]
Low		a		

The [ATR] value for a mid vowel is determined by the [ATR] value of the following vowel. Mid, low and high vowels trigger harmony in a preceding mid vowel. Pulaar [ATR] harmony is a right-to-left process and it normally applies from a suffix to the root (Krämer 2003, Sasa 2003). The language is strictly suffixing. Nouns carry a class marker and verbs are followed by inflectional affixes. Hence, roots never occur without an affix. If a root has a mid vowel, it is thus not possible to determine the underlying [ATR] value of this vowel. The examples in (59) illustrate the harmony process. The forms in (59)a) show that mid vowels in the root alternate in their [ATR] value depending on whether they are followed by a [+ATR] or [-ATR] vowel in the affix. The alternations in (59)b) indicate that high and low vowels also trigger the harmony.

(59) Examples of Pulaar [ATR] harmony.

(a) lef-el	lɛf-ɔn	'ribbon dim. sg. & plural'
dog-oo-ru	dɔg-ɔw-ɔn	'runner & dim. plural'
(b) beel-i	bɛɛl-ɔn	'puddles & dim. plural'
ɓet-ir-dɛ	ɓɛt-dɛ	'to weigh with & to weigh'
ser-du	sɛr-ɔn	'riffle butt & dim. plural'
feyy-u-dɛ	fɛyy-a	'to fell & imperfective'

As for the targets, only mid vowels undergo harmony. High and low vowels never show alternations for their [ATR] value. When they occur in a non-final syllable, where high or low vowels are potential targets, the disharmonic form is preferred to a reversal of the regressive assimilation pattern. The forms in (60) show the immunity to harmony of these vowels. High vowels are always [+ATR], and the low vowel is inalterably [-ATR].

(60) High and low vowels fail to undergo harmony in Pulaar

paɗ-el	paɗ-ɔn	'shoe dim. sg. & plural'
	dill-ɛrɛ	'riot'
	fuy-ɛrɛ	'pimple'

Summarizing, only mid vowels are targets of the process. However, all vowels, i.e., high, mid and low, trigger [ATR] harmony in Pulaar. This behavior is problematic for underspecification since it predicts that predictable information should not be active in the phonology.[70] Let us develop the counterargument for this claim that comes from Pulaar harmony. Looking back at the Pulaar vowel inventory in Table 26, it can be seen that the only vowels which can have either tongue root position are the two mid vowels. High vowels always have an advanced tongue root position while the only low vowel always has a retracted tongue root position. This means that [ATR] is contrastive only for mid vowels. For high and low vowels, [ATR] is predictable from their height specifications. According to underspecification theories, the [ATR] value for high and low vowels should not play an active role in the phonology of the language. However, as the generalizations drawn from vowel harmony indicate, the [ATR] specification for these vowels is capable of triggering a process of harmony in preceding elements, bringing evidence to the active status of this value in the phonology of Pulaar.

4.3.4 Contrast-coindexing vs. underspecification

In this section I compare the contrast-coindexing proposal with an underspecification account of the facts under study here. Remember that the claim made by contrast-coindexing is that minimal contrast needs to be incorporated into the phonological representation because it is relevant for phonetic patterns and phonological processes. Given that contrast-coindexing is couched within Optimality Theory, first I consider the status of underspecification within this framework. Next, I present the

[70] Pulaar makes a counterargument for this strong underspecification claim. But it is compatible with an approach under which harmony applies in this language after predictable features are specified.

different predictions made by contrast-coindexing and underspecification and show how contrast-coindexing is superior in explaining certain patterns, including Lena metaphony.

4.3.4.1 Optimality Theory and underspecification

Optimality Theory is an output-oriented framework, which means that any intermediate stages are dispensed with in favor of parallel evaluation of constraints (at least in the traditional, non-serial versions of this theory). Thus, given that there is no serial derivation in OT, there are no *parts* of the phonological derivation that could be characterized by underspecification. Within OT, the only levels at which forms could be underspecified would be the input or the output.

Input underspecification seems incompatible with the output orientation of OT, more precisely, with the Richness of the Base principle. However, this principle does not in and of itself ban the use of input underspecification. It is the crucial use of input underspecification in statements like "affix vowels are not specified in the input for the feature [F]" and "only [αF], and not [–αF], is specified on vowels in the input" that is prohibited by the Richness of the Base principle. In fact, previous studies have shown that input underspecification might be the result of Lexicon Optimization (Inkelas 1994, Inkelas et al. 1997, cf. Smolensky 1993, Beckman 1997 for only fully specified inputs).

The condition of relevance here is that the grammar does not contain a separate constraint system governing inputs which could enforce a particular degree of (under)specification. The constraint ranking should be able to select the correct output form irrespective of the degree of input (under)specification. In OT, the input could potentially be underspecified but the surface form is crucial for assessing the different phonological phenomena in a given language. This means that the process has to be surface-true, regardless of the input.

Recall that this dissertation is concerned with the representation of minimal contrast. In relation to this, it is important to consider the use of underspecification to signal the contrastive status of features. A possibility worth considering here is the existence of an underspecification algorithm or function that applies to inputs before they go into GEN. This algorithm would give out inputs that might be fully specified or have some degree of underspecification. Clearly, how to implement such an algorithm is not a straightforward task and might in fact, prove unattainable. But the relevant point is that, even if input underspecification could be secured in the system, an unspecified candidate would not necessarily be selected as the optimal one. This would therefore blur any possible explanatory power of underspecification with respect to the role of minimal contrast in certain processes. This results from the fact that such an underspecification approach mixes two things. On the one hand, phonological processes might change surface contrasts and make features specified or unspecified. On the other hand, contrastivity would rely on the presence or absence of features in the input. However, this is not a reliable indicator of contrast. Something might have been underspecified but then underwent assimilation or some other process so that it became specified. Such an approach blurs results since it equates being specified with being contrastive. Note that contrast-coindexing does not run into this problem since it separates contrastivity from the result of phonological processes. The contrastive status of the different elements in a language are evaluated based on the output representation.

The argument about the inability of underspecification to reliably indicate contrast carries over to serial version of OT (e.g. Kiparsky 2000, to appear, Ito & Mester 2002, 2003, Bermúdez-Otero [in prep]). Recall that the claim put forth here is that the output of phonology should include information about minimal contrast since, as seen in chapter 2, contrastivity plays a role in phonetic patterns. In a serial approach to OT, the output of phonology would arguably be the output of the last level or stratum. As explained earlier, the final optimal candidate would not necessarily be unspecified since phonological processes might make feature values specified. This would also be the case in a serial OT framework.

4.3.4.2 Differences between contrast-coindexing and underspecification

This section discusses the differences between underspecification (Radical and Contrastive Underspecification, and Modified Contrastive Specification) and contrast-coindexing with respect to their implications for phonological phenomena. The focus is on the predictions made by each approach as to what elements may be a trigger, target or both in a process that involves the element in question. Table 27 presents these predictions.

Table 27. Predictions made by underspecification and contrast-coindexing[71]

UNDERSPECIFIED ELEMENTS	NON-CONTRAST-COINDEXED ELEMENTS
-cannot be triggers	***-may be triggers***
-may be only targets	-may be only targets
-may be not targeted[72]	-may be not targeted
SPECIFIED ELEMENTS	**CONTRAST-COINDEXED ELEMENTS**
-will be only triggers	***-may be only triggers***
-may be only targets	-may be only targets
-may be not targeted	-may be not targeted

The predictions in Table 27 show that the main difference between both approaches is that a non-contrast-coindexed element can be both a trigger and a target, whereas an underspecified element cannot function as a trigger. Only specified elements may be triggers. This means that underspecified elements cannot be active in a process that calls for that feature (or feature value). On the other hand, non-contrast-coindexed elements may be phonologically active, implying that these

[71] The following table presents the predictions made by underspecification theory and contrast-coindexing with respect to transparency and blocking. These complement the predictions in Table 27. A word is necessary about how underspecified elements might be blockers. These elements might lack the relevant feature node targeted by a process. Assuming that the process needs to be local, then it will not be able to skip over an underspecified element (Archangeli & Pulleyblank 1987).

UNDERSPECIFIED ELEMENTS	NON-CONTRAST-COINDEXED ELEMENTS
-may be transparent	-may be transparent
-may be blockers	-may be blockers
SPECIFIED ELEMENTS	**CONTRAST-COINDEXED ELEMENTS**
-may be transparent	-may be transparent
-may be blockers	-may be blockers

[72] Underspecified elements will not be targeted in those cases where they lack the relevant feature node targeted by a given process.

elements can display a dual behavior: they may be relevant or active for some process but inactive for some other one. The reason for this behavior is that property that is not minimally contrastive is present in the representation and thus, a potential trigger, although it lacks a contrast-coindex. Consequently, a phonological process might make reference to all elements with that feature or property regardless of their contrast-coindexing status (i.e., both minimally and not minimally contrastive), or only to those with a contrast-coindex. According to the contrast-coindexing proposal, we expect to find cases where a feature that does not participate in a certain process is active for some other pattern.

The behavior of /i/ in Standard Yoruba illustrates such a case. The featural specification of the high front vowel seems to be inactive in an assimilatory process that otherwise treats all other vowels similarly. Yoruba has a total regressive assimilation process that applies in vowel hiatus contexts across words within a noun phrase (Pulleyblank 2003). However, when the word-initial vowel is [i], this vowel assimilates to the word-final one. Note that /u/ does not occur word-initially in Standard Yoruba. The examples in (61) illustrate the assimilation pattern.

(61) Yoruba total assimilation across words

/ow**ó** **a**dé/ → [ow**á** **a**dé] ‘money of Ade’

/ar**á** **ì̲**lú/ → [ar**á** **à**lú] ‘townsman’

Underspecification has been proposed to account for this special behavior of /i/ in Yoruba. Under this approach, the high front vowel is maximally underspecified for all features (Pulleyblank 1988). However, there is evidence showing that some processes in Yoruba, such as /r/-deletion, make explicit reference to the [+high] specification for /i/ (Pulleyblank 2003). /r/ deletes between two identical vowels and adjacent to a high vowel. This pattern is problematic for the underspecification account since Yoruba /i/ would be underspecified/inactive for assimilation, but specified/active for some other. An underspecified representation for /i/ predicts that this vowel should not be able to trigger any process. Note that assimilation is a post-lexical phenomenon since it applies across words (see (61) above), and /r/-deletion belongs to the lexical phonology of Yoruba (Mohanan 1991). This means that not even a relative ordering between these processes and the redundancy/coocurrence rules will be able to account for the observed pattern.

Lena also exemplifies a case where a non-minimally contrastive element, the high front vowel, is both present and absent in the phonology. As section 4.2 showed, metaphony in Lena is triggered only by inflectional high vowels that are minimally contrastive for height. The nominal paradigm indicates that /u-o/ are contrastive in the language. However, Lena lacks a contrast between affixal /i-e/. Consequently, the front vowel in this variety does not have a contrast-coindex for height (section 4.2.4.2). The facts from Lena metaphony could seem also compatible with an underspecification account that considers the front vowel as underspecified for height. This would explain its inactivity during harmony. For example, Dyck

(1995) pursues an analysis along this line within the framework of Modified Contrastive Specification (see section 4.3.2.3 for an overview of Dyck's analysis).

However, there is evidence indicating that inflectional [i] is not underspecified for height. First of all, there is evidence to support that the realization of this high front vowel has a phonetic target for height (section 4.2.2.2) suggesting that this property is not underspecified in the output. Certain work adopting output underspecification shows that this kind of representation lacks a phonetic target so its realization is variable and fully dependent on neighboring sounds (Keating 1988). For instance, Choi (1992) found that vowels in Marshellese do not have a target for back and, consequently, this quality is determined mainly by surrounding consonants. The Lena front vowel is realized as [i] under certain conditions (section 4.2.2.2) and crucially, in these circumstances its production is not variable from [e] to [i]. This vowel surfaces as either [e] or [i] but not something inbetween as an output underspecification approach would predict. In fact, the front vowel seems to get a [+high] feature due to assimilation to other elements within the same word. For instance, when the stressed stem vowel is [i], the inflectional element tends to be pronounced as [i]. The sources consulted for this study provide a limited number of examples showing this assimilation. However, they do not point to any limitations in the number of syllables that might separate the stressed vowel and the inflectional one. Thus, based on the description of the sources, it seems plausible that there could be cases with an intervening vowel between the trigger and the target. These words would show that the process implies assimilation of [+high] rather than a phonetic effect present only at the surface level.

A more concrete piece of evidence against an underspecification account of Lena front vowels is that [i] may occur as the result of analogy to words from the same semantic field that have an inflectional [i]. The forms triggering analogy have an inflectional [i] as a result of the assimilation process explained above. The aim here is not to present a full fleshed-out account of analogy but rather to point out that analogy involves the copy of a phonological feature from one form into another (Bybee 1985, Burzio 1999, 2000, Zuraw 2000, Rose & Walker 2004). The term analogy has been used to refer to semi-systematic lexical exceptions to otherwise general sound patterns. The basic insight is that such exceptions arise through the influence of other lexical items, specifically items that are related phonologically or non-phonologically, for example morphologically or semantically. In Lena, analogy applies at the phonological level (given the assumptions of the above-cited work), resulting in the transfer of the vowel height features from a semantically-related word to another. This means that the high vowel has a specified representation for its height features. Note that Lena analogy illustrates a process triggered by an element that is not contrast-coindexed for height, which is one of the predictions in Table 27. Lena analogy is triggered by a non-contrast-coindexed inflectional [i]. This analogical process also targets a non-contrast-coindexed inflectional front vowel.

4.4 Further cases

In this section, I introduce another case where minimal contrast plays a relevant role for some phonological phenomena. I show that the contrast-coindexing proposal provides a sound account for this case by making explicit reference to the contrast-coindices as indicators of the minimal contrast status of the different elements in a given language. Table 28 includes the predictions made by contrast-coindexing (repeated from Table 27) together with sample language cases. The following section considers the prediction that contrast-coindexed elements may not be targeted, presenting a case study from Gaagudju in order to illustrate how a contrast-coindexing analysis can explain the observed facts. Note that previous sections (4.2.4 and 4.3.4.2) already examined the predictions that contrast-coindexed elements may be the only triggers (e.g. Lena metaphony) and that non-contrast coindexed elements may be triggers (e.g. in Yoruba and Lena analogy). This section also argues that not only markedness but also faithfulness constraints can make reference to contrast-coindices. The analysis of Lena metaphony relied on a markedness constraint mentioning the contrast-coindex for height. Gaagudju illustrates a case where faithfulness constraints could require identity of contrast-coindexed output elements.

Table 28. Predictions made by contrast-coindexing and sample language cases

NON-CONTRAST-COINDEXED ELEMENTS	
Prediction	**Sample language case**
-may be triggers	Lena analogy, Yoruba
-may be only targets	Gaagudju retroflex harmony
-may be not targeted	Pulaar [ATR] harmony[73]
CONTRAST-COINDEXED ELEMENTS	
Prediction	**Sample language case**
-may be only triggers	Lena harmony
-may be only targets	Pulaar [ATR] harmony
-may be not targeted	Gaagudju retroflex harmony

4.4.1 Gaagudju

Let us consider another prediction made by the contrast-coindexing proposal, namely that a non-coindexed element might be the only target of a given process (see Table 28). It is necessary to explain how this state of affairs comes about under the contrast-coindexing approach. The prediction in question follows from the assumption that constraints might make reference to the presence of certain coindices. Crucially, they cannot make reference to the lack of coindices. This stems from the idea that phonological rules do not refer explicitly to zero. But then, how can non-contrast-coindexed elements be singled out as the only undergoers? Notice that this corresponds to instances where a contrast-coindexed element is not targeted.

These cases, where the only target of a process is a non-contrast-coindexed

[73] Pulaar [ATR] harmony is compatible with a contrast-coindexed analysis. Recall that this process only targets mid vowels but is triggered by all vowels. Mid vowels are the only Pulaar vowels that are minimally contrastive for [ATR] in the language. Thus, the observation is that only vowels that are minimally contrastive for [ATR] are possible targets. I do not develop a full analysis here.

element, can be analyzed as the result of constraint interaction. The relevant conflict would be between a constraint initiating the process and a faithfulness constraint protecting contrast-coindexed elements. If the faithfulness constraint dominates the constraint triggering the phenomenon, then only non-coindexed elements would be targeted by the process. This further assumes that the faithfulness constraint preserving the relevant element in general, regardless of its coindexing, is low ranked. In order to illustrate this analysis, I introduce data from the Australian language Gaagudju, which has a pattern of retroflexion harmony where the target is a consonant that is not minimally contrastive for retroflexion.

Australian Aboriginal languages tend to have up to a four-way contrast among their coronal consonants. These are usually divided into two categories: apical, where the active articulator is the tongue tip, and laminal, articulated with the tongue blade. Within each of these two categories, further subdivisions are made on the basis of the place of articulation. The laminal sounds can be dental or alveopalatal, while the apical sounds can be alveolar or retroflex.[74] Gaagudju belongs to a group of languages that only show a three-way contrast among its coronal consonants: apico-alveolar, apico-retroflex and lamino-alveopalatal (Hamilton 1993, 1996, Harvey 2002). The Gaagudju consonant inventory is given in Table 29.

[74] The precise terms used for the different places of articulation vary depending on the source. I adopt the terms that are more common and widely used in recent research on Australian languages.

Table 29. Gaagudju consonant inventory

	Labial	Alveolar	Retroflex	Alveopalatal	Velar
Stop	p	t	ʈ	c	k
Nasal	m	n	ɳ	ɲ	ŋ
Lateral		l	ɭ		
Trill		r			
Approximant	w		ɻ	j	

The contrast between alveolars and retroflexes is illustrated by the (near) minimal pairs in (62) taken from Harvey (2002).

(62) Alveolar vs. retroflex contrast in Gaagudju

pa**t**a	'leg'	pa**ʈ**a	'beeswax'
wa**n**miri	'grey hair'	wa**ɳ**malaj	'mud'
pa**l**apumu	'to talk'	pa**ɭ**apumu	'to sing'
ca**r**a	'he went down'	ca**ɻ**a	'beard'

Like in other Australian languages, the alveolar vs. retroflex contrast is maintained only post-vocalically. This contrast is neutralized in word-initial positions. In Gaagudju, word-initial apicals are consistently realized as alveolar (Hamilton 1996). Butcher (1995) notes that word-initial apicals seem to represent an original single phoneme which has failed to 'split', as it exists in postvocalic positions, rather than, a merging of two originally contrasting sounds. Interestingly, these word-initial apicals undergo retroflex assimilation when followed by a retroflex consonant within the same word (Hamilton 1993, 1996, Butcher 1995, Steriade 1995, Gafos 1999, Hansson 2001, Harvey 2002). Assimilation does not target apicals in any other position. Also, non-apicals are reported not to undergo assimilation. Examples in (63) illustrate this pattern.

(63) Retroflex harmony in Gaagudju (Harvey 2002)

(a)	**ʈ**eeɳmi	'again'
	ɳaʈeeɲmar	'water snake'
(b)	**n**aawu	'pronoun.3rd sg. masc.'
	niiɲja	'just'
(c)	**k**oɳmu	'morning'
(d)	mon**t**aɳbu	'they finish'

In (63)a) the word-initial apical agrees in retroflexion with the following consonant. The forms in (63)b) show that the initial apical does not assimilate to the place of a following non-retroflex consonant, indicating that only retroflex elements can trigger the process. (63)c) shows that a non-apical initial consonant [k] fails to undergo the assimilation. Finally, the alveolar apical in (63)d) fails to assimilate to the preceding retroflex, indicating that assimilation only targets word-initial elements.

The main generalization from Gaagudju is that apical consonants are targeted by retroflex harmony only when they are not minimally contrastive for retroflexion, namely word-initially. Minimally contrastive apicals fail to undergo the harmony. This observation can be accounted for by the contrast-coindexing proposal, according to which those elements minimally contrastive for retroflexion are coindexed for this property. Apicals in word-initial positions are not contrast-coindexed for retroflex, whereas apicals in other positions bear such a coindex. Here, the focus is on the target of harmony rather than on the trigger or the constraint driving the process. Following Ní Chiosáin & Padgett (1997), I analyze the harmony process as being triggered by a SPREAD constraint requiring that the retroflex feature of an apical consonant is associated with a preceding apical consonant[75].

(64) SPREAD-L-[retroflex][76]

A [+retroflex] feature associated with an apical segment S_α is also associated to any apical segment S_β that precedes S_α.

The constraint in (64) conflicts with the faithfulness constraint that preserves the retroflex specification of consonants, IDENT-IO[retroflex]. If SPREAD dominates IDENT, then all apicals would assimilate to a preceding retroflex consonant. On the other hand, if IDENT is ranked above SPREAD, then assimilation does not apply at all. The facts from Gaagudju do not accommodate to either of these two situations. In

[75] I adopt Ní Chiosáin & Padgett's (1997) spreading constraint but do not argue for or against it. As noted in the main text, the constraint driving the harmony is not crucial in the analysis but rather what consonants can be targeted by the harmony. This results from constraint interaction.

[76] The harmony domain is not totally clear from the descriptions of the language. It seems to be either the word or the morpheme but without any further clarifications, I decided to exclude the domain of application for the constraint.

this language, assimilation is limited to apicals that are not minimally contrastive for retroflex, i.e., apicals in word-initial position. The contrast-coindexing proposal allows us to account for this situation: vowels with a contrast-coindex for retroflex are not affected by the harmony. This can be captured by introducing a faithfulness that makes reference to contrast-coindexed elements, given in (65).

(65) IDENT-IO[retroflex]$_{\mathbf{R}}$

Let $\beta_{\mathbf{R}}$ be an output segment contrast-coindexed for [retroflex] and α the input correspondent of β. If $\beta_{\mathbf{R}}$ is [γretroflex], then α is [γretroflex].[77]

IDENT-IO[retroflex]$_{\mathbf{R}}$ preserves the retroflex value of elements that are contrast-coindexed for [retroflex]. Word-initial apicals in Gaagudju are not contrast-coindexed for this property. Therefore, the constraint in (65) is silent about any changes that these apicals may undergo. However, the general IDENT-IO[retroflex] constraint bans modification of any apical. The ranking between the three relevant constraints is shown in (66).

(66) IDENT[retroflex]$_{\mathbf{R}}$ >> SPREAD-L-[retroflex] >> IDENT[retroflex]

[77] Note that retroflex is assumed to be binary here and the contrast-coindex for retroflex is assigned to both [+retroflex] and [-retroflex] segments.

The tableaux in Table 30 illustrate how this ranking works for a word that undergoes retroflex harmony (a), and for a form that does not undergo the assimilation (b).

Table 30. Tableaux illustrating the analysis for Gaagudju retroflex assimilation

(a) **ʈ**ee**ɳ**mi 'again' → retroflex harmony

/teeɳmi/	IDENT[retroflex]$_R$	SPREAD-L-[retroflex]	IDENT[retroflex]
☞ a. ʈeeɳmi			*
b. teeɳmi		*!	

(b) mon**taɳ**bu 'they finish'→ no retroflex harmony

/mon**taɳ**bu/	IDENT[retroflex]$_R$	SPREAD-L-[retroflex]	IDENT[retroflex]
a. montʈ$_R$aɳbu	*!		*
☞ b. mont$_R$aɳbu		*	

In tableau (a), the potential target of the SPREAD constraint is a word-initial apical. This consonant lacks a contrast-coindex for retroflex because apicals in this position do not contrast for retroflexion.[78] For this reason, IDENT[retroflex]$_R$ is not violated by either candidate. Thus, the lower ranked constraint SPREAD-L-[retroflex] is crucial in selecting the optimal candidate. Candidate (b), which fails to undergo assimilation, fatally violates the SPREAD constraint and it is ruled out. Candidate (b), the actual winner, incurs a violation of the low ranked faithfulness constraint but it satisfies the constraint driving the harmony. In tableau (b), the potential target of the

[78] Section 2.5.2.5 explains how contrast-coindexing treats neutralization, i.e., how segments in neutralizing positions do not get a contrast-coindexed for the neutralized property.

harmony constraint is a word-medial apical consonant, an element that bears a contrast-coindex for retroflex given that it minimally contrasts for this property in this position. Consequently, the top-ranked constraint IDENT[retroflex]$_{\mathbf{R}}$ rules out any candidate that modifies the retroflex specification of this medial apical. Candidate (a) is ruled out due to its violation of this constraint. On the other hand, candidate (b) satisfies the highly ranked faithfulness constraint at the expense of violating the SPREAD constraint. This candidate is selected as the optimal form.

The analysis of Gaagudju illustrates an instance where a phonological process targets only elements that are not contrast-coindexed for some property. As described above, this is the result of the interaction between some markedness constraint initiating the process and a faithfulness constraint that makes reference to contrast-coindexed elements. No reference to lack of coindices is necessary to account for these cases.

To conclude this section, it is worth noting that there is a further application for IDENT[F]$_D$, i.e., an identity constraint that makes reference to a particular contrast-coindex. Such a constraint could explain why the SPREAD constraint is not vacuously satisfied by changing the contrastive specification in the trigger. For example, coming back to tableau (a) in Table 30, high ranking of IDENT[retro]$_R$ prevents a candidate such as [tee**n**mi], where the underlying retroflex trigger is changed to [-retroflex], from being selected as the winner. The high-ranked contrast-coindexed IDENT constraint prevents changing the retroflex specification of the trigger, which is minimally contrastive for retroflexion. This application of

$IDENT[F]_D$ provides a means of preventing the satisfaction of spreading by simply deleting the features to be spread (Walker 2000).

To overcome this challenge, previous research in the area of nasal harmony has appealed to the cover constraint F'[nas], which encompasses the group of constraints that disallow other possible ways of satisfying nasal spreading (other than changing the nasal specification of a target vowel), for example through deletion or denasalization of the trigger nasal (McCarthy & Prince 1995, 1999, Walker 2000). Note that in order to obtain nasal harmony, the spreading constraint initiating the harmony has to outrank IDENT-IO[+nasal]. This indicates that IDENT[+nas] is not responsible for protecting the nasal specification of the trigger element since it is low ranked. Accordingly, denasalization of the nasal trigger must violate some constraint other than just IDENT-IO[+nasal] (Walker 2000). The proposed $IDENT[F]_D$ constraints, which makes reference to a specific contrast-coindex, could be used to prevent features that are the focus of a spreading constraint from deleting in triggers, [+nasal] in the case of nasal harmony. $IDENT[F]_{Nas}$ would protect elements that are contrastively nasal, including prototypical nasal triggers.

4.4.2 Summary

To conclude this chapter, I recapitulate how the use of contrast-coindexing of markedness and faithfulness constraints obtains the typological predictions introduced earlier (see Table 28). These predictions are repeated in Table 31.

Table 31. Predictions made by contrast-coindexing

NON-CONTRAST-COINDEXED ELEMENTS
-may be triggers
-may be only targets
-may be not targeted
CONTRAST-COINDEXED ELEMENTS
-may be only triggers
-may be only targets
-may be not targeted

Markedness constraints might require that the trigger or the target be contrast-coindexed for a given property. The shorthand notations MARK(trigger)$_{CC}$ MARK(target)$_{CC}$ stand for contrast-coindexed markedness constraints. MARK stands for a traditional markedness constraints that applies to coindexed and non-coindexed elements. As for faithfulness constraints, FAITH$_{CC}$ preserves contrast-coindexed elements and FAITH applies to all elements. Let us schematically illustrate how the predictions in Table 31 result from the interaction of these constraints. The relevant rankings as shown in Table 32.

Table 32. Rankings accounting for prediction made by contrast-coindexing

NON-CONTRAST-COINDEXED ELEMENTS	**RELEVANT RANKINGS**	**SAMPLE LANGUAGE**
-may be triggers	MARK>>FAITH	Lena analogy
-may be only targets	$FAITH_{CC}$>>MARK>>FAITH	Gaagadju harmony
-may be not targeted	MARK(target)$_{CC}$>>FAITH	Pulaar [ATR] harmony
CONTRAST-COINDEXED ELEMENTS		
-may be only triggers	MARK(trigger)$_{CC}$>>FAITH	Lena harmony
-may be only targets	MARK(target)$_{CC}$>>FAITH	Pulaar [ATR] harmony
-may be not targeted	$FAITH_{CC}$>>MARK>>FAITH	Gaagadju harmony

The ranking MARK >> FAITH results in a process that does not show any restrictions based on the contrast-coindexing representation of the elements involved. On the other hand, the ranking $FAITH_{CC}$ >> MARK >> FAITH corresponds to a case like that exemplified by Gaagudju retroflex harmony. The markedness constraint targets only non-coindexed elements due to the high ranking of the faithfulness constraint preserving identity only of contrast-coindexed elements $FAITH_{CC}$. Finally, the rankings MARK(trigger)$_{CC}$ >> FAITH and MARK(target)$_{CC}$ >> FAITH single out coindexed elements as the only triggers and targets, respectively. For instance, vowel height harmony in Lena involved high ranking of a markedness constraint that singles out vowels contrast-coindexed for height as the triggers of the phenomenon. Summarizing, the contrast-coindexing proposal introduced in this thesis predicts different patterns based on the interaction between faithfulness and markedness constraints, following classic Optimality Theory. The new development is that constraints can make reference to contrast-coindices. This gives rise to phenomena such as those in Table 32, where the minimal contrast status of the elements involved may be relevant.

CHAPER 5

CONCLUDING REMARKS

5.1 Further extensions

5.1.1 Allophony and minimal pairs

In this section, I extend the contrast-coindexing proposal to cases of allophonic phenomena, where relevant minimal pairs may not be identified due to the masking effects of allophony. Let us examine a hypothetical example as a means of illustration. Consider a language L that displays an allophonic process by which the alveolar stop /t/ always surfaces as the affricate [ts] before the front high vowel /i/. This means that the sequence *[ti] never occurs in the language. Further assume that this allophonic pattern takes place root internally, i.e., alternations between [t] and [ts] may not be found for some forms[79], and that the sound [ts] does not otherwise occur in the language.[80] The examples in (67) show some words that can and cannot be present in this hypothetical language L.

(67) Words in hypothetical allophonic language L

/pate/ → [pate]	*[patse]
/pati/ → [patsi]	*[pati]

[79] Cases with morphological alternations do not pose a problem for the contrast-coindexing proposal as developed this far because different morphological elements can be assessed for minimal contrast independently of each other (see section 4.2.4.2.2).

[80] Note that this example resembles the behavior of /t/ in Japanese.

The result of this allophonic process is that it gets rid of some potential minimal pairs relevant for assessing minimal contrast for vowels. For example, [pate] does not form a minimal pair with *[pati]. Similarly, [patsi] does not constitute a minimal pair with *[patse]. In this situation, [e] and [i] in [pate] and [patsi] do not get a contrast-coindex for height, although these two vowels are minimally contrastive for height in other forms of the language.

From the point of view of the influence of minimal contrast on phonetics, the lack of contrast-coindices predicts that the final vowels in [pate] and [patsi] might exhibit different behavior compared with those same vowels in words where they are coindexed for height. This is a prediction that would have to be tested since I am not aware of any reports bearing on this issue. As for the relevance of minimal contrast in phonology, this lack of coindices due to allophony predicts that [i, e] might trigger a phonological process by virtue of being minimally contrastive for height except in forms like [pate] and [patsi], where they are not minimally contrastive. In order to clarify this prediction, let us assume that our hypothetical language L has a vowel height harmony triggered only by high vowels that are minimally contrastive for height. This is the pattern observed in Lena. The examples in (68) illustrate how this pattern would apply.

(68) Vowel height harmony in hypothetical language L[81]

(a) /pami/ → [p**i**mi$_{\mathbf{h}}$]

(b) /pati/ → [p**a**tsi] *[p**i**tsi]

The form in (68)a) undergoes harmony triggered by [i$_{\mathbf{h}}$] because it is contrast-coindexed, i.e., minimally contrastive, for height. On the other hand, the word in (68)b) does not show harmony because its last vowel is not contrast-coindexed for height. This is so because allophony eliminates or does not allow for some potential minimal pairs (e.g. [pitsi] vs. *[pitse]).

I am not aware of any example refuting or supporting the prediction resulting from the interaction between allophony and minimal contrast. However, such a pattern seems unlikely to occur in any language. In the next section, I present an approach to allophonic phenomena that results in contrast-coindexing in those forms where allophony masks minimal pairs (e.g. [pate] and [patsi] in our hypothetical language). Thus, the unlikely pattern explained above is no longer a prediction of contrast-coindexing. Lexical Phonology offers the theoretical framework to distinguish between processes that are structure-preserving and those that are not (e.g. allophony).

[81] Note that throughout this section I only include the contrast-coindices relevant for the discussion, i.e., the height contrast-coindex for the final vowels.

5.1.2 Contrast-coindexing and OT-Lexical Phonology

The crucial assumption made in Lexical Phonology (LP) is that there is a distinction between lexical phonology processes and postlexical phonology processes (e.g. Kiparsky 1982, 1985, Mohanan 1986). One of the main differences between lexical and postlexical phenomena is that the former are structure-preserving (e.g. Kiparsky 1985). According to LP, the output of lexical processes is confined to segments that already exist in underlying representations, i.e., only phonemic sounds. The idea is that there is a lexical inventory which is smaller than the inventory of surface forms. Thus, LP treats allophonic patterns, such as the affrication presented in the previous section, which are not structure-preserving, as belonging to the postlexical phonology of a given language. I come back to this point later.

LP has been developed within Optimality Theory (OT) by several researchers in order to account for cases of phonological opacity (e.g. Booij 1997, Kiparsky 2000, to appear, Ito & Mester 2001, 2002). Ito & Mester (2001, 2002) adopt a type of stratal OT called *weak parallelism*. Their system is parallelist in its basic operation but explicitly recognizes the lexical phonology and the postlexical phonology as separate modules that operate in sequence. This differs from the strictly serialist conception of opacity in Kiparsky (to appear). Ito & Mester assume that cyclicity is restricted to the distinction between lexical and postlexical phonology. They consider the lexical phonology as a single, parallel constraint system. In OT-Lexical Phonology (OT-LP), the lexical and postlexical modules constitute separate constraints systems with different rankings. The two modules interact serially, with the output of the lexical module serving as the input to the postlexical module. The output of the final module is the observed surface form of the language (McCarthy 2002).

OT-LP captures the insight of traditional LP that the lexical phonology is structure preserving (Ito & Mester 2001). In OT, the lexical segment inventory emerges directly from the lexical constraint ranking itself, rather than being separately stipulated. Furthermore, structure preservation can be 'turned off' postlexically by re-ranking some constraints and activating an allophonic process. On the other hand, some alternations are exclusively lexical phenomena and are not at work at the postlexical level. Coming back to the affrication process described above, this allophonic pattern is not structure-preserving. Thus, it can be argued to apply only in the postlexical phonology, whereas lexically the process does not take place, and the alveolar stop is the output of the lexical module. Consequently, if allophony does not occur at the lexical level, the issue in relation to masking potential minimal pairs does not arise. This means that those vowels that were not minimally contrastive in the environment of affrication do get a contrast-coindex lexically. Returning to our hypothetical examples, the output of /pati/ is [pati] at the lexical level, and it forms a minimal pair with [pate], leading to coindexing of [i_h] and [e_h] for height. The relevant observation is that the output of the lexical module does show the minimal contrast (i.e., contrast-coindices), which allophony would obscure. The proposal is that contrast-coindexing applies in relation to the lexical phonology candidates rather than the post-lexical ones.

Following work within OT-LP that notes that certain generalizations only hold at the lexical level and may be opaque at the postlexical level (e.g. Booij 1997), I suggest that minimal contrast might be opaque postlexically. In some cases, the necessary conditions for assigning contrast-coindices (i.e. presence of minimal pairs) might not be met by the postlexical representation as a result of allophony. My proposal is that, given that the input to the postlexical phonology already has contrast-coindices, these are maintained postlexically, despite not being surface true. In other words, the elements of the postlexical output preserve the contrast-coindices of their correspondents in the input.

In the hypothetical example developed earlier, the output of lexical phonology contains forms such as [$pati_h$], which functions as the input to the postlexical module. Lexical [$pati_h$] is mapped into postlexical [$patsi_h$], which undergoes allophony but still maintains the height coindex for the last vowel since its input correspondent is annotated for that minimal contrast. This extension of the contrast-coindexing proposal with OT-LP is able to prevent the unlikely prediction described in the previous section, where allophony blocks coindexing and the same segment behaves as minimally contrastive only in non-allophonic environments.

To conclude this section, it is necessary to point out another potentially problematic case for the contrast-coindexing proposal, even assuming the extension to OT-LP proposed in the previous paragraphs. These cases involve allophonic patterns that result in sounds that already exist in the language. For example, taking the affrication process familiar from the previous example, assume that this pattern is attested in another language L', in which /ts/ is a phoneme and words such as [patse] can be found. In this language. The forms in (69) show words that can and cannot occur in this language L'. Note that there is neutralization between /t/ and /ts/ before /i/.

(69) Words in hypothetical allophonic language L'

/pate/ → [pate]

/patse/ → [patse]

/pa**t**i/ → [pa**ts**i] *[pati]

/patsi/ → [patsi]

In this language L', [i] in the allophonic environment gets a contrast-coindex for height due to the presence of minimal pairs such as [$\text{patsi}_{\mathbf{h}}$] vs. [$\text{patse}_{\mathbf{h}}$]. However, [e] is not coindexed when it occurs after the alveolar stop because there are no minimal pairs such as [pate] vs. *[pati]. This predicts that [e] might behave as minimally contrastive in all contexts except when following [t]. This prediction does not seem desirable, although I do not know of any example that refutes it. Under the assumption that such predicted pattern is unlikely to be attested, it is important to consider whether the relevant vowel [e] could be assigned a height coindex in an OT-LP extended version of contrast-coindexing. The difference between this example (L') and the previous one (L) is that in the latter allophony is structure preserving and in the former it is not, since [ts] is not part of the inventory. For this reason, the postlexical status of affrication in language L' is not so clear from the point of view of structure preservation. However, postlexical processes are not only characterized by not being structure-preserving. According to LP, postlexical phenomena cannot refer to morphological labels, cannot have exceptions, are not easily accessible to native-speaker intuition and may apply across word boundaries (Gussenhoven & Jacobs 1998). Clearly, whether an allophonic pattern is postlexical does not only depend on structure-preservation. What both instances of allophony, structure-preserving and non-structure-preserving, share is that minimal contrast is obscured at the surface level. Both can be seen as opaque minimal contrast due to the masking effects of allophony. Further research in OT-LP in relation to the interaction between allophony and minimal contrast will prove fruitful.

5.2. Further considerations

Among the proposals in this dissertation is a proposed new approach to length contrasts based on contrast-coindexing. Here, I show that the evidence presented in this study is not the only argument against a moraic representation of length contrasts. Previous research has pointed out further problems with such an approach to length. Note that the current study does not argue against the use of moras as units of weight. I review the basic tenets of Moraic Theory, paying special attention to how this theory represents length contrasts for vowels and consonants (long vs. short vowels and geminate vs. singleton consonants). The main arguments that motivate Moraic Theory are presented, together with some of the problems it faces with respect to the representation of long versus short segments. To conclude, I compare Moraic Theory with the contrast-coindexing approach to length contrasts, examining in what ways this new approach solves the problems faced by Moraic Theory.

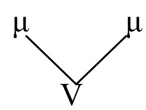
5.2.1 Moraic representation of length

The most widely extended representation of segmental length is that presented by Moraic Theory (Hayes 1989, Hyman 1986, McCarthy & Prince 1986). This theory formalizes the notion of the mora, or unit of weight, as a level of representation between the syllable and the segment. The first references to the mora were made within the context of stress, tone and accent assignment. It was noted that the position of these prosodic elements depends on a distinction between light (mono-moraic) and heavy (bimoraic) syllables. The main insight of Moraic Theory is that phonological processes are not sensitive to segment count but rather to syllable weight. The only segments that might bear a mora, and thus contribute to weight, are vowels and coda consonants. The latter are moraic on a language-specific basis, giving rise to different patterns depending on their status. On the other hand, onsets are always non-moraic, i.e., they do not contribute their own mora (but see Topintzi 2006).

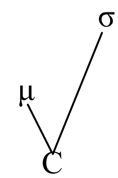
In Moraic Theory, the representation of length is captured by the segments' linkage to prosodic positions. Long vowels are linked to two moras. Underlying geminate consonants are inherently moraic and surface-linked to a mora and a syllable node. Thus, the contrast between singletons and geminates is reduced to a question of underlying weight (Ham 2001).[82] Figure 14 illustrates the moraic representation of long vowels and geminate consonants.

Figure 14. Moraic representation

a. Long vowels



b. Geminate consonants



The next section gives an overview of some arguments for Moraic Theory together with issues raised against these arguments. First, the onset/coda asymmetry is at work in weight-sensitive processes and in cases of compensatory lengthening. However, evidence against this asymmetry has been found concerning both phenomena. Second, the status of geminates as inherently heavy has been challenged by several languages where these consonants do not participate in weight-related processes. Third, moraic consistency, one of the Moraic Theory principles, seems not to hold in the light of a typological survey by Gordon (1999, 2004).

[82] Some studies argue for a direct relationship between the mora and the actual manifestation of phonetic duration (e.g. Hubbard 1995, Broselow at al. 1997). Arguments against this direct relationship are presented in Muller (2001).

5.2.2 Arguments for and against the moraic theory

5.2.2.1 Onset/Coda asymmetry

As mentioned in the introduction to Moraic Theory, onset segments are claimed to never be moraic, indicating their irrelevance in weight-sensitive processes. A syllable with a consonant cluster in onset position and a single vowel in the nucleus behaves in exactly the same way with respect to weight as a syllable with a single consonant in the onset. On the other hand, the number of elements in the rime plays a role in weight-sensitive phenomena.[83] For example, syllables with more moraic elements in the rime, i.e., heavier syllables, attract stress in weight-sensitive languages.

A further asymmetry between onsets and codas comes from compensatory lengthening. This process is defined as deletion of a segment together with lengthening of a neighboring element. For instance, in Eastern Andalusian Spanish deletion of an obstruent in coda position conditions the lengthening of the following consonant. The examples in (70) illustrate this pattern.

(70) Eastern Andalusian compensatory lengthening (Campos-Astorkiza 2003)[84]

[des#ato]	'I untie'	[de#**bb**lokeo]	'clearing'
[sub#ordinado]	'subordinate'	[su#**mm**arino]	'submarine'

[83] There tends to be a limit on this. Many languages do not distinguish CVC and CVCCC in terms of their weight.
[84] # indicates a morpheme boundary.

The seminal work by Hayes (1989) develops the moraic analysis of compensatory lengthening. The main claim of this approach is that lengthening takes place in order to preserve a stranded mora after segment deletion. This means that only deletion of a mora-bearing segment might lead to this kind of lengthening. Hayes (1989) claims that this prediction is borne out, because in his typological survey there are no cases of onset deletion triggering compensatory lengthening. This asymmetry is captured by moraic theory and its claim that onset consonants are non-moraic. The moraic conservation approach to compensatory lengthening relies on this moraic difference between onset and coda elements.

However, these claims about the different behavior of onsets and codas with respect to weight-sensitive phenomena and compensatory lengthening have been challenged by several studies. First, moraic onsets have been reported in the literature. For example, Pirahã stress assignment is sensitive to onset elements (Everett and Everett 1984, Smith 2002, Topintzi 2004). In Bella Coola, word minimality requirements treat CV and VV as equal in weight (Bagemihl 1991, Topintzi 2005b). Arabela presents a case of stress retraction sensitive to onset quality (Topintzi 2005a). These facts undermine one of the basic tenets of moraic theory. If the door for moraic onsets is opened, then it is relevant to reconsider the initial typological considerations upon which this theory was built.

Second, several cases of compensatory lengthening triggered by onset deletion have been documented. For instance, Samothraki Greek and Onondaga (Kavitskaya 2002) are languages where deletion of an onset leads to lengthening of a following vowel. Furthermore, there are some cases where compensatory lengthening arises through deletion of an onset and subsequent lengthening of the preceding consonant (for example Lango (Noonan 1992)). This last pattern might be seen as preservation of the lengthened consonant's mora through syllabification of this segment to the following syllable (thus giving rise to a geminate configuration). However, this case does not fall under the strong claim of the moraic conservation account that only deletion of moraic elements might cause compensatory lengthening. It should also be noted that other analyses of compensatory lengthening have been proposed that provide grounded explanations for this phenomenon and do not rely on moraic considerations (Fowler 1983, Blevins and Garrett 1998, Kavitskaya 2002, Campos-Astorkiza 2005).

5.2.2.2 Geminates

According to the moraic representation of geminates, these consonants are always moraic and should contribute to syllabic weight. Tranel (1991) investigates this prediction and argues that in fact there are languages where syllables closed by a geminate consonant count as light. Selkup (Tranel 1991, Ringen and Vago 2002) is one such language. This West Siberian language has a weight-sensitive stress system. It treats syllables with long vowels as heavy and syllables closed by a consonant or a geminate as light. Some other languages where geminates are light include Tübatulabal and Malayalam (Tranel 1991), and Cypriot Greek (Arvaniti 1991, Arvaniti and Rose 2003).

Word-initial geminates also present a problem for moraic theory. If geminate consonants are inherently moraic, then it follows that onset geminates should count in weight-sensitive phenomena. However, this runs opposite to the claim that onsets are non-moraic. But, how do word-initial geminates behave with respect to weight? In fact, these geminates can be treated as moraic or non-moraic on a language-particular basis (Muller 2001). For instance, word-initial geminates in Leti (Hume et al. 1997, Muller 2001) are non-moraic. Evidence comes from word minimality requirements. In this language, lexical words have to be minimally bimoraic. There are no words that consist of an initial geminate and a short vowel, which indicates that these geminates do not contribute a mora to the word. In Trukese (Davis 1999), word-initial geminates are moraic, since minimal word requirements are sensitive to these geminates, unlike in Leti.

The facts just presented seem to indicate that different weight representations are needed for Leti and Trukese geminates. However, it is still necessary to capture that both elements are geminate consonants regardless of their asymmetrical weight behavior. If we rely solely on moraic representation, two different forms would have to be interpreted as geminates. This seems undesirable if the goal is to unify the representation of geminates. Furthermore, if some (or all) initial geminates are non-moraic, commonalities between initial and medial geminates would be lost. Moraic representations should be independent of length, allowing at the same time for the connection between moraic elements and longer segments. In the next section, I introduce Gordon's work, which relates the phonetic aspects of weight-sensitive processes to the selection of certain segments as moraic or non-moraic.

5.2.2.3 Moraic consistency

The principle of moraic consistency predicts that all aspects of grammar within a given language should treat the same configurations as heavy or light (Broselow 1995). For examples, if closed syllables count as heavy for stress assignment, they should do so for word minimality requirements and other weight-sensitive morphological processes such as truncation. However, cases contrary to this prediction have been cited in the literature (Steriade 1991, Archangeli 1991, Crowhurst 1991). Lithuanian presents an example of moraic inconsistency. Zec (1988) shows that in Lithuanian, sonorant consonants in coda position and not obstruents are moraic for some morphological processes, such as formation of infinitive verb forms. Steriade (1991) notes that a word minimality constraint on Lithuanian monosyllables disallows CV roots and allows CVV and CVC. In this case, minimality is indifferent to the sonority of the coda consonant. Lunden (2006) presents a case of moraic inconsistency from Norwegian. In this language, CVC syllables exhibit a weight asymmetry: CVC is usually heavy but behaves as light word-finally.

Another problematic example for moraic consistency comes from the Mongolian language Buriat as described by Walker (1994). In Buriat, only vowels contribute to weight and CVV(C) syllables count as heavy for stress assignment.

Syllables with short vowels are light, regardless of coda consonants, which behave as non-moraic. Buriat has only one possible complex coda /ŋg/. This complex coda can follow a short vowel (CVŋg) but it cannot occur after a long vowel (*CVVŋg). The challenging observation for moraic theory is that CVŋg behaves as light for stress assignment but blocks a second moraic (i.e. a vowel) element from being added.

After an extensive survey of weight-sensitive phenomena, Gordon (1999, 2004) concludes that weight criteria are not uniform within a language, but consistency is found for each particular process. This means that weight depends on the type of process and not on the language as previous work had suggested (see Broselow 1995). Gordon proposes that phonetics plays an important role in explaining why different processes use different weight criteria, and in accounting for the specific weight divisions chosen by each language. Taking stress and tone as examples, he argues that these two processes show different behavior with respect to weight criteria because they have different phonetic implementations: tone relies on the fundamental frequency and harmonics of the segments, and stress relies on total perceptual energy of the syllable rime. Focusing on stress, Gordon claims that any given language will choose the weight division that separates the syllables into two maximally distinct groups with respect to total perceptual energy. This corresponds to what he calls phonetic effectiveness, which is mediated through structural simplicity (Gordon 2004).

An interesting finding in Gordon's work is that phonological considerations such as the inventory of coda consonants affects the phonetic measure of total perceptual energy, which, as he claims, in turn influences the choice of weight criterion. This means that segments do not contribute to weight only based on their syllabic position but also depending on the language's phonological structure. This approach to syllable weight does not assume that geminate consonants are inherently weight-contributing, and so, it is able to account for the behavior of geminate consonants as non-moraic in Selkup and other languages. The choice of a weight criterion based on geminate consonants depends on how phonetically effective that criterion is.

5.2.3 A new look at length contrasts

To recapitulate, one of the main challenges for Moraic Theory is that the mora has a double duty in the representation: it marks weight and length. Most of the problems Moraic Theory faces come from this dual behavior of moras. The proposal developed in this dissertation separates weight marking from contrastive length marking. Contrast-coindexing annotates minimal length contrast in the representation, while moras are in charge of reflecting weight. It should be emphasized that the current study does not argue against moras as units of weight.

The approach developed here is that Dispersion Theory can be extended to account for length contrasts. Such an analysis does not rely on moras to establish contrasts between long and short vowels. This was illustrated in section 3.2 with the Lithuanian inventory. A question for further consideration is how a Dispersion Theory analysis can account for the distribution of length contrasts across languages.

For example, the fact that some languages may have consonant length contrasts intervocalically but not in word-initial or -final position. Optimality Theory offers the adequate machinery for a successful analysis. It is beyond the goal of this section to develop an account of length contrast distributions. Rather, I just suggest a possible direction. The asymmetrical distribution of a contrast, such as consonant length, could be analyzed as a case of positional neutralization, either as the effect of a positional markedness constraint or a positional faithfulness constraint. Following the markedness approach, a constraint would militate against long consonants word initially or finally. This constraint would be grounded on the perceptual characteristics of consonants and the fact that consonantal length contrasts are harder to perceive when not surrounded by vowels (cf. Steriade (1997) on Licensing by Cue) . Flanking vowels provide richer acoustic cues to signal the beginning and end of the consonant. On the other hand, the faithfulness approach would posit a general markedness constraint against long consonants. A positional faithfulness constraint protecting intervocalic positions would preserve length contrasts in this position. A fully fleshed analysis along either of these lines deserves further research.

5.3 Conclusions and issues for further research

The main claim of this dissertation is that minimal contrast plays an important role both for phonetic patterns and phonological phenomena. I further argue that minimal contrast has to be explicitly included in the phonological representation. The contrast-coindexing function is introduced in order to encode minimal contrast in the representational structure. The account developed here is motivated by generalizations drawn from first-hand experimental data and from empirical data reported in previous studies.

The Lithuanian case study brings new facts to research on the phonology-phonetics interaction. The experimental results indicate that minimal contrast actively influences the outcome of phonetics: the presence of minimal length contrast attenuates the voicing effect on vowel duration. It is relevant to notice that the phonetic pattern is still present for those vowels that are minimally contrastive. The voicing effect is not totally suppressed for these vowels. This is in accordance and further supports the view adopted in this study, namely, that phonology and phonetics form two different components, and that the patterns observed in these components behave differently (i.e. categorically in the case of phonology and gradiently in the phonetics).

The analysis pursued for the Lithuanian findings advances research within Dispersion Theory by extending its scope to cases of length contrast. I show that the same family of constraints responsible for the occurrence of contrasts in height, backness and so on for vowels can account for contrasts based on duration. This account raises interesting questions about how to better deal with asymmetrical systems like that of Lithuanian, where diachronic changes led to differences in the distribution of minimal contrasts. For example, in Lithuanian length is minimally contrastive only among high and low vowels. I propose to relativize the constraints ruling over vowel length with respect to vowel peripherality. As a result, a two-way contrast in length is maintained for peripheral (high and low) vowels, whereas non-peripheral (mid) vowels only present a one-way contrast in length. Clearly, this approach would benefit from further research considering other asymmetrical systems and the relationship among other vowel features.

Evidence from different phonological phenomena indicate the importance of minimal contrast. For instance, in Lena, only high vowels that are minimally contrastive for height can trigger metaphony. The contrast-coindexing proposal allows us to easily capture this kind of pattern. I argue that both faithfulness and markedness constraints can make reference to contrast-coindices in order to signal out minimally contrastive elements. I further show that the interaction between these contrast-coindexed constraints give rise to an attested factorial typology. The prediction is that contrast-coindexed elements might be selected as the only trigger (e.g. Lena metaphony) or the only target. Non-contrast-coindexed elements may be the only targets (e.g. Gaagudju) but crucially, they cannot act as the sole triggers for a given process. In view of this typology, more cases are expected to be found where reference to contrast-coindices, i.e., minimal contrast, will bring insight into their analyses.

An interesting and important question concerns the relation between contrast-coindexing and constraints. First, it is relevant to consider what constraints can make reference to contrast-coindices. In chapter 4, I assumed the null hypothesis, i.e., that all constraints can refer to these coindices. Both faithfulness and markedness contrast-coindexed constraints are proposed, namely IDENT[F]$_D$ and SPREAD[F]$_D$.

An issue that requires further investigation is whether all types of markedness and faithfulness constraints may single out contrast-coindexed elements. In relation to this, it will be worth considering constraints that apply to elements bigger than the segment (e.g. the syllable). This will also shed light over the role of the segment in the definition of minimal pair (see footnote 16).

Second, the co-relevancy issue deserves further research. Co-relevancy was first mentioned in relation to minimal contrast and phonetic patterns, where I argued that minimal contrast affects patterns that modify the same dimension along which the contrast operates. Regarding phonological constraints, it is necessary to determine whether constraints may refer only to contrast-coindices that are relevant for the particular property involved in the phonological process. For instance, in Lena metaphony, the constraint that singles out high vowels contrast-coindexed for height as triggers is a LICENSE constraint that requires licensing of height features, i.e., the same dimension as the coindex. Similarly, in Gaagudju, the relevant faithfulness constraint requires [retroflex] identity only for those elements that are contrast-coindexed for this property. Thus, the case studies analyzed in this thesis seem to suggest that constraints may single out elements that are contrast-coindexed for the property that is directly relevant to the process. Further cases where phonological phenomena are sensitive to minimal contrast will give more support to this preliminary conclusion. If this conclusion turns out to be right, then it will be necessary to explicitly restrict the relation between constraints and contrast-coindices by defining in formal terms how constraints may refer only to certain coindices.

To conclude, contrast-coindexing makes some predictions with respect to patterns of acquisition. Let us consider a phonological process triggered only by elements that are contrast-coindexed for some property. Assuming that the child has followed a learning path in which she acquired the appropriate ranking for the process, e.g. SPREAD>>IDENT, but not yet discovered her language's contrasts[85], at first the child is expected to overapply that process until she learns the contrasts that are present in her language. She needs to know what elements are contrast-coindexed for the relevant property in order to identify the possible triggers. For example, a learner of Lena might start out by applying metaphony to words with an inflectional high front or back vowel, and gradually, as she learns the contrasts among the inflectional vowels, metaphony will be restricted only to forms with a high back vowel.

It should be noted that the child does not need to learn all the words in a given language in order to discover all the minimal contrasts present in that system. This is the case because minimal contrast is not established based on attested minimal pairs but rather based on possible minimal pairs. This means that the child needs to learn the grammar, i.e., the constraint ranking, of her language in order to discover what contrasts are possible. A more detailed description and consideration of the predictions about learnability made by the contrast-coindexing proposal is beyond the scope of this thesis but will benefit from further research.

[85] Alternatively, the child could follow a learning path where she learns the ranking for contrasts first, and then acquires the relevant ranking for the process in question.

REFERENCES

Abramson, A. S. 1962. The vowels and tones of standard Thai: Acoustical measurements and experiments. *International Journal of American Linguistics* 28, 2.

Abramson, A. S & N. Ren. 1990. Distinctive vowel length: duration vs. spectrum in Thai. *Journal of Phonetics* 18, 79-92.

Alderete, J. 1999. *Morphologically Governed Accent in Optimality Theory*. Ph.D. dissertation, University of Massachusetts, Amherts.

Ambrazas, V. 1997. *Lithuanian Grammar*. Vilnius: Baltos Lankos.

Anttila, A. 1997. Deriving variation from grammar. In Hinskens et all (eds.) *Variation, Change and Phonological Theory.* Amsterdam: John Benjamins, 35-68.

Archangeli, D. 1988. *Underspecification in Yawelmani phonology and morphology.* Ph.D. dissertation, MIT.

Archangeli, D. 1988. Underspecification in phonology. *Phonology* 5: 183–207.

Archangeli, D. 1991. Syllabification and Prosodic Templates in Yawelmani. *Natural Language and Linguistic Theory,* 231-283.

Archangeli, D. & D.T. Langendoen. 1997. *Optimality Theory: An Overview*. Blackwells Publishing.

Archangeli, D. & D. Pulleyblank. 1984. Extratonality and Japanese Accent. Ms., MIT and McGill University.

Archangeli, D. & D. Pulleyblank. 1987. Maximal and minimal rules: Effects of tier scansion. In J. McDonough & B. Plunkett (eds.) *NELS 17*. Amherst: GLSA, 16-35.

Archangeli, D. & D. Pulleyblank. 1989. Yoruba vowel harmony. *Linguistic Inquiry* 20, 2, 173-217.

Arvaniti, A. 1991. *The Phonetics of Modern Greek Rhythm and its Phonological Implications*. Ph.D. dissertation, University of Cambridge.

Arvaniti, A. & S. Rose. 2003. Two sources of evidence against moraic timing of geminates. LSA Meeting, Atlanta, GA, January 2003.

Bagemihl, B. 1991. Syllable structure in Bella Coola. *Linguistic Inquiry* 22, 589-646.

Baković, E. 2000. *Harmony, Dominance and Control*. Ph.D. dissertation, Rutgers The State University of New Jersey.

Balšaitytė, D. 2004. Spectral characteristics of vowels in modern Lithuanian. *Respectus Philologicus* 5, 10.

Barrie, M. 2002. Tonal contrast in Cantonese. Presented at the Montréal−Ottawa−Toronto Phonology Workshop, McGill University, Montréal, February 2002.

Barrie, M. 2003. Contrast in Cantonese vowels. *Toronto Working Papers in* Linguistics 20, 1−19.

Beckman, J. 1997. Positional faithfulness, positional neutralization, and Shona vowel harmony *Phonology* 14.1.

Beckman, J. 1998. *Positional Faithfulness.* Ph.D. dissertation, University of Massachusetts, Amherst.

Beckman, M.E. 1986. *Stress and Non-Stress Accent.* Netherlands Phonetic Archives 7. Dordrecht: Foris.

Beckman, M.E., J. Edwards & J. Fletcher. 1992. Prosodic structure and tempo in a sonority model of articulatory dynamics. In G. Docherty & D.R. Ladd (eds.) *Papers in Laboratory Phonology II: Gesture, Segment, Prosody*. Cambridge: Cambridge University Press, 68-86.

Behne, D., A. Takayuki, P. Czigler & K. Sullivan. 1999. Vowel duration and spectra as perceptual cues to vowel quantity: A comparison of Japanese and Swedish. In ICPhS, San Francisco.

Berinstein, A. 1979. A cross-linguistic study on the perception and production of stress. *UCLA Working Papers in Phonetics 47*, 1-59.

Bermúdez-Otero, R. (in prep). *Stratal Optimality Theory*. Oxford Studies in Theoretical Linguistics. Oxford: Oxford University Press.

Blevins, J. 2004. *Evolutionary Phonology*. Cambridge: Cambridge University Press.

Blevins, J. & A. Garrett. 1998. The origins of consonant-vowel metathesis. *Language* 74, 508-56.

Blevins, J. & A. Garrett. 2004. The evolution of metathesis. In B. Hayes, R. Kirschner & D.Steriade (eds.), *Phonetically Based phonology.* Cambridge: Cambridge University Press.

Boersma, P. 1998. *Functional Phonology: Formalizing the Interactions between Articulatory and Perceptual Drives.* Ph.D. dissertation, University of Amsterdam, The Hague.

Boersma, P.& B. Hayes. 2001. Empirical tests of the gradual learning algorithm. *Linguistic Inquiry* 32, 45-86.

Bonet, E., M.R. Lloret & J. Mascaró. 2007. Domain and directionality in Catalan ATR harmony. Presented at OCP 4, Rhodes, Greece, January 18-21, 2007.

Booij, G. 1997. Non-derivational phonology meets Lexical Phonology. In I. Roca (ed.), *Derivations and Constraints in Phonology*. Oxford: Clarendon Press, 261-288.

Bradley, T. G. 2001. *The phonetics and phonology of rhotic duration contrast and neutralization*. Ph.D. dissertation, Pennsylvania State University.

Bradley, T. G. & A. M. Delforge. 2006. Systemic contrast and the diachrony of Spanish sibilant voicing. In D. Arteaga & R. Gess (eds.), *Historical Romance Linguistics: Retrospectives and Perspectives*. Amsterdam: John Benjamins. 19-52.

Broselow, E. 1995. Skeletal positions and moras. In J. Goldsmith (ed.), *The Handbook of Phonological Theory*. Cambridge, MA and Oxford: Blackwell, 175-205.

Broselow, E., S. Chen & M. Huffman. 1997. Syllable weight: convergence of phonology and phonetics. *Phonology* 14, 47-82.

Browman, C. & L. Goldstein. 1986. Towards and articulatory phonology. *Phonology* 3, 219-252.

Browman, C. P., & Goldstein, L. 1989. Articulatory gestures as phonological units. *Phonology, 6,* 201-251.

Browman, C. & L. Goldstein. 1992. Articulatory phonology: An overview. *Phonetica* 49, 155-180.

Buder, E. & C. Stoel-Gammon. 2002. American and Swedish children's acquisition of vowel duration: Effects of vowel identity and final stop voicing. *Journal of the Acoustical Society of America* 111, 1854-1864.

Burzio, L. 1999. Surface-to-Surface Morphology: When your representations turn into constraints. Paper presented at the 1999 Maryland Mayfest, University of Maryland, College Park.

Burzio, L. 2000. Segmental contrast meets output-to-output faithfulness. *The Linguistic Review* 17, 368-384.

Butcher, A. 1995. The phonetics of neutralization: the case of Australian coronals. In J. Windsor Lewis (ed.), *Studies in General and English Phonetics. Essays in honour of J.D. O'Connor*. London: Routledge.

Bybee, J. 1985. *Morphology: A study of the relation between meaning and form.* Amsterdam: John Benjamins.

Byrd, D. 1996. A phase window framework for articulatory timing. *Phonology* 13, 139-169.

Byrd, D., A. Kaun, S. Narayanan & E. Saltzman. 2000. Phrasal signatures in articulation. In M. Broe & J. Pierrehumbert (eds.), *Acquisition and the Lexicon: Papers in Laboratory Phonology V* Cambridge. Cambridge University Press, 70-88.

Calabrese, A. 1985. Metaphony in Salentino. *Rivista di grammatica generativa* 9-10, 1-140.

Calabrese, A. 1988. *Towards a Theory of Phonological Alphabets,* Ph.D. dissertation, MIT.

Calabrese, A. 1998. Metaphony Revisited. *Rivista di Linguistica* 10, 7-68.

Campos-Astorkiza, R. 2003. Compensatory lengthening as root number preservation. In E. Hajicová, A. Kotesovcová, & J. Mírovský (eds.), *Proceedings of the XVII International Congress of Linguists.* Prague: Matfyzpress, MFF UK.

Campos-Astorkiza, R. 2005. A typological analysis of compensatory consonant lengthening. Phonology and Phonetics in Iberia, Barcelona, Spain, June 2005.

Catford, J.C. 1977. *Fundamental problems in phonetics*. Bloomington: Indiana University Press.

Chen, M. 1970. Vowel length variation as a function of the voicing of the consonant environment. *Phonetica* 22, 125-159.

Cho, T. 2001. *Effects of prosody in articulation in English*. Ph.D. dissertation, University of California, Los Angeles.

Choi, J.D. 1992. *Phonetic Underspecification and Target Interpolation: An Acoustic Study of Marshallese Vowel Allophony*. Ph.D. dissertation University of California, Los Angeles.

Chomsky, N. & M. Halle. 1968. *The Sound Pattern of English*. Harper Row, New York.

Clements, G. N. 1985. The Geometry of phonological features. *Phonology Yearbook* 2, 223-252.

Clements, G. N. 1991. Vowel Height Assimilation in Bantu Languages. *Proceedings* of *BLS* 17, 25-63.

Clumeck, H. 1967. Patterns of soft palate movement in six languages. *Journal of Phonetics* 4: 337-351.

Cohn, A. 1993. Nasalization in English: phonology or phonetics? *Phonology* 10, 43-81.

Crosswhite, K. 2001. *Vowel Reduction in Optimality Theory*. New York: Routledge.

Crosswhite, K. 2004. Vowel reduction. In B. Hayes, R. Kirchner & D. Steriade (eds.), *Phonetically Based Phonology*. Cambridge: Cambridge University Press, 191-231.

Crowhurst, M. 1991. Demorification in Tübatubal: Evidence from initial reduplication and stress. *Proceedings of the North Eastern Linguistics Society* 21, 49-63.

Crystal, H. & A. House. 1988. Segmental durations in connected speech signals: current results. *Journal of the Acoustical Society of America* 83, 1553-1573.

D'Arcy, A. 2004. Unconditional neutrality: Vowel harmony in a two-Place model. *Toronto Working Papers in Linguistics* 23, 2, 1−46.

Davis, S. 1991. Coronals and the phonotactics of nonadjacent consonants in English. In C. Paradis & J.F. Prunet (eds.), *The special status of coronals: Internal and external evidence.* San Diego: Academic Press, 49-60

Davis, S. 1999. On the representation of initial geminates. *Phonology* 16, 93-104.

De Jong, K. 1995. On the status of redundant features: the case of backing and rounding in American English. In B. Cornell & A. Arvaniti (eds.), *Papers in Laboratory Phonology IV*. Cambridge University Press, 68-86.

De Jong, K. & B. Zawaydeh. 2002. Comparing stress, lexical focus, and segmental focus: patterns of variation in Arabic vowel duration. *Journal of Phonetics* 30, 53-75.

De Lacy, P. 1999. Tone and prominence. Ms. University of Massachusetts, Amherst.

Delattre, P. 1962. Some factors of vowel duration and their cross-linguistic validity. *Journal of the Acoustical Society of America* 34, 1141-1143.

Delvaux, V. 2000. Phonetic control of the [oral] feature for the contextually nasalized French oral vowels. *Seventh Conference on Laboratory Phonology*, Max Planck Institute for Psycholinguistics, Nijmegen.

Dillon, C. M. 2003. Metaphony as morpheme realization, not vowel harmony. Ms. Indiana University.

Downing, L. 2006. Positional licensing of markedness in vowel harmony. Presented at OCP3, Budapest, 17-19 January, 2006.

Dresher, B. E. 1998a. Contrast in Inventories. Presented at the Montréal−Ottawa−Toronto Phonology Workshop, University of Ottawa, February 1998.

Dresher, B. E. 1998b. On Contrast and Redundancy. Presented to the Canadian Linguistic Association, University of Ottawa.

Dresher, B. E. 2003a. Contrast and asymmetries in inventories. In A.M. Di Sciullo (ed.) *Asymmetry in grammar, Vol. 2: Morphology, phonology, acquisition*. Amsterdam: John Benjamins, 239-257

Dresher, B. E. 2003b. The Contrastive Hierarchy in Phonology. *Toronto Working Papers in Linguistics* 20, 47−62.

Dresher, B. E., G. L. Piggott, & K. D. Rice. 1994. Contrast in Phonology: Overview. *Toronto Working Papers in Linguistics* 13, iii−xvii.

Dresher, E. & X. Zhang. 2004. Contrast in Manchu vowel systems. In C. Naher (ed.), *Proceedings of the First International Conference on Manchu-Tungus Studies. Volume 2: Trends in Tungusic and Siberian Linguistics.* Wiesbaden: Harrassowitz.

Dyck, C. 1995. *Constraining the Phonology-Phonetics Interface with Exemplification from Spanish and Italian Dialects.,* Ph.D. dissertation, University of Toronto.

Edwards, J. E., M.E. Beckman & J. Fletcher. 1991. The articulatory kinematics of final lengthening. *Journal of the Acoustical Society of America* 89, 369-382.

Eisner, J. 1997. Efficient generation in primitive Optimality Theory. *Proceedings of the 35th Annual Meeting of the Association for Computational Linguistics,* 313-320.

Ellison, T. M. 1995. Phonological derivation in Optimality Theory. *Proceedings of the Fifteenth International Conference on Computational Linguistics*, 1007- 1013.

Engstrand, O. 1988. Articulatory correlates of stress and speaking rate in Swedish VCV utterances. *Journal of the Acoustical Society of America* 83, 1863-1875.

Everett, D. & K. Everett. 1984. On the relevance of syllable onsets to stress placement. *Linguistic Inquiry* 15, 705-711.

Finley, S. 2006. A correspondence approach to vowel harmony in Lena Spanish. HUMDRUM 2006.

Flemming, E. 1995. *Auditory Representations in Phonology,* Ph.D. dissertation, University of California, Los Angeles.

Flemming, E. 1996. Evidence of constraints on contrast: the dispersion theory of contrast. *UCLA Working Papers in Phonology* 1, 86-106.

Flemming, E. 1997. Phonetic optimization: compromise in speech production. In V. Miglio & B. Morén (eds.) *University of Maryland Working Papers in Linguistics* 5. *Selected Phonology Papers from the Hopkins Optimality Theory Workshop 1997/University of Maryland Mayfest 1997*, 72-91.

Flemming, E. 1999. How to formalize constraints on perceptual distinctiveness. Talk presented at ICPhS, San Francisco.

Flemming, E. 2004 Contrast and perceptual distinctiveness. In B.Hayes, R.Kirchner & D.Steriade (eds.), *Phonetically-Based Phonology.* Cambridge University Press, 232-276.

Flemming, E. 2005. Deriving natural classes in phonology. *Lingua* 115, 287-309.

Fowler, C. 1983. Converging sources of evidence on spoken and perceived rhythms of speech: Cyclic production of vowels in monosyllabic stress feet. *Journal of Experimental Psychology* 112, 3, 386-412.

Gafos, A. 1999. *The Articulatory Basis of Locality in Phonology*. New York: Garland.

Gnanadesikan, A. 1997. *Phonology with Ternary Scales*. Ph.D. dissertation, University of Massachusetts, Amherst.

Gordon, M. 1999. *Syllable Weight: Phonetics, Phonology and Typology*. Ph.D. dissertation, University of California, Los Angeles.

Gordon, M. 2002 A phonetically-driven account of syllable weight. *Language* 78, 51-80.

Gordon, M. 2004. Syllable weight. In B. Hayes, R. Kirchner & D. Steriade (eds.), *Phonetically Based Phonology*. Cambridge: Cambridge University Press, 277-312.

Guenther, F.H. 1995a. Speech sound acquisition, coarticulation, and rate effects in a neural network model of speech production. *Psychological Review* 102, 594-621.

Guenther, F.H. 1995b. A modeling framework for speech motor development and kinematic articulator control. In K. Elenius & P. Branderud (eds.), *Proceedings of the XIIIth International Congress of Phonetic Sciences*. Stockholm: KTH and Stockholm University, 92-99.

Gussenhoven, C. 2001. Suprasegmentals. In N.J. Smelser & P. B. Baltes (eds.), *International Encyclopedia of the Social and the Behavioral Sciences*. Oxford: Pergamon, 15294-15298.

Gussenhoven, C. & H. Jacobs. 1998. *Understanding phonology.* Hodder Arnold Publications.

Guthrie, M. 1968. Note on Nzɛbi (Gabon). *Journal of African Linguistics* 7, 101-129.

Granda Gutiérrez, G. de. 1960. Las vocals finales del dialecto leonés. In A. Galmés de Fuentes (ed.), *Trabajos sobre el dominio románico leonés*. Vol. II. Madrid: Editorial Gredos, 27-117.

Hale, M. & M. Kissock. 2007. The phonetics-phonology interface and the acquisition of perseverant underspecification In G. Ramchand and C. Reiss (eds.), *The Oxford Handbook of Linguistic Interfaces*. Oxford: Oxford University Press, 81-101.

Hale, M. & C. Reiss. Phonology as cognition. In N. Burton-Roberts, P. Carr & G. Docherty (eds.) *Phonological Knowledge: Conceptual and Empirical Foundations*. Oxford University Press, 161-184.

Hall, D.C. 2007. *The Role and Representation of Contrast in Phonological Theory*. Ph.D. dissertation, University of Toronto.

Ham, W. H. 2001. *Phonetic and Phonological Aspects of Geminate Timing*. New York: Routledge.

Hamann, S. 2003. *The Phonology and Phonetics of Retroflexes*. LOT Publications.

Hamilton, P. J. 1993. On the internal structure of the coronal node. *ESCOL* 93, 129 -140.

Hamilton, P.J. 1996. *Phonetic Constraints and Markedness in the Phonotactics of Australian Aboriginal Languages*. Ph.D. dissertation, University of Toronto.

Hammond, M. 1997. Parsing in Optimality Theory. Ms. University of Arizona, Tucson.

Hansson, G. 2001. *Theoretical and Typological Issues in Consonant Harmony.* Ph.D. dissertation, University of California, Berkeley.

Hansson, G. (to appear) Effects of contrast recoverability on the typology of harmony systems. In P. Avery, B. E. Dresher & K. Rice *(eds.) Contrast in Phonology: Perception and Acquisition*. Berlin: Mouton de Gruyter.

Harrison, K.D. & A. Kaun. 2000. Pattern-responsive Lexicon Optimization. In *Proceedings of the Northeastern Linguistics Society* 30.

Harvey, M. 2002. *A Grammar of Gaagudju*. Walter De Gruyter.

Hayes, B. 1989. Compensatory lengthening in moraic phonology. *Linguistic Inquiry* 20, 253-306.

Hayes, B. 1995. *Metrical Stress Theory.* Chicago: The University of Chicago Press.

Hayes, B. & D. Steriade. 2004. Introduction: the phonetic bases of phonological markedness. In In B.Hayes, R.Kirchner & D.Steriade (eds.), *Phonetically-Based Phonology.* Cambridge University Press, 1-33.

Heiberg, A. 1999. *Features in Optimality Theory: A Computational Model.* Ph.D. dissertation, University of Arizona, Tucson.

Herbert, R.K. 1986. *Language Universals, Markedness Theory and Natural Phonetic Processes*. Berlin: Mouton de Gruyter.

Hertrich, I. & Hermann Ackermann**.** 1997. Articulatory control of phonological vowel length contrasts: Kinematic analysis of labial gestures. *Journal of the Acoustical Society of America* 102, 1, 523-536.

Hombert, J.M., Ohala, J.J., & Ewan, W.G. 1979. Phonetic explanations for the development of tones. *Language* 55, 37 - 58.

Hualde, J I. 1989. Autosegmental and metrical spreading in the vowel-harmony systems of northwestern Spain. *Linguistics* 27, 773-805.

Hualde, J.I. 1992. Metaphony and count/mass morphology in Asturian and Cantabrian dialects. In C. Laeuffer & T.A. Morgan (eds.), *Theoretical Analysis in Romance Linguistics*. Amsterdam: John Benjamins, 99-114.

Hualde, J. I. 1998. Asturian and Cantabrian Metaphony. *Rivista di Linguistica* 10, 99-108.

Hubbard, K. 1995. Toward a theory of phonological and phonetic timing: evidence from Bantu. In B. Connell & A. Arvaniti (eds.), *Papers in Laboratory Phonology IV*. Cambridge University Press, 168-187.

Hulst, H. van der & N. Smith. 1987. Vowel harmony in Khalkha and Buriat (East Mongolian). F. Beukema & P. Coopmans (eds.), *Linguistics in the Netherlands*. Dordrecht: Foris. 81-91.

Hume, E., J. Muller & A. van Engelenhoven. 1997. Non-moraic geminates in Leti. *Phonology* 14, 371-402.

Hume, E. & K. Johnson. 2001. A model of the interplay of speech perception and phonology. In E. Hume & K. Johnson (eds.), *The Role of Speech Perception in Phonology*. New York: Academic Press.

Hussein, L. 1994. *Voicing-dependent vowel duration in standard Arabic and its acquisition by adult American students*. Ph.D. dissertation, Ohio State University.

Hyman, L. 1977. On the nature of linguistic stress. In L. Hyman (ed.), *Studies on Stress and Accent, Southern California Occasional Papers in Linguistics* 4, 37-82.

Hyman, L. 1986. *A Theory of Phonological Weight*. Publications in Languages Sciences 19, Foris, Dordrecht.

Hyman, L. 2001. On the limits of phonetic determinism in phonology: *NC revisited. In B. Hume & K. Johnson (eds.), *The Role of Speech Perception Phenomena in Phonology*. Academic Press, 141-185.

Inkelas, S. 1994. The consequences of optimization for underspecification. In J. Beckman (ed.), Proceedings of the Northeastern Linguistics Society 25, 287-302.

Inkelas, S. 2006. Underspecification. In K. Brown (ed.), *Encylopedia of Language and Linguistics*. Elsevier: Oxford, 224-226.

Inkelas, S., O. Orgun & C. Zoll. 1997. The implications of lexical exceptions for the nature of grammar. In I. Roca (ed.), *Derivations and Constraints in Phonology*. Oxford: Clarendon Press, 393-418.

Ito, J. & A. Mester. 2001. Structure preservation and stratal opacity in German. In L. Lombardi (ed.), *Segmental Phonology in Optimality Theory.* Cambridge University Press, 261-295

Ito, J. & A. Mester. 2002. Lexical and postlexical phonology in Optimality Theory: evidence from Japanese. In G. Fanselow & C. Féry (eds.) *Linguistische Berichte. Sonderheft 11: Resolving Conflicts in Grammars,* 183-207

Ito, J. & A. Mester 2003. On the sources of opacity in OT: coda processes in German. In C. Féry & R. van de Vijver (eds.), *The Syllable in Optimality Theory,* Cambridge University Press. 271-303

Ito, J. & A. Mester (in press) Systemic markedness and faithfulness. *CLS* 39.

Ito, J., A. Mester & J. Padgett. 1995. Licensing and redundancy: Underspecification in Optimality Theory. *Linguistic Inquiry 26*, 571-614

Jakobson, R., G. Fant & M. Halle. 1952. *Preliminaries to Speech Analysis.* MIT Press.

Jiménez, J., & M.-R. Lloret. 2007. Andalusian vowel harmony: Weak triggers and perceptibility. Presented at OCP 4, Rhodes, Greece, January 18-21, 2007.

Jones, D. & D. Ward. 1969. *The Phonetics of Russian.* Cambridge: Cambridge University Press.

Kager, R. 1999. *Optimality Theory*. Cambridge: Cambridge University Press.

Karttunen, L. 1998. The proper treatment of optimality in computational phonology. In Finite State Methods in Natural Language Processing, 1-12.

Kaun, A. 1995. *The Typology of Rounding Harmony: An Optimality Theoretic Approach*. Ph.D. dissertation, University of California, Los Angeles.

Kavitskaya, D. 2002. *Compensatory Lengthening: Phonetics, Phonology, and Diachrony.* New York: Routledge.

Kaye, J. 1982. Harmony Processes in Vata. In H. van der Hulst & N. Smith (eds.), *The Structure of Phonological Representations.* Dordrecht: Foris, 385-452.

Kaze, J. 1989. *Metaphony in Spanish and Italian Dialects Revisited*, Ph.D. dissertation, University of Illinois, Urbana-Champaign.

Kaze, J. 1991. Metaphony and Two Models for the Description of Vowel Systems. *Phonology* 8, 163-170.

Keating, P. 1984. Phonetic and phonological representation of stop consonant voicing. *Language* 60, 286-319.

Keating, P. 1985. Universal phonetics and the organization of grammars. In. V.A. Fromkin (ed.) *Phonetic Linguistics*. New York: Academic Press, 115-32.

Keating, P. 1988. Underspecification in phonetics. *Phonology* 5, 275-292.

Keating, P. 1990. The window model of coarticulation: articulatory evidence. In J. Kingston & P. Keating (eds.), *Papers in Laboratory Phonology I.* Cambridge: Cambridge University Press, 451-470.

Keating, P. 1996. The phonology-phonetics interface. In U. Kleinhenz (ed.) *Interfaces in Phonology*, *Studia grammatica* 41. Berlin: Akademie Verlag, 262-278.

Kelso, J. A. S., Vatikiotis-Bateson, E., Saltzman, E. L., & Kay, B. 1985. A qualitative dynamic analysis of reiterant speech production: Phase portraits, kinematics, and dynamic modeling. *Journal of the Acoustical Society of America* 77, 266–280.

Kenstowicz, M. & C. Kisseberth. 1977. *Topics in Phonological Theory*. New York: Academic Press.

Kingston, J. & R.L. Diehl. 1994. Phonetic knowledge. *Language* 70, 419-454.

Kingston, J. & D. Solnit. 1989. The inadequacy of underspecification. In *Proceedings of NELS* 19.

Kiparsky, P. 1982. From Cyclic Phonology to Lexical Phonology. In H. van der Hulst & Norval Smith (eds.), *The Structure of Phonological Representations*. Dordrecht: Foris, 131-176.

Kiparsky, P. 1985. Some consequences of Lexical Phonology. *Phonology Yearbook*, 2., 85-138.

Kiparsky, P. 2000. Opacity and Cyclicity. *The Linguistic Review* 17, 351-366

Kiparsky, P. (to appear) *Paradigm Effects and Opacity*. CSLI monograph.

Kirchner, R. 1998. *An Effort-Based Approach to Consonant Lenition*. Ph.D. dissertation, University of California, Los Angeles.

Kirchner, R. 2001. Phonological contrast and articulatory effort. In L. Lombardi (ed.), *Segmental Processes in Optimality Theory.* Cambridge University Press.

Kirchner, R. 2004. Consonant lenition. In B.Hayes, R.Kirchner & D.Steriade (eds.), *Phonetically-Based Phonology.* Cambridge University Press, 313-345.

Klatt, D.H. 1973. Interaction between two factors that influence vowel duration. *Journal of the Acoustical Society of America* 54, 1102-1104.

Klimas, A. 1970. Some attempts to inventory Lithuanian phonemes. In T.F. Magner & W.R. Schmalstieg (eds.), *Baltic Linguistics*. University Park: The Pennsylvania State University Press.

Kohler, K.J. 1984. Phonetic explanation in phonology: the feature fortis/lenis. *Phonetica* 41, 150-174.

Krämer, M. 2003. What is wrong with the right side? Edge (A)symmetries in phonology and morphology. Ms. University of Ulster. ROA 576-0203.

Ladefoged, P. 2001. *A course in phonetics*. Boston: Heinle and Heinle.

Ladefoged, P. & I. Maddieson. 1996. *The Sounds of the World's Languages.* Cambridge, MA: Blackwell.

Laeufer, C. 1992. Patterns of voicing-conditioned vowel durations in French and English. *Journal of Phonetics* 20, 411-440.

Lehiste, I. 1970. *Suprasegmentals*. Cambridge, MA: The MIT Press.

Lindblom, B. 1986. Phonetic universal in vowel systems. In J.J. Ohala & J.J. Jaegger (eds.), Experimental Phonology. Orlando: Academic Press, 13-44.

Lindblom, B. 1990. Explaining phonetic variation: A sketch of the H&H theory. In H.J. Hardcastle & A. Marchal (eds.), *Speech production and speech modeling*. Dordrecht: Kluwer, 403-440.

Lisker, L. 1974. On time and timing in speech. In T.A. Sebeok (ed.), *Current Trends in Linguistics* 12. The Hague: Mouton, 2387-2418.

Lubker, J.F. & T. Gay. 1982. Anticipatory labial coarticulation: Experimental, biological and linguistic variables. *Journal of the Acoustical Society of America* 71, 437-448.

Lubowicz, A. 2002. Derived environment effects in Optimality Theory. *Lingua* 112, 243-280.

Lubowicz, A. 2003. *Contrast Preservation in Phonological Mappings*. Ph.D. dissertation, University of Massachusetts, Amherst.

Lunden, A. 2006. *Weight, final lengthening and stress: A phonetic and phonological case study of Norwegian*. Ph.D. dissertation, University of California, Santa Cruz.

Mackenzie, S. 2002. Contrast, Inventories and Vowel Harmony in OT. Presented to the Canadian Linguistic Association, University of Toronto, May 2002.

Mackenzie, S. 2005. Similarity and Contrast in Consonant Harmony Systems. *Toronto Working Papers in Linguistics* 24, 169−182.

Maddieson, I. 1977. Further studies on vowel length before aspirated consonants. *UCLA Working Papers in Phonetics* 38, 82-89.

Maddieson, I. & J. Gandour. 1976. Vowel length before aspirated consonants. *UCLA Working Papers in Phonetics* 31, 47-52.

Maiden, M. 1991. *Interactive morphonology: Metaphony in Italy.* Routledge.

Manuel, Sharon. 1999. Cross-language studies: relating language-particular coarticulation patterns to other language-particular facts. In W. J. Hardcastle & N. Hewlett (eds.), *Coarticulation: Theory, Data and Techniques.* Cambridge: Cambridge University Press, 179-198.

Manuel, S. & R. Krakow. 1984. Universal and language particular aspects of vowel-to-vowel coarticulation. *Haskins Status Report on Speech Research* SR-77/78

Martinet, A. 1952. Function, structure and sound change. *Word* 8.1, 1-32.

Mathiassen, T. 1996. *A Short Grammar of Lithuanian*. Columbus, OH: Slavica Publishers.

McCarthy, J. 1984. Theoretical consequences of Montañes vowel harmony. *Linguistic Inquiry* 15, 291-318.

McCarthy, J. 1988. Feature geometry and dependency: A review. *Phonetica* 43, 84-108.

McCarthy, J. 2002. *A Thematic Guide to Optimality Theory*. Cambridge: Cambridge University Press.

McCarthy, J. & A. Prince. 1986. Prosodic Morphology. Ms. University of Massachusetts, Amherst and Brandeis University.

McCarthy, J. & A. Prince. 1995. Faithfulness and reduplicative identity. In J. Beckman, S. Urbanczyk & L. Walsh (eds.), *University of Massachusetts Occasional Papers in Linguistics 18*. Amherst, MA:GLSA, 249-384.

McCarthy, J. & A. Prince. 1999. Faithfulness and identity in prosodic morphology. In H. van der Hulst, R. Kager & W. Zonneveld (eds.), *The Morphology-Prosody Interface.* Cambridge University Press, 218-309.

McCarthy, J. & A. Taub. 1992. Review of C. Paradis and J.-F. Prunet, eds. (1991) *The Special Status of Coronals*. *Phonology* 9, 363–372.

McGregor, W. 1990. *A functional grammar of Gooniyandi.* Amsterdam: Benjamins.

Mester, A. 1986. *Studies in tier structure*. Ph.D. dissertation, University of Massachusetts, Amherst.

Mester, A. & J. Ito. 1989. Feature predictability and underspecification: Palatal prosody in Japanese mimetics. Language 65:258–293.

Mohanan, K.P. 1986. *The Theory of Lexical Phonology*. Dordrecht: Reidel.

Mohanan, K.P. 1991. On the bases of Radical Underspecification. In *Natural Language and Linguistic Theory* 9, 285-325.

Muller, J. 2001. *The Phonology and Phonetics of Word-Initial Geminates*. Ph.D. dissertation, Ohio State University.

Myers, J. 1999. Lexical phonology and the lexicon. Ms. National Chung Cheng University. ROA 330-0699.

Myers, S. 1998. Surface underspecification of tone in Chichewa. *Phonology* 15, 367-391.

Nam, H. & E. Saltzman. 2003. A competitive, coupled oscillator of syllable structure. *Proceedings of the XVth International Congress of Phonetic Sciences* (3), 2253-2256.

Neira Martínez, J. 1955. *El Habla de Lena*. Oviedo: Instituto de Estudios Asturianos.

Neira Martínez, J. 1963. La metafonía en las formas verbales del imperative y del perfecto. In *Archivum*, Oviedo.

Neira Martínez, J. 1978. La oposición continuo/discontinuo en las hablas asturianas. In *Estudios Ofrecidos a Emilio Alarcos Llorada III*, Oviedo.

Neira Martínez, J. 1982. La metafonia por /-i/ en los Bables centrales. In *De Dialectologia Asturiana*.

Ní Chiosáin, M. & J. Padgett. 1997. Markedness, segment realization, and locality in spreading. Report no. LRC-97-01, Linguistics Research Center, Department of Linguistics, UC Santa Cruz.

Ní Chiosáin, M. & J. Padgett. 2001. Markedness, segment realization, and locality in spreading. In L. Lombardi (ed.), *Segmental phonology in Optimality Theory: constraints and representations*. Cambridge: Cambridge University Press, 118-156.

Ní Chiosáin, M. & J. Padgett. to appear. Contrast, comparison sets, and the perceptual space. In S. Parker (ed.), *Phonological argumentation: essays on evidence and motivation.* Equinox Publishing.

Noonan, M. 1992. *A Grammar of Lango*. Mouton De Gruyter.

Odden, D. 1991. Vowel geometry. *Phonology* 8, 261-289.

Ohala, J. J. 1981. The listener as a source of sound change. In C. S. Masek, R. A. Hendrick, & M. F. Miller (eds.), *Papers from the Parasession on Language and Behavior. Chicago: Chicago Ling. Soc.* 178 - 203.

Ohala, J. J. 1993. The phonetics of sound change. In C. Jones (ed.), *Historical Linguistics: Problems and Perspectives*. London: Longman, 237-278.

Öhman, S.E.G. 1966. Coarticulation in VCV utterances: Spectrographic measurements. *Journal of the Acoustical Society of America* 39, 151-168.

Ondráčkova, J. 1962. Contribution to the question concerning the rhythmical units in Czech. *Phonetica* 8, 55-72.

Padgett, J. 1995. *Stricture in Feature Geometry*. CSLI Publications.

Padgett, J. 1997. Perceptual distance of contrast: vowel height and nasality. In R. Walker, M. Katayama & D. Karvonen (eds.), *Phonology at Santa Cruz Vol. 5*. Santa Cruz, CA: Linguistic Research Center, UC Santa Cruz, 63-78.

Padgett, J. 2002. Feature classes in phonology. *Language* 78, 81-110.

Padgett, J. 2003a. Systemic contrast and Catalan rhotics. Ms.

Padgett, J. 2003b. Contrast and post-velar fronting in Russian. *Natural Language and Linguistic Theory* 21.1, 39-87.

Padgett, J. 2003c. The emergence of contrastive palatalization in Russian. In E. Holt (ed.), *Optimality Theory and Language Change*. Dordrecht: Kluwer Academic Publishers, 307-336.

Padgett, J. & M. Zygis (to appear). The evolution of sibilants in Polish and Russian. *Journal of Slavic linguistics*.

Paradis, C. 1992. *Lexical Phonology and Morphology: The Nominal Classes in Fula*. New York, London: Garland.

Paradis, C. & J.-F. Prunet. 1991. *The Special Status of Coronals*. Academic Press.

Penny, R. 1969. *El Habla Pasiega. Ensayo de Dialectología Montañesa.* London: Tamesis Books Ltd.

Penny, R. 1970. Mass-nouns and metaphony in the dialects of north-western Spain. *Archivum Linguisticum* 1, 21-30

Penny, R. 1978. *Estudio Estructural del Habla de Tudanca.* Tübingen: Max Niemeyer Verlag.

Perkell, J.S., M.L. Matthies, M.A. Svirsky & M.I. Jordan. 1993. Trading relations between tongue-body raising and lip rounding in production of the vowel /u/: A pilot "motor equivalence" study. *Journal of the Acoustical Society of America* 93, 2948-2961.

Port, R. F. 1981. Linguistic timing factors in combination. *Journal of the Acoustical Society of America* 69, 262-274.

Port, R.F, S. Al-Ani & S. Maeda. 1980. Temporal compensation and universal phonetics. *Phonetica* 37, 235-252.

Poser, W. 1986. Diyari Stress, metrical structure assignment, and the nature of metrical representations. *West Coast Conference on Formal Linguistics* 5: 178-91.

Pouplier, M. 2003. The dynamics of error. In M-J Solé, D. Recasens & J. Romero (eds.), *Proceedings of the XVth International Congress of the Phonetics Sciences, Barcelona, Spain*. Rundle Mall: Causal Productions, 2245-2248.

Prince, A. & P. Smolensky. 1993. *Optimality Theory: Constraint Interaction in Generative Grammar*, ms., Rutgers University and University of Colorado, Boulder. Corrected version, 2004, Blackwell.

Pulleyblank, D. 1986. *Tone in Lexical Phonology*. Dordrecht: Reidel.

Pulleyblank, D. 1988. Vocalic underspecification in Yoruba. *Linguistic Inquiry*, 19, 2, 233-270.

Pulleyblank, D. 2003. Yoruba vowel patterns: asymmetries through phonological competition. Ms. UBC.

Revithiadou, A., M. van Oostendorp, K.Nikolou & M.A. Tiliopoulou. 2005. Vowel harmony in contact-induced systems: The case of Asia Minor dialects of Greek. Ms., University of the Aegean & Meertens Institute.

Rice, K. 1995. On Vowel Place Features. *Toronto Working Papers in Linguistics* 14, 73−116.

Rice, K. 2007 Markedness in phonology. In P. de Lacy (ed.), *The Cambridge Handbook of Phonology.* Cambridge University Press, 196-236.

Ringen, C. O. & R.M. Vago. 2002. Geminates: Heavy or long? Ms. University of Iowa and Queens College & The Graduate Center, City University of New York.

Rochet, A.P. & B.L. Rochet. 1991. The effect of vowel height on patterns of assimilation nasality in French and English. *Proceedings 12th ICPhSc, Aix-en-Provence,* vol.3, 54-57.

Rodríguez Castellano, L. 1952. *La Variedad Dialectal del Alto Aller*. Oviedo.

Rodríguez Castellano, L. 1954. *Aspectos del Bable Occidental*. Oviedo: Instituto de Estudios Asturianos.

Rose, S. & R. Walker. 2004. A typology of consonant agreement as correspondence. *Language* 80, 475-531.

Rosner, B. S. & J.B. Pickering. 1994. *Vowel perception and production*. Oxford: Oxford Science Publications.

Saltarelli, M. 2005. Durational asymmetries and the Theory of Quantity: Temporal proportions at phonetic interface. In T. Geerts, I. van Ginneken & H. Jacobs (eds.), Romance Languages and Linguistic Theory 2003, 219–234.

Saltzman, E. 1995. Intergestural timing in speech production: Data and modeling. In K. Elenius & P. Branderud (eds.), *Proceedings of the XIIIth International Congress of Phonetic Sciences*. Stockholm: KTH and Stockholm University, 84-91.

Saltzman, E. & D. Byrd. 2000. Task-dynamics of gestural timing: Phase windows and multifrequency rhythms. *Human Movement Science* 19, 499-526.

Saltzman, E. & K.G. Munhall. 1989. A dynamical approach to gestural patterning in speech production. *Ecological Psychology* 1, 333-382.

Samek-Lodovici, V. 1992. Universal *Constraints* and Morphological Gemination: a Crosslinguistic Study. Ms. Brandeis University.

Samek-Lodovici, V. & A. Prince. 1999. Optima. Ms. University of London and Rutgers University.

Sanders, N. 2003. *Opacity and Sound Change in the Polish Lexicon*. Ph.D. dissertation, University of California, Santa Cruz.

Sasa, T. 2003. Directionality in vowel harmony: Evidence from Pulaar. Presented at the USC Phonology Workshop, University of Southern California, Nov. 14, 2003.

Scarborough, R. 2006. Lexically-conditioned phonetics: Frequency & neighborhood effects on coarticulation. Presented at the Annual Meeting of the Linguistics Society of America, Albuquerque, NM, Jan. 2006.

Schmalsteig, W. R. 2005. A note on the proto-east Baltic vowel system**.** *Baltistica* XL (1), 5-7.

Smith, J. 2002. *Phonological Augmentation in Prominent Positions.* Ph.D. dissertation, University of Massachusetts, Amherst.

Smith, J. to appear. Representational complexity in syllable structure and its consequences for Gen and Con. In S. Blaho, P. Bye & M. Krämer (eds.), *Freedom of Analysis?*. Berlin: Mouton de Gruyter.

Smith, C. 1995. Prosodic patterns in the coordination of vowel and consonant gestures. In B. Connell & A. Arvaniti (eds.), *Papers in Laboratory Phonology IV*. Cambridge: Cambridge University Press, 205-222.

Smolensky, P. 1993. Harmony, markedness, and phonological activity. Handout of keynote address, Rutgers Optimality Workshop 1, October 23. ROA-87.

Spears, A. 2006. Nasal coarticulation in the French vowel /i/: A phonetic and phonological Study. M.A. thesis, UNC-Chapel Hill.

Sprouse, R. 1997. A case for enriched outputs. Handout from TREND.

Steriade, D. 1987. Redundant values. CLS 23,2: 339-362.

Steriade, D. 1991. Moras and other slots. *Proceedings of the Formal Linguistics Society of Midamerica* 1, 254-80.

Steriade, D. 1993. Closure, release, and nasal contours. In M.K. Huffman & R.A. Krakow (eds.), *Nasals, Nasalization and the Velum*: *Phonetics and Phonology*, Academic Press, 401-470.

Steriade, D. 1995. Underspecification and markedness. In J.Goldsmith (ed.) *A Handbook of Phonological Theory,* Basil Blackwell, 114-175.

Steriade, D. 1997. Phonetics in Phonology: the case of laryngeal neutralization. Ms.

Stevens, K. N. 1998. *Acoustic phonetics.* Cambridge, MA: MIT Press.

Stevens, K. N, J. Keyser & H. Kawasaki. 1986. Towards a phonetic and phonological theory of redundant features. In J. S. Perkell & D. KH. Klatt (eds.) *Invariance and Variability in Speech Processes*. Hillsdale: Lawrence Erlbaum,.

Tekorienė, D. 1990. *Lithuanian: Basic Grammar and Conversation*. Kaunas: Spindulys.

Tesar, B. 1995. *Computational Optimality Theory.* Ph.D. Dissertation, University of Colorado.

Tesar, B. & P. Smolensky. 1998. Learnability in Optimality Theory. *Linguistic Inquiry* 29.2, 229-268.

Tessier, A.M. 2004. Input "cluster" and contrast preservation in OT. In B. Schemeiser, V. Chand, A. Kelleher & A. Rodriguez, *WCCFL 23 Proceedings*. Sommerville, MA: Cascadilla Press, 101-114.

Topintzi, N. 2004 Moraic onsets and WSP partition in Pirahã . Presented at 2nd Cambridge Postgraduate Conference.

Topintzi, N. 2005a. Moraic Onsets and WSP Partition in Pirahã. In *Camling 2004*, Proceedings of the Second Postgraduate Conference in Language Research, Cambridge University.

Topintzi, N. 2005b. Word Minimality in Bella Coola as evidence for moraic onsets. Presented at the 41st Regional Meeting of the Chicago Linguistic Society, Chicago, Illinois.

Topintzi, N. 2006. *Moraic Onsest*. Ph.D. dissertation, University College London.

Tranel, B. 1991. CVC light syllables, geminates, and moraic theory. *Phonology* 8, 291-302.

Traunmüller, H. 1982. Vokalismus in der westniederösterreichischen Mundart. *Zeitschrift für Dialektologie und Linguistik* 2, 289-333.

Tsunoda, T.. 1981. *The Djaru language of Kimberley, Western Australia*. Canberra: Pacific Linguistics.

Vatikiotis-Bateson, E. & Kelso, J. A. S. 1993. Rhythm type and articulatory dynamics in English, French and Japanese. *Journal of Phonetics* 21, 231–265.

Walker, R. 1994. Buriat syllable weight and head prominence. In J. Merchant, J. Padgett & R. Walker (eds.), *Phonology at Santa Cruz* Vol. 3, 99-110.

Walker, R. 2000. *Nasalization, Neutral Segments and Opacity Effects.* New York: Garland.

Walker, R. 2004. Vowel feature licensing at a distance: Evidence from Northern Spanish language varieties. In V. Chand, A.Kelleher, A. J. Rodríguez, and B. Schmeiser (eds.), *Proceedings of WCCFL 23*, 787-800.

Walker, R. 2005. Weak triggers. *Natural Language and Linguistic Theory* 23, 917-989.

Walther, M. 1996. OT-simple: A construction-kit approach to Optimality Theory implementation. Ms. Heinrich-Heine Universität.

Yip, M. 1991. Coronals, consonant clusters and the coda condition. In C. Paradis & J.F. Prunet (eds.), *The Special Status of Coronals*. Academic Press, 61-78.

Zec, D. 1988. *Sonority Constraints on Prosodic Structure*. Ph.D. Dissertation, Stanford University.

Zhang, X. 1996. *Vowel Systems of the Manchu-Tungus Languages of China*. Ph.D. dissertation, University of Toronto.

Zsiga, E. C. 1995. An acoustic and electropalatographic study of lexical and post-lexical palatalization in American English. In B. Connell & A. Arvaniti (eds.), *Phonology and phonetic evidence, papers in laboratory phonology IV*. Cambridge: Cambridge University Press, 282-302.

Zsiga, E. C. 1997. Features, gestures, and Igbo vowels: an approach to the phonology/phonetics interface. *Language* 73, 2, 227-274.

Zuraw, K. 2000. *Exceptions and regularities in phonology.* Ph.D. dissertation, University of California, Los Angeles.