AUDITORY REPRESENTATIONS IN PHONOLOGY

Edward S. Flemming

Table of Contents

Preface vii

Acknowledgements ix

1. Introduction 3
- 1.1. Auditory Features in Phonology 3
- 1.2. The Dispersion Theory of Contrast 4
- 1.3. Overview of the Analyses 5
  - 1.3.1. Enhancement 6
  - 1.3.2. Assimilation 9
  - 1.3.3. Neutralization 12
- 1.4. Organization of the Dissertation 14

2. The Dispersion Theory of Contrast 15
- 2.1. The Dispersion Theory of Contrast 15
- 2.2. A Formal Model of Dispersion 17
  - 2.2.1. Auditory Representations 17
  - 2.2.2. Auditory Dimensions 18
  - 2.2.3. Constraints on Contrasts 25
  - 2.2.4. The Scope of Analyses 29
  - 2.2.5. The Status of Faithfulness Constraints 33
- 2.3. Evidence for the Dispersion Theory 35
  - 2.3.1. Inventory Structure 35
  - 2.3.2. Enhancement 38
  - 2.3.3. Neutralization 40
  - 2.3.4. Contrast Preservation in English Stop Voicing 47
- 2.4. Working with Constraints on Contrast 48
- 2.5. The Analysis of Auditorily-Based Phenomena 50

3. Ways of Maximizing Distinctiveness 53
- 3.1. Enhancement 53
  - 3.1.1. F2: Backness and Rounding 54
  - 3.1.2. Low F2: Pharyngealization and Labialization 54
  - 3.1.3. Lowering Noise Frequency: [-anterior] and Rounding 55

3.1.4. Low F3: Retroflexion and Rounding 56
3.1.5. Other Cases of Enhancement 56
3.2. Contrasts on Multiple Dimensions 57
3.3. Constraining the Grouping of Dimensions in Contrasts 59
3.4. Durational Enhancement 61

4. Consonant-Vowel Assimilation 65
4.1. Assimilation of Vowels to Consonants 66
4.1.1. Fronting of Vowels Adjacent to Coronals 66
4.1.2. Rounding of Vowels Adjacent to Labials 81
4.1.3. Rounding of Vowels Adjacent to Retroflexes 89
4.2. Assimilation of Consonants to Vowels 99
4.2.1. Front Vowels Condition Coronalization 99
4.2.2. Round Vowels Condition Labiality 110
4.3. Unified Feature Theory 112

5. Neutralization 119
5.1. Front Glides cannot Contrast after Coronals 120
5.2. Restrictions on the Cooccurrence of Labials and Round Vowels 125
5.2.1. Other Examples 130
5.2.2. Non-Neutralizing Dissimilation: Lahu 131
5.3. Coronal-Velar Neutralization before Laterals 132
5.4. Dentals and Labio-Dentals 135
5.5. Simplification 137
5.6. Summary 139

6. Minimization of Allomorphy 141
6.1. Allomorphy 141
6.2. Cyclicity and Paradigm Leveling 145

7. Conclusions 153
7.1. The Dispersion Theory of Contrast 153
7.2. Auditory Representations 153
7.3. Paradigmatic Constraints 154
7.4. Phonetic and Phonological Representations 154

References 157

Index 169

Preface

This is a substantially revised version of my 1995 dissertation from UCLA. The main goals of the revisions were to simplify the formulation of the dispersion theory of contrast, and to give a fuller (and more accurate) account of the relevant acoustic phonetics. This has resulted in extensive, if sometimes superficial, changes in the representations and constraints introduced in chapter 2. I have also eliminated the MAXDUR constraints, which favored maximizing the duration of auditory features, leaving MINDIST constraints as the only constraints on auditory representations. This entailed reworking the analyses of consonant-vowel assimilation in chapter 4 since many of them originally depended on MAXDUR constraints. The broad dissemination of work on Paradigm Uniformity/Output-Output Correspondence constraints in the years since 1995 has made it possible to shorten the discussion of this topic in chapter 6. I have not added any detailed discussion of research on the role of auditory and perceptual factors in phonology that has appeared since I originally wrote my dissertation. Some useful references for those interested in exploring these developments are Boersma (1998), Hume (1998), Jun (1995), Silverman (1995), Steriade (1997), Wright (1996), and the papers in Hume and Johnson (2001).

Acknowledgements

I owe a profound debt of gratitude to the members of my doctoral committee, Bruce Hayes, Peter Ladefoged, and Donca Steriade. This dissertation has benefitted immeasurably from their comments and guidance.

The importance to phonology of acoustics was brought home to me by Donca Steriade in her 1992 seminar on feature geometry. Special thanks are due to her for providing that inspiration and, as chair of my committee, for her forbearance during my wayward progress through this project.

I would also like to thank the following for generously contributing various combinations of comments, data, encouragement, and friendship: Abeer Alwan, Dani Byrd, Keith Johnson, Jongho Jun, Sun Ah Jun, Abby Kaun, Michael Kenstowicz, Robert Kirchner, Peggy MacEachern, Joe Pater, and Dan Silverman. Special thanks go to Richard Wright for providing all of the above, plus beer.

Finally, I would like to thank Daisy for her invaluable and unstinting lack of interest in this dissertation.

Cambridge, Massachusetts
June 1995

I would like to take this opportunity to add my thanks to the many people who have provided feedback on the research presented in this book in the years since I completed my dissertation. In particular, I am grateful for the contributions of students in the various seminars at Stanford where I tested out ideas that have ended up in this revised version.

Stanford, California
July 2001

CHAPTER 1

Introduction

1.1. AUDITORY FEATURES IN PHONOLOGY

The central thesis of this dissertation is that phonological representations incorporate auditory/acoustic features. Most current theories of phonological features exhibit a strong articulatory bias in that features are defined primarily in articulatory terms (e.g. Clements 1985, 1991, Sagey 1986), but this has not always been the case. The features presented in Jakobson, Fant, and Halle (1952) are all primarily defined in acoustic terms. The ascendancy of articulatorily based features is marked by Chomsky and Halle's (1968) 'The Sound Patterns of English', which presents a comprehensive set of articulatorily defined phonological features. This articulatory bias has been reinforced by Sagey's (1986) development of a feature theory which explicitly represents active articulators.

The transition from an acoustic bias to an articulatory bias in feature theory has been made without any explicit claim that phonology is based purely on articulation, let alone arguments in favour of such a claim. In fact, both Jakobson, Fant, and Halle (1952) and Chomsky and Halle (1968:299) state that features should be defined in both articulatory and acoustic terms, so the substantial de facto change between these two feature systems was not accompanied by any explicit theoretical shift[1].

Obviously it would be a striking result if it could be shown that phonology is sensitive only to articulatory properties, so this is an issue that deserves to be addressed directly. We shall see that in fact there are many phonological phenomena which have no articulatory basis but can be understood in auditory terms.

However, it is not sufficient to simply expand the existing feature set to include some features whose primary definition is acoustic or auditory. We will see that articulatory and auditory features behave differently. In the terms of Optimality Theory (Prince and Smolensky 1993), auditory and articulatory features are referred to by distinct families of constraints. So it is more useful to think in terms of parallel auditory and articulatory representations for utterances:

Each kind of representation is subject to different constraints, and the relationship between them is determined by articulatory-to-acoustic mappings.

1.2. THE DISPERSION THEORY OF CONTRAST

Auditory representations are required so that phonological forms can be evaluated with respect to constraints which refer to auditory properties. We will propose that there is a family of constraints that implement a preference that the auditory difference between contrasting sounds should be maximized—i.e. contrasts should be easy for listeners to discriminate. The implementation of these constraints requires auditory representations in order to allow us to determine the distinctiveness of contrasts. Articulatory representations, on the other hand, have no bearing on distinctiveness.

The constraints on distinctiveness are formalized as part of a theory of phonological contrast dubbed 'the dispersion theory of contrast' after Lindblom's (1986, 1990a) Theory of Adaptive Dispersion, which it resembles conceptually. The core of the theory is the claim that the selection of contrasts is subject to three goals:

(1) i. Maximize the number of contrasts
ii. Maximize the distinctiveness of contrasts
iii. Minimize articulatory effort

These goals are hypothesized to derive from the communicative function of language. The number of phonological contrasts should be maximized in order to enable a language to differentiate a substantial vocabulary of words without words becoming excessively long. The auditory distinctiveness of the contrasts should be maximized so that the differences between words can easily be perceived by a listener, minimizing confusion. The third requirement, that effort should be minimized is probably a general principle of human motor behaviour, not specific to language.

The three requirements on contrasts conflict: maximizing the number of contrasts and minimizing effort reduces the distinctness of the contrasts. Thus the selection of an inventory of contrasts involves achieving a balance between these requirements. A source of cross-linguistic variation is variation in the compromise that given languages adopt.

This model has two distinctive properties. First, it gives a central role to auditory representations. This is the main focus of the dissertation. Second, it includes constraints on contrasts—i.e. constraints on the differences between words. This implies that the well-formedness of a phonological form cannot be determined in isolation, but must be evaluated in relation to the forms with which it can contrast. Evidence for this position is presented in chapter 2, where the dispersion theory of contrast is developed in detail. In the remainder of this chapter we will provide an overview of the evidence for auditory representations.

1.3. OVERVIEW OF THE ANALYSES

The evidence for auditory representations in phonology comes from the existence of phenomena which are difficult to analyze in purely articulatory terms, but which can be accounted for in a framework which includes auditory representations. So the bulk of this dissertation involves analyses of such phenomena. They are summarized in the table below with examples of the languages in which they are attested and references to the sections where analyses are presented. The cases can be loosely divided into three kinds: Enhancement, consonant-vowel assimilation, and neutralization phenomena. We will discuss each type in turn, providing an overview of the analyses that are presented in subsequent chapters. References to sources of data etc can be found in the sections referred to in this overview.

(2) Enhancement relationships

Front vowels are unrounded	[-back] → [-round]	Many examples (§3.1.1)
Back vowels are rounded	[+back] → [+round]	Many examples (§3.1.1)
Pharyngealized consonants are labialized	d^{ʕ} → d^{ʕw}	Modern Aramaic, Modern Syriac (§3.1.2)
[-anterior] sibilants are rounded	ʃ → ʃ^{w} ʂ → ʂ^{w}	English, French (§3.1.3) Polish (§3.1.3)
Retroflex approximants are rounded	ɹ → ɹ^{w}	English (§3.1.4)

(3) Assimilation

a. Assimilation of vowels to consonants

coronal conditions fronting	to → tø	Cantonese, Lahu, Lhasa Tibetan (§4.1.1)
plain labial conditions rounding	pɯ → pu	Tulu, Acehnese, Turkish (§4.1.2)
retroflex conditions rounding	iɖ → yɖ	Wembawemba, Wergaia (§4.1.3)

b. Assimilation of consonants to vowels

front vowels condition coronality	pi → tʃi, tsi ki → tʃi, tsi	ChiMwi:ni, Slavic, Romance (§4.2.1)
round vowels condition labiality	ku → fu tu → fu	Luganda (§4.2.2)

(4) Neutralization

a. Dissimilatory cooccurrence constraints

Front glides cannot cooccur with coronals	*tj	American English (§5.1)
Round vowels cannot cooccur with labials	*up	Cantonese, Highland Yao (§5.2)
Velars and alveolars do not contrast before laterals	*tl *kl	English etc, Katu dialects (§5.3)

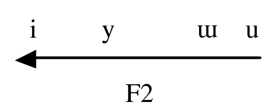
b. Other

Dental fricative becomes labio-dental	ð → v	Cockney English (§5.4)
Palatalized consonant becomes coronal	p^j → t	Old Czech > E. Bohemian Czech (§5.5)
Labialized consonant becomes labial	dw → b kw → p	Early Latin > Classical Latin Latin > Romanian (§5.5)

1.3.1. Enhancement

The most direct evidence for constraints which favor maximizing the auditory distinctiveness of contrasts comes from enhancement phenomena. A familiar example of the effects of these constraints is the correlation between backness and lip-rounding in vowels. In most languages, front vowels are unrounded and back vowels are rounded. In the UPSID database (Maddieson 1984), 94.0% of front vowels are unrounded and 93.5% of back vowels are rounded. It is hard to imagine any articulatory basis for this relationship. The tongue and the lips are articulatorily relatively independent, so it would appear to be as easy to round the lips with the tongue body forward as with it retracted. On the other hand, there is a straightforward perceptual account of the covariation of backness and rounding. In acoustic terms, front and back vowels are primarily differentiated by the frequency of the second formant (F2), with front vowels having a high F2, and back vowels having a low F2. Lip-rounding generally lowers F2, so the maximally distinct F2 contrast is between front unrounded and back rounded vowels (Liljencrants and Lindblom 1972, Stevens, Keyser, and Kawasaki 1986). This is illustrated in (5) which shows the approximate positions of front and back rounded and unrounded high vowels on the F2 dimension[2]. Front rounded vowels and back unrounded vowels yield less than maximally distinct contrasts.

(5) High vowels on the F2 dimension:



This example illustrates two of the central claims of this dissertation: Firstly, the analysis makes crucial reference to the markedness of contrasts. That is, front rounded vowels are not dispreferred because they are inherently marked, but because they yield less distinct contrasts between front and back vowels. I.e. it is the contrast between [y] and [u] which is marked, not [y] itself. Secondly, it is very clear that the relevant notion of distinctiveness must be auditorily based. If distinctiveness were articulatorily-based, then it would seem that a contrast between front rounded [y] and back unrounded [ɯ] should be as distinct as one between [i] and [u]—in both cases the vowels differ in both backness and rounding.

The analysis is formulated in the framework of Optimality Theory (Prince and Smolensky 1993) in chapter 2. The central element is a meta-constraint requiring that the auditory distinctiveness of contrasts should be maximized. That is, the less distinct a contrast is, the more marked it is. Selected contrasts are shown in (6), ranked from most marked (least distinct) to least marked (most distinct):

(6) *y-ɯ >> *y-u >> *i-u

Providing a more general formulation of these markedness relationships is achieved by employing constraints which make direct reference to the auditory distinctiveness of contrasts. Evaluation of these constraints obviously presupposes auditory representations for the contrasting sounds. Details of the proposed representations and constraints are also presented in chapter 2.

The correlation between backness and rounding is just one of many examples in which physiologically independent articulations combine to yield auditorily more distinct contrasts. We will refer to these as 'enhancement' phenomena, after a related use of this term by Stevens, Keyser, and Kawasaki (1986). The list of examples from (2) is repeated here (7), with references to the sections in which each pattern is discussed. These are instances of enhancement which clearly demonstrate the auditory nature of this phenomenon.

(7) Enhancement relationships

Front vowels are unrounded	[-back] → [-round]	Many examples (§3.1.1)
Back vowels are rounded	[+back] → [+round]	Many examples (§3.1.1)
Pharyngealized consonants are labialized	$d^{ʕ}$ → $d^{ʕw}$	Modern Aramaic, Modern Syriac (§3.1.2)
[-anterior] sibilants are rounded	ʃ → $ʃ^{w}$ ʂ → $ʂ^{w}$	English, French (§3.1.3) Polish (§3.1.3)
Retroflex approximants are rounded	ɹ → $ɹ^{w}$	English (§3.1.4)

All of these cases are analyzed as the direct consequence of constraints favoring the maximization of the auditory distinctiveness of contrasts:

- Pharyngealized consonants are labialized. Pharyngealized consonants in a number of languages, including Modern Aramaic, Modern Syriac, and Cairene Arabic, are realized with lip-rounding. The relationship between rounding and pharyngealization is similar to the relationship between rounding and backness: Pharyngealized consonants are distinguished from their plain counterparts by low F2 transitions and lip-rounding further lowers F2, as described above.

- Non-anterior fricatives are rounded. Palato-alveolar sibilants in French and English, and retroflex sibilants in Polish, are produced with some lip-rounding. These non-anterior sibilants are differentiated from anterior sibilants by the frequency at which energy is concentrated in the fricative spectrum. This frequency is lower in non-anterior fricatives because there is a larger resonating cavity in front of the noise source than in an anterior fricative (e.g. [s]). Lip-rounding further lowers the resonant frequency of this front cavity, and so makes non-anterior sibilants more distinct from their anterior counterparts.

- Retroflexion and rounding. The English retroflex approximant [ɹ] is usually produced with lip-rounding. Retroflexes are distinguished from other sounds by a low third formant (F3), and lip-rounding further lowers F3, enhancing this difference.

In each case, there is no articulatory basis for the cooccurrence for these articulations because lip-rounding is essentially physiologically independent of the position of the tongue root and tongue tip/blade.

To the extent that enhancement phenomena have been discussed in phonology, they have been analyzed in terms of re-write rules that fill in unmarked or unspecified feature values (e.g. Stevens, Keyser, and Kawasaki 1986) as in (8), or as feature co-occurrence constraints (e.g. Calabrese 1988) as in (9).

(8) [+back] → [+round]
[-back] → [-round]

(9) *[+back, -round]
*[-back, +round]

These analyses are problematic in two respects. First, they lack generality because they do not directly express the fact that these patterns arise out of a preference for more distinct contrasts. For example, Stevens et al (1986) discuss in detail the perceptual basis for enhancement relations, but specify each observed relationship in terms of a separate rule. So the general explanatory framework that predicts enhancement relationships remains unformalized, and consequently cannot be employed in phonological analyses.

Second, the formulations in (8) and (9) do not express the fact that it is contrasts which are enhanced. They imply that back vowels should be rounded regardless of what they contrast with. This is not correct. As shown in §2.3.1, only contrasts are enhanced, so the constraints in (8-9) no longer apply where front-back contrasts are neutralized.

1.3.2. Assimilation

Most of the phenomena in (3) are analyzed as involving articulatory assimilation, but constraints on distinctiveness still play a crucial role, interacting with articulatory constraints to yield a variety of patterns of neutralization and enhancement. Articulatory assimilation is analyzed as a consequence of a class of constraints against the effort involved in fast articulator movements ('movement constraints'). This leads to a preference for adjacent segments to be articulatorily similar. These effort minimization constraints can interact with distinctiveness constraints to yield patterns of contextual neutralization or enhancement.

Neutralization of indistinct contrasts is a basic effect of constraints on the distinctiveness of contrasts. In general, if effort minimization constraints (or any other contextual markedness constraints) make it impossible to produce a sufficiently distinct contrast in some context, then it is preferable to neutralize the contrast in that context (cf. Steriade 1995, 1997). For example, five vowels [i, e, a, o, u] are permitted in stressed syllables in Sicilian Italian, but the contrasts between high and mid vowels are neutralized in unstressed syllables (Mazzola 1976). The short duration of unstressed vowels makes it difficult to realize peripheral vowel qualities like [i, a, u], but avoiding these qualities makes it impossible to realize three adequately distinct vowel heights. So the mid vowels are eliminated, leaving a satisfactory contrast between higher and lower vowels, i.e. [ɪ, ʊ] vs. [ɐ] (this analysis is developed in §2.3.3.1). Most of the analyses in this dissertation involve some variant of the basic patterns of enhancement and neutralization.

Assimilation can give rise to neutralization by rendering a contrast insufficiently distinct. For example movement constraints favor prolonging some degree of labial constriction into a vowel adjacent to a labial consonant. Although a plain labial constriction is articulatorily distinct from lip-rounding, their acoustic effects are essentially the same. So an unrounded vowel that acquires a plain labial constriction through assimilation is auditorily very similar to a rounded vowel with a similar tongue body position. Consequently minimal rounding contrasts can be neutralized next to labials, as in Mapila Malayalam and Acehnese where contrasts between [ɯ] and [u] are neutralized in the environment of labials. The result of neutralization is a rounded vowel [u] because this yields a more distinct F2 contrast with front vowels. So plain labials can condition rounding via neutralization of rounding contrasts. The connection between plain labials and rounding here is auditory: the two articulations have very similar acoustic effects.

Articulatory assimilation also creates additional cues to contrasts. For example, assimilation of consonants to the tongue body position of an adjacent vowel results in vowel-dependent variations in formant transitions. E.g. F2 at consonant release is higher preceding a vowel with high F2 (a front vowel), and lower preceding a vowel with low F2 (back vowel). These differences in formant transitions provide additional cues to the vocalic F2 contrast. This contrast can be further enhanced by exaggerating these differences, e.g. by palatalizing consonants before front vowels and/or velarizing consonants before back vowels (cf. §3.4). We will argue that coronalization of velars by front vowels (e.g. ki → tʃi) is a further enhancement of vowel or glide F2 distinctions. Palatalizing a velar stop results in a palatal stop, which is liable to affrication, probably due to the length of the contact between tongue and palate. This affrication provides a further cue to the frontness of the following vowel or glide. Changing the palatal to a palato-alveolar affricate enhances this difference in affrication because the sibilant palato-alveolar frication is louder than non-sibilant palatal frication, but a palato-alveolar is otherwise acoustically similar to a palatal (§4.2.1.1).

The summary of these and other broadly assimilatory patterns from (3) is repeated in (10).

(10) Assimilation

a. Assimilation of vowels to consonants

coronal conditions fronting	to → tø	Cantonese, Lahu, Lhasa Tibetan (§4.1.1)
plain labial conditions rounding	pɯ → pu	Tulu, Acehnese, Turkish (§4.1.2)
retroflex conditions rounding	iɖ → yɖ	Wembawemba, Wergaia (§4.1.3)

b. Assimilation of consonants to vowels

front vowels condition coronality	pi → tʃi, tsi ki → tʃi, tsi	ChiMwi:ni, Slavic, Romance (§4.2.1)
round vowels condition labiality	ku → fu tu → fu	Luganda (§4.2.2)

- Coronal conditions fronting. Most kinds of coronal constriction are most easily produced if the tongue body is fronted because this makes it possible to place the tongue-tip or blade at the front of the mouth without much extension of the tip. If the tongue body is front during a coronal, then effort minimization also favors fronting of adjacent vowels as in English. This partial fronting effect can make vowel F2 contrasts insufficiently distinct, resulting in neutralization. E.g. [y-u] and [ø-o] contrasts are neutralized between coronals in Cantonese. The fronting effect of coronals is thus fundamentally articulatory, but distinctiveness constraints play a role in explaining why effort minimization is not satisfied by retracting the tongue body during coronals, and where fronting results in neutralization.

- Retroflex conditions rounding. High front vowels are rounded before retroflexes in Wembawemba. This process is analyzed as a form of compensatory enhancement of the retroflexion contrast. Movement constraints make retroflexion difficult adjacent to a high front vowel because retroflexion requires a lower, more retracted tongue body position to allow room for the tongue tip to be curled back towards the palate. Consequently Wembawemba avoids full retroflexion following [i]. Retroflexes are distinguished from alveolars by lower F3 closure transitions. Reduced retroflexion would yield a higher F3, so this is compensated by rounding the lips which also serves to lower F3. This pattern is thus related to the enhancement of retroflexes by rounding (above).

- Round vowels condition labiality. The main examples of this pattern involve the development of labial affricates and fricatives preceding the 'super-high' rounded vowel of early Bantu languages. The high airflow at the release of a stop can generate significant frication at the lips if the rounded constriction is small. We hypothesize that the resulting rounded labial fricative was reinterpeted as an auditorily similar plain labio-dental fricative. This change could have served to enhance the frication difference which would have become the primary cue to the high vs. super-high contrast as the vowel height difference itself was lost.

All of the phenomena considered here are problematic for an articulatory feature theory like Sagey's. Coronals and front vowels do not have any features in common, so it is hard to account for the observed interactions between them. Sagey proposes that labials and round vowel share a [labial] node, and uses this to account for the rounding effect of plain labials, via an additional rule rounding [labial] vowels. Clements (1991) and Hume (1992) have proposed feature systems according to which these both these problematic classes are grouped by single features, [coronal] and [labial] respectively. This allows these assimilations to be characterized as the spreading of these features between consonants and vowels. Neither of these proposals contributes to the analysis of the conditions on these assimilations—e.g. coronalization is almost always accompanied by affrication, and retroflex coronals do not condition fronting (as detailed in § 4.1.3). We will see that these conditions follow if it is recognized that these cases do not involve simple articulatory assimilation, instead they arise from the interaction of articulatory assimilation with auditorily-based enhancement and neutralization.

1.3.3. Neutralization

The patterns in (4a) (repeated here as 11) are labeled as dissimilatory cooccurrence constraints because most of them have been analyzed as OCP-related constraints against sequences of segments that share a particular feature (cf. also Kawasaki 1982). Again, in the case of the first two patterns, this implies the existence of features that group coronals and front vowels/glides, and labials and round vowels respectively. The constraint against coronal-lateral sequences has also been analyzed as an OCP constraint against sequences of coronal consonants (e.g. Borowsky 1986). It will be argued here that all of these cases actually involve neutralization of indistinct contrasts.

(11) Dissimilatory cooccurrence constraints

Front glides cannot cooccur with coronals	*tj	American English (§5.1)
Round vowels cannot cooccur with labials	*up	Cantonese, Highland Yao (§5.2)
Velars and alveolars do not contrast before laterals	*tl *kl	English etc, Katu dialects (§5.3)

- Front glides and coronals. Coronal-palatal glide sequences are auditorily similar to plain coronals because palatal glides are distinguished by a high F2, but a plain coronal typically has a relatively high F2 at release anyway. Consequently the contrast [tj-t] is dispreferred. There is evidence that the contrast is problematic rather than the sequences [tj] and [dj] per se, because there are dialects of American English that neutralize the contrast in favor of the palatalized alveolar, i.e. *do* and *dew* are both pronounced [d^{i}u].

- Round vowels and labials. Cantonese exhibits a complex array of restrictions on the coccurrence of round vowels and labials. Front round vowels cannot occur with either a preceding or following labial (*py, *yp), while back rounded vowels can occur with a preceding labial, but not with a following labial (pu, *up). It is proposed here that the restriction on the front rounded vowels arises because contrasts like [pi-py, ip-yp] would be insufficiently distinct. This is because movement constraints require some lip constriction on vowels adjacent to labials, and this results in auditory effects which are very similar to lip rounding. Thus the apparent dissimilation here closely parallels assimilatory rounding of vowels adjacent to labials: both fundamentally involve neutralization of a contrast between rounded and unrounded vowels due to the influence of labial consonants. Back vowels will generally neutralize to rounded vowels because that enhances the contrast with front vowels, and for the same reason front vowels will generally neutralize to unrounded vowels, as in Cantonese.

The restriction against back rounded vowel-labial sequences like *[up] is analyzed as the result of neutralization of the contrast between labial and velar consonants in this context—i.e [up-uk] is insufficiently distinct. This is because formant transitions associated with labials and velars are liable to be very similar adjacent to back rounded vowels. This analysis explains why only coda labials are problematic, because the release burst distinguishes labials and velars in onset, but coda consonants are unreleased in Cantonese so only the inadequate formant transition cues are available in this context.

- Coronals and velars before laterals. Coronal stop-lateral clusters (e.g. [tl]) are disallowed in languages like English because they are easily confused with velar stop-lateral clusters (e.g. [kl]). The two types of sequence are auditorily very similar because the stop closure is at or behind the place of the lateral, so the release burst and formant transitions following the stop are strongly influenced by the lateral constriction rather than reflecting the stop place. Labial stop-lateral sequences remain distinct because the labial closure is in front of the alveolar lateral, so a labial burst is still generated in [pl, bl] sequences. The contrast [kl-tl] can be eliminated by disallowing either [tl] or [kl], and both restrictions are attested, sometimes with dialectal variation between the two, as in Katu, or free variation, as in Mong Njua.

(12) Other

Dental fricative becomes labio-dental	ð → v	Cockney English (§5.4)
Palatalized consonant becomes coronal	p^j → t	Old Czech > E. Bohemian Czech (§5.5)
Labialized consonant becomes labial	dw → b kw → p	Early Latin > Classical Latin Latin > Romanian (§5.5)

The remaining phenomena in (12) are also analyzed as involving neutralization of contrasts between auditorily similar sounds. This is clearest in the case of the neutralization between dental and labio-dental fricatives found in many dialects of English. This process is mysterious given conventional articulatory features because it involves a non-assimilatory change from [coronal] to [labial]. But dental and labio-dental fricatives are acoustically very similar, and easily confused even by speakers who maintain the distinction (Miller and Nicely 1955). So this receives a straightforward analysis as neutralization of an insufficiently distinct contrast.

The other two patterns in (12) involve replacement of a complex consonant or cluster by a simple consonant. They again show a relationship between front glides and plain coronals, and between round glides and plain labials. We will suggest, following Ohala (1992) that auditory similarity between these clusters and the corresponding simple consonants plays a key role in accounting for these patterns.

1.4. ORGANIZATION OF THE DISSERTATION

The organization of the dissertation largely follows the structure of this introduction. Chapter two introduces the dispersion theory of contrast and the formalization of auditory representations, together with evidence that distinctiveness constraints evaluate contrasts. The next three chapters apply the dispersion theory in the analysis of the problematic phenomena introduced above. Enhancement phenomena are analyzed in chapter 3, assimilation in chapter 4, and neutralization in chapter 5. Chapter 6 addresses some problems relating to alternations and dispersion theory, and conclusions are presented in chapter 7.

NOTES

1. The same position is adopted in the recent discussion of phonological features by Clements and Hume (1995:245). Sagey (1986), on the other hand, appears to differentiate articulatorily defined features from acoustically-defined features (chapter 4), a position which is made explicit in the Garland edition of her dissertation.

2. The positioning of vowels is based on measurements of vowel formants for Dutch and German summarized in Disner (1983), and for Korean (Han 1963), and on modeling of the effects of lip-rounding reported in Stevens (1999), pp. 291-3. There is significant cross-linguistic variation in the F2 of high front rounded vowels (Schwartz, Beautemps, Abry, and Escudier 1993), and the same probably applies to back unrounded vowels, although less data are available on this point. However, the ordering of the vowels in terms of F2 is consistent.

CHAPTER 2

The Dispersion Theory of Contrast

The previous chapter provided an introduction to constraints on the auditory distinctiveness of contrasts. These constraints are novel not only in referring to auditory representations, but also in being constraints on the well-formedness of contrasts. Contrast is a relationship between possible words so these constraints imply that the well-formedness of a word cannot be evaluated in isolation, it must be evaluated with reference to a set of forms that it contrasts with. This chapter focuses on this aspect of constraints on the distinctiveness of contrasts, placing them within the context of a theory of phonological contrast, the dispersion theory, which provides the basic framework for all of the analyses in this dissertation.

First, we will discuss the basic assumptions of the theory of contrast, then we will develop a formalization of the theory in terms of Optimality Theory. The bulk of the chapter is then devoted to providing support for the model, in particular for the claim that there are constraints on the well-formedness of contrasts. In the process we will show how some of the basic types of auditorily-based processes (enhancement and neutralization) are analyzed in dispersion theory. Subsequent chapters apply the model to the specific cases outlined in the introduction.

2.1. THE DISPERSION THEORY OF CONTRAST

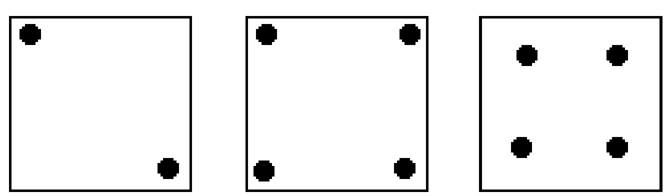
The theory of contrast outlined here is dubbed the ‘dispersion theory’ after Lindblom’s (1986, 1990a) ‘Theory of Adaptive Dispersion’, which it resembles in many respects. The core of the theory is the claim that the selection of phonological contrasts is subject to three functional goals:

i. Maximize the number of contrasts
ii. Maximize the distinctiveness of contrasts
iii. Minimize articulatory effort

These goals derive from language’s function as a means for the transmission of information. The number of phonological contrasts should be maximized in order to enable us to differentiate a substantial vocabulary of words without words becoming excessively long. The auditory distinctiveness of the contrasts should be maximized so that the differences between words can easily be perceived by a listener. The third requirement, that effort should be minimized appears to be a general principle of human motor behavior, and is not specific to language.

These ideas are far from new. They have antecedents in the work of Passy (1891) and Zipf (1949), for example, and have been developed in detail by Martinet (1952, 1955) and Lindblom (1986, 1990a). The latter has developed quantitative models of contrast selection based on the principles of maximization of distinctiveness and minimization of effort (but not maximization of the number of contrasts).

An important property of these goals is that they conflict. This point can be illustrated by considering the selection of contrasting sounds from a schematic two dimensional auditory space, shown in figure 1. Figure 1a shows an inventory which includes only one contrast, but the contrast is maximally distinct, i.e. the two sounds are well separated in the auditory space. If we try to fit more sounds into the same auditory space, the sounds will necessarily be closer together, i.e. the contrasts will be less distinct (figure 1b). Thus the goals of maximizing the number of contrasts and maximizing the distinctiveness of contrasts inherently conflict. Minimization of effort also conflicts with maximizing distinctiveness. Assuming that not all sounds are equally easy to produce, attempting to minimize effort reduces the area of the auditory space available for selection of contrasts. For example, if we assume that sounds in the periphery of the space involve greater effort than those in the interior, then, to avoid effortful sounds it is necessary to restrict sounds to a reduced area of the space, thus the contrasts will be less distinct, as illustrated in figure 1c. Note that while minimization of effort and maximization of the number of contrasts both conflict with maximization of distinctiveness, they do not directly conflict with each other.



(a)	(b)	(c)
Two segments	Four segments	Four segments
Most separation	Less separation	Least separation
More effort	More effort	Less effort

Figure 1. Selection of contrasts from a schematic auditory space.

Given that the three requirements on contrasts conflict, the selection of an inventory of contrasts involves achieving a balance between them. A source of cross-linguistic variation is variation in the compromise that given languages adopt.

The next section presents a formalization of dispersion theory in terms of Optimality Theory (Prince and Smolensky 1993) and a model of auditory representations. Optimality theory is suitable for this purpose, because it provides a system for specifying the resolution of conflict between constraints. Evidence for the model is provided in §2.3, where it is shown that key predictions flowing from the existence constraints on contrast are confirmed.

2.2. A FORMAL MODEL OF DISPERSION

According to dispersion theory, determining an inventory of contrasts involves selecting sounds in accordance with the constraints on contrasts outlined above. To formalize this model, we need to provide auditory representations, and formulations of the constraints on contrast. We will consider these components of the model in turn.

2.2.1. Auditory Representations

The auditory representation must include all auditory properties of a sound relevant to phonological patterning. What degree of detail is relevant is an empirical issue, but it is probably quite considerable, so the features proposed here are not intended to be a complete set, they are simply sufficient for the analyses in this dissertation. Further study will undoubtedly reveal the need for enrichment of the representations.

We will represent sounds as located in a multi-dimensional auditory space. Examples of dimensions postulated here are listed in (1). Note that, given the definitions offered here, most of these dimensions could be regarded as acoustic rather than auditory. The representations are labeled as auditory to emphasize the fact that it is distinctiveness to the human ear that is relevant to language, and follows a similar use of the term by Ladefoged 1997:611ff. Also, as the theory is developed it is expected that the particulars of the processing of sound by the peripheral auditory system will be found to be relevant.

(1)	Formant frequencies (F1, F2, F3)	Frequencies of formants
	Noise Frequency	Frequency of first peak in noise spectrum
	Diffuseness	Diffuseness of noise spectrum
	Noise Loudness	Loudness of noise in the spectrum
	Loudness	Overall loudness
	VOT	Voice Onset Time

These dimensions are scalar, i.e. they are essentially multi-valued features. For example we will represent F1 in terms of a five point scale (2). This provides a direct representation of auditory distance between sounds on a dimension in terms of the difference between their values on that dimension. For example [i] has an F1 value of 1 and [a] has an F1 value of 5, so these vowels are separated by a distance of 4 on the F1 dimension. The sounds [i] and [ɪ], on the other hand, differ by only 1 on this dimension. A representation of auditory distinctiveness is required to evaluate the distinctiveness of contrasts

(2) F1 dimension:

1	i
2	ɪ
3	e
4	ʌ
5	a

Sounds are specified auditorily by matrices of dimension values, e.g. [F1 *1*, F2 *6*, F3 *3*] for [i]. That is, since dimensions are scalar features, standard feature notation is used with the modification that dimensions take integer values rather than the +/- values of binary features.

Not all dimensions are relevant to all sounds. Only sounds with a relatively open vocal tract (vowels, approximants, and nasals) have well-defined formants, so these dimensions will be specified for these sounds, but not for fricatives and stop closures. Similarly, not all sounds involve a significant noise component, so not all sounds will be specified for Noise Frequency.

2.2.2. Auditory Dimensions

This section provides an overview of proposed dimensions and how sounds are specified in terms of them. More detailed discussion of particular dimensions will be provided as required for particular analyses.

2.2.2.1. Formant Frequencies

The first two formant frequencies are the primary dimensions of vowel quality. As noted above, the frequency of the first formant, F1, corresponds to vowel height, and is divided into five levels as shown in (3). F2 corresponds loosely to the front-back dimension, but is also strongly influenced by rounding, which generally lowers F2. So, as shown in (4), front unrounded vowels have the highest F2, while back rounded vowels have the lowest F2.

(3) F1 dimension:

1	i
2	ɪ
3	e
4	ʌ
5	a

(4) F2 dimension:

5	i
4	y
3	ɨ
2	ɯ
1	u

Note that distinguishing five levels on each dimension is essentially arbitrary. It is sufficient for present purposes, but it is likely that finer distinctions could be motivated. Dimensions are generally presented with highest values at the top, except in the case of F1 where this ordering is reversed to place high vowels at the top of the scale.

The third formant dimension is divided into five levels also. F3 is highest in high, front, unrounded vowels. It is lower in low and back vowels, and generally lower still in rounded vowels (back or front). [ɹ] has substantially lower F3 than any other vowel (Peterson and Barney 1952).

(5) F3 dimension:

5	i
4	ɯ, a
3	u, y
2	
1	ɹ

All sonorants have formant structure, so formant frequencies are also relevant to glides, laterals and nasals. In addition, during the formation and release of an obstruent constriction, there are intervals during which the articulator forms an approximant constriction. The formant frequencies associated with these intervals, often referred to as formant transitions, are of phonological relevance and are discussed in §2.2.2.8.

2.2.2.2. Noise Frequency

Fricatives differ in the frequencies where energy is concentrated. Simple models of fricative acoustics imply that there should generally be well-defined peaks in the fricative noise spectrum whose frequencies depend on the size of the cavity in front of the fricative constriction (Stevens 1989). The fricative noise source is filtered by the front cavity, so the peaks in the fricative spectrum are at the resonant frequencies of the front cavity. The larger the cavity, the lower its resonant frequencies, and thus the lower the frequency of the first peak in the fricative spectrum. 'Noise Frequency' (NF) is intended to refer to this frequency.

In practice it can be difficult to identify clear resonance peaks in fricative spectra, but general spectral shape accords fairly well with theory (cf. Johnson 1997:121ff.). An alternative basis for this dimension which avoids the problem of peak-picking but yields much the same ordering of fricatives is the frequency of the first moment (or 'center of mass') of the fricative spectrum (Jassem 1979, Forrest, Weismer, Milenkovic, and Dougall 1988). That is, even if consistent peaks are hard to identify, the filtering effect of the front cavity does result in energy being concentrated at higher frequencies with smaller front cavities, and consequently the first moment of the spectrum increases in frequency.

For present purposes we will differentiate six levels of Noise Frequency (6). This is not sufficient to differentiate all the levels that are likely to be relevant to distinguishing fricatives ranging from pharyngeal to coronal, but it is sufficient for present purposes. Most of the analyses in which Noise Frequency plays a crucial role involve sibilant fricatives, so five levels [NF *2–6*] are used to differentiate these. Sounds with lower noise frequency can be specified [NF *1*] (probably rounded velars, uvulars, and pharyngeals).

(6) Noise Frequency:

6	s
5	s^{w}
4	ʃ
3	ʂ
2	ʂ^{w}
1	χ

In labial and non-sibilant dental fricatives the front cavity is so small that its resonant frequencies are too high to be significantly represented in the speech signal—there is little energy in the noise source at such high frequencies, and radiation losses are greater at higher frequencies. As a result the spectrum is relatively flat, but lower frequencies tend to dominate because the amplitude of the noise source is greater at lower frequencies and radiation losses are greater at higher frequencies (Fant 1960), so we will assume that they are specified [NF 2] (like [ʂ^{w}] in (6)).

The dimension of noise frequency is also relevant to the representation of stop bursts (§2.2.2.9).

2.2.2.3. Diffuseness

Fricative spectra can also be differentiated by the distribution of energy across the spectrum. As mentioned above, labials have a relatively flat or diffuse spectrum due to the lack of an effective front cavity to filter the noise source. The same largely applies to non-sibilant dentals. Other fricatives have more pronounced spectral peaks. We will dub this feature ‘diffuse’, after the related feature proposed by Jakobson, Fant, and Halle (1952). However, they applied this term to both consonants and vowels whereas we will restrict its application to fricative sounds, including stop bursts (§2.2.2.9).

(7) Diffuseness:

[+diffuse]	θ, f
[-diffuse]	x, ʃ, s

Diffuseness is formulated as a binary feature since it is being treated as an essentially qualitative distinction. So far we do not have any motivation for attempting to quantify degrees of ‘peakedness’ vs. flatness of a spectrum.

2.2.2.4. Noise Loudness

A third dimension which differentiates fricative sounds is the loudness of noise. The distinction relevant to fricatives is between high intensity sibilants, and other quieter fricatives. The lower levels of this dimension are relevant to distinguishing the loudness of frication in stop bursts, as discussed below.

(8)	Noise Loudness:	5	s, ʃ
	(NL)	4	x, f, θ

2.2.2.5. Loudness

In addition to Noise Loudness, we will also specify overall Loudness (the auditory correlate of intensity), which is relevant to all classes of sounds. As has often been observed, intensity corresponds loosely to sonority, and is important in distinguishing manner classes. We will differentiate six levels, ranging from silent voiceless stop closures, through fricatives, sibilant fricatives, nasals, and laterals to low vowels.

(9)	Loudness:	5	a
		4	l
		3	n
		2	s
		1	f
		0	p closure

2.2.2.6. Voice Onset Time

Voice Onset Time (VOT) is the interval between stop release and the onset of voicing. It may range from zero (pre-voiced) through small (voiceless unaspirated), to large and positive (voiceless aspirated). This dimension differs from all others discussed so far in that it is temporal where the others are spectral. We will treat VOT just like the other dimensions, although it is not obvious where in the temporal sequence of segments such dimensions should be specified.

(10) VOT:	2	p^h	'long VOT'
	1	p	'short VOT'
	0	b	'zero VOT'

Note that final stops and unreleased stops in consonant clusters have no VOT specification since there is no applicable voice onset.

The feature [+voice] is used here to refer to the presence of low-frequency periodicity during a sound (a result of vocal fold vibration). So fully voiced stops are [+voice], whereas all voiceless stops are [-voice].

2.2.2.7. The Representation of Time

The representation of time raises a great many issues, most of which will be skirted in this dissertation. We will generally assume the standard form of representation in which time is divided into discrete segments. However, there is evidence for the phonological significance of auditory segments smaller than usually assumed. Specifically, it is necessary to include formant transitions into and out of obstruents (and nasals), and stop bursts.

During the formation and release of an obstruent constriction, there are intervals during which the articulator forms an approximant constriction, which has formant structure. The formant frequencies adjacent to the obstruent are thus characteristic of that obstruent, and provide important cues to its place of articulation (Delattre, Liberman, and Cooper 1955). So a vowel-fricative-vowel sequence, e.g. [asi], contains five segments (11). Following Laver (1994) we will call the interval preceding the formation of the constriction the 'approach' transition, and the interval following the constriction the 'release' transition.

Note that an obstruent is not necessarily accompanied by approximant transitional segments. In (11), these segments are the consequence of making the transition from vowel to fricative, but in a sequence such as [as], only one transition appears.

$$
\begin{array}{cccccc}
 & \text{a} & \begin{array}{c}\textit{approach}\\ \textit{transition}\end{array} & \text{s} & \begin{array}{c}\textit{release}\\ \textit{transition}\end{array} & \text{i} \\
(11) & \begin{bmatrix}\text{F1} & \mathit{5}\\ \text{F2} & \mathit{3}\\ \text{F3} & \mathit{4}\\ \text{(etc)} & \end{bmatrix} & \begin{bmatrix}\text{F1} & \mathit{1}\\ \text{F2} & \mathit{4}\\ \text{F3} & \mathit{5}\\ \text{(etc)} & \end{bmatrix} & \begin{bmatrix}\text{NF} & \mathit{6}\\ \text{NL} & \mathit{5}\\ \text{-diffuse} & \\ \text{(etc)} & \end{bmatrix} & \begin{bmatrix}\text{F1} & \mathit{1}\\ \text{F2} & \mathit{4}\\ \text{F3} & \mathit{5}\\ \text{(etc)} & \end{bmatrix} & \begin{bmatrix}\text{F1} & \mathit{1}\\ \text{F2} & \mathit{5}\\ \text{F3} & \mathit{5}\\ \text{(etc)} & \end{bmatrix}
\end{array}
$$

2.2.2.8. Formant Transitions

Second and third formant transitions are important cues to the place of articulation of consonants, but vary depending on the adjacent vowel (Lindblom 1963a). The nature of this variation differs somewhat between languages (Sussman, Hoemeke, and Ahmed 1993). Alveolars and dentals typically have a relatively invariant [F2 *4*] transition but may have [F2 *3*] adjacent to back vowels. The transitions of labials and velars vary substantially with the following vowel (Lindblom 1963a, Krull 1987, Sussman, Hoemeke, and Ahmed 1993). We can make the generalizations that labials tend to have lower F2 and F3 than the adjacent vowel because a labial constriction generally lowers all formants, however the formant transitions are liable to be relatively flat adjacent to back rounded vowels with very low F2. Velars tend to have F2 and F3 values close to those of the following vowel, because the place of articulation of a plain velar typically varies according to vowel context (Houde 1967, Keating and Lahiri 1993).

As discussed in the following section, these generalizations do not apply to consonants with strong secondary articulations such as palatalization or labialization. In these cases, the formant transitions generally reflect the secondary articulation, not the primary place.

First formant transitions have not been shown to be relevant to place distinctions in obstruents. This may be because an obstruent constriction results in a low F1 regardless of place. Other aspects of F1 transitions may be relevant to place, such as rate of change (Stevens 1999:334ff.), but I am not aware of any relevant experimental evidence.

Differences in formant transitions are not necessarily equivalent to comparable differences in vowel formants. In fact differences in the end-point of a formant transition are probably less distinct than similar magnitude differences realized over a greater duration during a vowel (see §3.4 for further discussion). When it is necessary to distinguish vowel and transition formant frequencies, the type of segment will be indicated together with the value on the formant dimension, e.g. [transition F2 *4*] or [Vowel F2 *4*].

2.2.2.9. Stop Contrasts

A released stop also contains a burst which consists of a transient, resulting from the initial explosion of air, followed by a short interval of frication, since the constriction is still narrow immediately after release, and oral pressure is high. Properties of the burst have been shown to be significant cues to place of articulation in stops (e.g. Dorman, Studdert-Kennedy, and Raphael 1977, Smits, ten Bosch, and Collier 1996).

The burst frication is essentially the same as a short duration fricative produced at the same place of articulation as the stop, and so can be specified using the NF and Diffuse dimensions already introduced in relation to fricatives (12).

(12) Features of stop bursts

	b	d	ɟ	ɢ
NF	2	6	4	1
Diffuse	+	-	-	-

Stop bursts also differ in intensity, but the duration of stop bursts is short enough to affect their perceived loudness, so their Noise Loudness is less than corresponding fricatives. The auditory impression of loudness depends on duration as well as intensity for short stimuli, i.e. given two short signals of equal acoustic intensity, the longer will sound louder (Scharf 1978). It appears that the perception of the loudness of a signal depends on energy integrated over some interval, so up to the threshold corresponding to that integration interval, longer signals sound louder, other things being equal. Experimental evidence has produced divergent estimates of this threshold, but stop bursts almost certainly fall below it (see the review in Beckman 1986, chapter 5), so the loudness of stop burst frication depends on duration as well as intensity. This is reflected in the Noise Loudness dimension, presented in full in (13).

Among stops, the key distinctions here are that voiced stops have quieter bursts than voiceless stops, and that voiceless labials have quieter bursts than other places of articulation (Zue 1976). We do not attempt to order voiceless labial bursts in relation to voiced bursts. All affricates have louder frication than stops given the much greater duration of frication—we will assume these are comparable to fricatives. Partially affricated stops are intermediate between stops and affricates in NL. Partial affrication is typical for palatal and palato-alveolar stops (see §3.2), but can be realized at other places of articulation.

(13) Noise Loudness

5	s, ʃ, tʃ
4	f, θ, x
3	t̠, c bursts
2	t, k bursts
1	p, b, d, g bursts
0	p closure, vowels

A stop may thus involve four segments: approach, closure, burst and release. In a plain stop, all these segments cue the same contrasts, e.g. an intervocalic alveolar stop can be given an auditory representation as in (14), where the approach transition, burst and release transition all signal its alveolar place of articulation.

(14)

approach transition	*closure*	*burst*	*release transition*
[F1 *1*, F2 *4*, F3 *5*, (etc)]	[Loudness *0*]	[NF *6*, NL *2*, -diffuse, (etc)]	[F1 *1*, F2 *4*, F3 *5*, (etc)]

Closure, burst and release can be independently contrastive. In an unreleased stop, e.g. the [p] and [t] in sentence-final English ‘cap’ and ‘cat’, the only features differentiating place are the closure transitions. Similarly, in a labial-velar stop, e.g. [k͡p], the approach transitions are important cues distinguishing the stop from a plain labial[1].

In stops with secondary articulations, such as palatalization, the characteristic release transitions of the stop place can be determined by the secondary articulation, so will usually be as shown in (15). Thus in sequences such as [spʲa] and [stʲa], place contrasts are marked mainly by the burst, not by formant transitions[2].

(15) Release features of palatalized and labialized stops

	C^j	C^w
F2	5	1
F3	2	1

The inclusion of release transitions in the representation is somewhat reminiscent of Steriade’s (1993a, 1994a) proposal to represent stops in terms of closure and release positions. However, the current proposal adopts much richer representations: approach transitions are included in addition to the release, the burst is represented independently of the release transitions, and transitions are possible with all obstruents.

Steriade's motivation for differentiating bi-positional stops from other mono-positional sounds was to account for the greater range of nasalization and laryngealization contrasts attested with stops than with other consonants. For example, we find contrasts between fully and pre-nasalized stops, and between fully and post-nasalized stops, but parallel contrasts are not observed with fricatives or approximants. Similar observations apply to laryngeal contrasts. In terms of Steriade's representations, these observations follow from the fact that [nasal] can associate to closure, release or both positions of a stop whereas there is only one position for it to associate to in a fricative or approximant.

Obviously this analysis is not open to us if we represent the approach and release of all obstruents. Steriade (1994b) has suggested an alternative account of these facts in terms of the distinctiveness of contrasts: Nasal, post-nasalized and pre-nasalized stops have qualitatively different acoustic properties: nasal and post-nasalized stops lack a burst since there is no pressure build-up because air escapes through the nose. There is no qualitative difference between pre- and post-nasalized continuants, just the fine difference in timing, which is not sufficient to maintain a robust contrast.

2.2.3. Constraints on Contrasts

We need to formalize constraints favoring the goals outlined in §2.1, repeated here:

i. Maximize the number of contrasts
ii. Maximize the distinctiveness of contrasts
iii. Minimize articulatory effort

Inventories of contrasts are selected so as to best satisfy these goals, but as noted above, these goals conflict so it is not possible to fully satisfy all of them. That is, given that the space of physiologically possible sounds is bounded, there is a trade-off between the number of contrasts and the distinctiveness of those contrasts. Similarly, there is a trade-off between minimization of effort and maximization of distinctiveness because avoiding effort involves restricting sounds to the lower effort region of the space of possible sounds. Fitting the same number of contrasting sounds into this smaller space results in less distinct contrasts. Thus selecting an inventory that best satisfies these goals involves finding an optimal balance between these conflicting goals. This optimization will be modeled within the framework of Optimality Theory (Prince and Smolensky 1993).

Optimality Theoretic models achieve optimization without numerical calculation by adhering to a requirement of strict constraint dominance, i.e. where two constraints conflict, the higher-ranked constraint prevails (Prince and Smolensky 1993:78). In the dispersion theory of contrast, assigning complete dominance to any one of the proposed fundamental constraints yields inappropriate results. For example, if maximization of the number of contrasts dominates, the result will be a huge number of very fine contrasts. The essence of the dispersion theory is that the conflicting goals are balanced against each other.

The balancing of conflicting scalar constraints can be modeled in terms of strict dominance by decomposing the scalar constraints into a ranked set of sub-cases. This technique is adopted by Prince and Smolensky (1993) in the analysis of syllable structure, where a general constraint requiring a syllable nucleus to be maximally sonorous is decomposed into a set of constraints against particular segments being in the nucleus, with the sub-constraints being ranked according to the sonority of the segments. The sub-constraints corresponding to the scalar constraints can then be interleaved, resulting in a balance between them. We will follow this strategy here.

For ease of exposition, we will start by considering the restricted case of selecting a set of contrasting sounds along one auditory dimension, specifically selection of vowels contrasting in F1 ('vowel height'). More complex cases will be discussed once the basic machinery has been exemplified.

2.2.3.1. Maximize the Auditory Distinctiveness of Contrasts

The requirement that the auditory distinctiveness of contrasts should be maximized can be decomposed into a ranked set of constraints requiring a specified minimal auditory distance between contrasting forms (16). Since we are initially considering only a single auditory dimension, we need only consider constraints in which the specified minimum distance is on a single dimension. The required distance is indicated in the format *Dimension:distance*, e.g. 'MINDIST = F1:2' is satisfied by contrasting sounds that differ in at least two on the F1 dimension.

(16) MINDIST = F1:1 >> MINDIST = F1:2 >>... >> MINDIST = F1:4

To encode the fact that auditory distinctiveness should be maximized, MINDIST = $D{:}n$ is ranked above MINDIST = $D{:}n{+}1$, i.e. the less distinct the contrast, the greater the violation.

2.2.3.2. Maximize the Number of Contrasts

The requirement that the number of contrasts should be maximized can be implemented in terms of a positive constraint, MAXIMIZE CONTRASTS that counts the number of contrasts in the candidate inventory. The largest inventory or inventories are selected by this constraint, all others are eliminated. Of course the largest candidate inventories will usually have been eliminated by higher-ranked constraints, so this constraint actually selects the largest viable inventory.

When attention is being restricted to contrasts on a particular dimension, we will indicate this by specifying the dimension on which the number of contrasts is to be maximized, e.g. MAXIMIZE F1 CONTRASTS.

2.2.3.3. Balancing the Requirements on Contrasts

The language-specific balance between these first two constraints on contrasts is modeled by specifying the language-specific ranking of the constraint MAXIMIZE CONTRASTS in the hierarchy of MINDIST constraints. Effectively, the first MINDIST constraint to outrank MAXIMIZE CONTRASTS sets a threshold distance, and the optimal inventory is the one that packs the most contrasting sounds onto the relevant dimension without any pair being closer than this threshold.

Continuing the example of the selection of F1 contrasts, the conflict between the two constraints on contrasts is illustrated in the tableau in (17). This tableau shows inventories of contrasting vowel heights and their evaluation by MINDIST and MAXIMIZE contrasts constraints. We are considering constraints on contrasts so the candidates evaluated here are sets of contrasting forms rather than outputs for a given input.

MINDIST constraints assign one mark for each pair of contrasting sounds which are not separated by at least the specified minimum distance. For example, candidate (b) violates MINDIST = F1:3 twice because the contrasting pairs [i-e] and [e-a] violate this constraint while [i-a] satisfies it, being separated by a distance of 4 on the F1 dimension. (Note that the number of violations will generally be irrelevant for MINDIST constraints ranked above MAXIMIZE CONTRASTS because it will always be possible to satisfy the MINDIST constraint by eliminating contrasts).

MAXIMIZE CONTRASTS is a positive scalar constraint, according to which more contrasts are better, so the evaluation by this constraint is indicated using one check mark (✓) for each contrasting sound—more check marks indicate a better candidate according to this constraint. The conflict between the two constraint types is readily apparent in (17): sets of vowel height contrasts which better satisfy MAXIMIZE F1 CONTRASTS incur worse violations of the MINDIST constraints.

(17)

		MINDIST = F1:1	MINDIST = F1:2	MINDIST = F1:3	MINDIST = F1:4	MAXIMIZE F1 CONTRASTS
a.	i-a					✓✓
b.	i-e-a			**	**	✓✓✓
c.	i-e-ε-a		**	***	***	✓✓✓✓

The effect of ranking MAXIMIZE F1 CONTRASTS at different points in the fixed hierarchy of MINDIST constraints is illustrated by the tableaux in (18) and (19). The ranking in (18) yields three distinct vowel heights—i.e. the winning candidate is (b). This candidate violates MINDIST = F1:3, but if we attempt to satisfy this constraint, improving distinctiveness, as in candidate (a), we violate higher-ranked MAXIMIZE F1 CONTRASTS by selecting only two contrasting vowel heights. It is not possible to fit three contrasting sounds with a minimum separation of 3 on the F1 dimension as specified in (5). Candidate (c) better satisfies MAXIMIZE F1 CONTRASTS than (b), maintaining four contrasting vowel heights, but (c) violates higher-ranked MINDIST = F1:2 since [e-ɛ] and [ɛ-a] each differ by only one step on the F1 dimension.

(18)

		MINDIST = F1:1	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3	MINDIST = F1:4
a.	i-a			✓✓!		
b.	☞ i-e-a			✓✓✓	**	**
c.	i-e-ɛ-a		*!*	✓✓✓✓	***	***

Thus the particular balance achieved here between maximizing the number of contrasts and maximizing the distinctiveness of the contrasts yields three contrasting heights. Altering the ranking of MAXIMIZE F1 CONTRASTS results in a different balance. For example, if less weight is given to maximizing the number of contrasts, ranking MAXIMIZE F1 CONTRASTS below MINDIST = F1:3, the winning candidate has just two contrasting vowel heights, differing maximally in F1 (19).

(19)

		MINDIST = F1:1	MINDIST = F1:2	MINDIST = F1:3	MAXIMIZE F1 CONTRASTS	MINDIST = F1:4
a.	☞ i-a				✓✓	
b.	i-e-a			*!*	✓✓✓	**
c.	i-e-ɛ-a		*!*	***	✓✓✓✓	***

It is apparent that not all conceivable rankings of MAXIMIZE CONTRASTS correspond to possible languages. The balance between maximization of the number of contrasts and maximization of the distinctiveness of contrasts is determined by the ranking of MAXIMIZE CONTRASTS relative to the MINDIST constraints. If all definable rankings were possible, we would expect to find languages which value the number of contrasts very highly, resulting in a huge number of very fine contrasts, and languages which value distinctiveness very highly, resulting in a handful of maximally distinct contrasts. Neither of these extremes is attested. It seems that there is a lower bound on the distinctiveness required for a contrast to be functional, and that there is an upper bound beyond which additional distinctiveness provides a poor return on the effort expended. This could be implemented by specifying that certain MINDIST constraints, referring to the smallest acceptable contrastive differences, are universally ranked above MAXIMIZE CONTRASTS, and that MAXIMIZE CONTRASTS is in turn universally ranked above another set of MINDIST constraints which make 'excessive' distinctiveness requirements. However it would be preferable to derive these bounds from general considerations of perceptibility and communicative efficiency.

Note that the need to place limits on possible constraint rankings is not novel to the dispersion theory. The same issue arises with respect to standard faithfulness constraints: If all faithfulness constraints are at the top of the ranking then all inputs will surface as well-formed outputs, i.e. this ranking would yield an unattested language with no restrictions on the form of words. Conversely, if all faithfulness constraints were at the bottom of the ranking then all inputs would be mapped to a single, maximally well-formed output (presumably the null output, i.e. silence).

2.2.3.4. Minimization of Effort

The analyses above do not include minimization of effort constraints. We will not develop a general account of articulatory effort. A broad family of constraints preferring minimal rates of articulator movement is proposed in chapter 4, otherwise specific effort constraints are motivated as they become relevant (e.g. 'Don't voice obstruents' and 'Don't have short peripheral vowels'). Sounds that violate effort constraints that outrank MAXIMIZE CONTRASTS will not be employed even if they would allow more contrasts or more distinct contrasts.

2.2.4. The Scope of Analyses

So far we have only exemplified the selection of contrasts along a single dimension. The scope of analyses must be expanded considerably if we are to evaluate the well-formedness of complete words. Here we will introduce some of the issues involved in scaling up the system outlined so far, then we will return to these questions at the end of the chapter (§2.4), having seen more examples of concrete analyses as a basis for discussion.

2.2.4.1. Contrasts on Multiple Dimensions

Concepts and notation necessary for the analysis of contrasts that differ along more than one dimension are introduced in this section, with exemplification from selection of vowel inventories in two dimensions, F1 and F2 (we will ignore F3 for now). Further issues raised by multi-dimensional contrasts are discussed in the next chapter, together with additional analyses.

A representation of the space of possible vowels is shown in (20). In a number of cases more than one IPA symbol could have been used in a given cell—e.g. [ɯ] has the same F1 and F2 specifications as central rounded [ʉ], although they may differ in F3. The blank cells in the second row are due to lack of suitable IPA symbols.

(20)

←F2

5	4	3	2	1		
i	y	ɨ	ɯ	u	1	F1
ɪ	ʏ			ʊ	2	↓
e	ø	ə	ɤ	o	3	
	ɛ	œ	ʌ	ɔ	4	
		a	ɑ		5	

This vowel space reflects the fact that the range of physiologically possible F2 values narrows as F1 increases (Liljencrants and Lindblom 1972, Atal, Chang, Mathews, and Tukey 1978:1545). This has the consequence that F2 contrasts are more restricted amongst low vowels, as we will see below. The quantization of the vowel space is rather crude but, as already noted, it would be straightforward to substitute a finer division of the space if analyses require it.

Selection of a vowel inventory can then be analyzed in terms of selecting vowels from the space in (20) so as to best satisfy MINDIST constraints and MAXIMIZE CONTRASTS. It is immediately apparent that we cannot simply rank unidimensional MINDIST constraints together because if MINDIST = F1:2 is ranked above MAXIMIZE CONTRASTS then a highly distinct contrast such as [i-u] would be rejected, because these vowels do not differ in F1. Rather MINDIST constraints must require a particular level of distinctiveness, which may be achieved by differences on either F1 or F2 (or both). This is achieved by the simple expedient of specifying for each MINDIST constraint all the differences that will satisfy it, e.g. 'MINDIST = F1:2 or F2:4' is satisfied by both [i-e] and [i-u].

An example of inventory selection using constraints of this form is shown in (21). The winning candidate is the canonical five vowel system (b), essentially because that is the largest inventory that can be packed into the vowel space while keeping every pair of vowels separated by at least F1:2 or F2:3. Candidate (a) has more distinct contrasts, but too few of them. Candidates (c)-(e) pack in more contrasts, but consequently violate high ranked MINDIST constraints. Candidate (f) contains 5 contrasting vowels, like the winning candidate, but they are less well dispersed than they could be because [i-ɯ] is a less distinct contrast than [i-u] (F2:3 vs. F2:4)[3].

(21)

		MINDIST = F1:1 or F2:2	MINDIST = F1:2 or F2:3	MAXIMIZE CONTRASTS	MINDIST = F1:3 or F2:4
a.	i u a			✓✓✓!	
b. ☞	i u e o a			✓✓✓✓✓	****
c.	i u e o ɛ ɔ a		*!*	✓✓✓✓✓✓ ✓	********
d.	i u e o a ɑ	*!	*	✓✓✓✓✓✓	*******
e.	i ɨ u e o a		*!*	✓✓✓✓✓✓	********
f.	i ɯ e o a			✓✓✓✓✓	*****!*

Vowels can also differ on more than one dimension simultaneously, e.g. [e-a] differ by F1:2 and F2:2. The distance between these sounds is greater than a distance of 2 on either dimension alone. Given that the MINDIST constraints are intended to implement a general preference for more distinct contrasts, this difference should be reflected in the ranking of MINDIST constraints. In other words:

(22) MINDIST = F1:2 >> MINDIST = F1:2 & F2:2

Where distances on multiple dimensions are written by conjoining the distances on each dimension with '&'—i.e. F1:2 & F2:2 is a distance of 2 on the F1 dimension and 2 on the F2 dimension.

We will now consider one case in which combined distance on F1 and F2 seems to be important—many further examples in which contrasts are distinguished by differences on multiple dimensions are discussed §3.2. The case we will consider here concerns the losing inventory (f) in (21). This is attested as the vowel inventory of Tokyo Japanese, so it must have some advantage over the canonical five vowel inventory (b). One possible analysis is that while the contrast [i-ɯ] is less distinct than [i-u], [o-ɯ] is more distinct than [o-u] because back rounded [ɯ] differs from [o] in F2 as well as F1.

This analysis depends crucially on representing the greater distinctiveness of a contrast that adds a difference on a second dimension i.e. that F1:2 & F2:1 >

F1:2. This is shown in the tableau in (23). An additional constraint, 'MINDIST = (F1:2 & F2:1) or F2:3' is added here, ranked above 'MINDIST = F1:3 or F2:4'. Candidate (a), the canonical five vowel inventory, violates this constraint because it contains the contrast [o-u]. The winner is thus candidate (b), even though this contains the contrast [i-ɯ] is less than maximally distinct.

(23)

		MINDIST =F1:1 or F2:2	MINDIST =F1:2 or F2:3	MAXIMIZE CONTRASTS	MINDIST = (F1:2 & F2:1) or F2:3	MINDIST = F1:3 or F2:4
a.	i u e o a			✓✓✓✓✓	**!	****
b. ☞	i ɯ e o a			✓✓✓✓✓	*	*****
c.	i ɯ e ɤ a			✓✓✓✓✓	*	******!

The violation of 'MINDIST = (F1:2 & F2:1) or F2:3' in the winning candidate is due to the contrast [i-e] which does not include and F2 difference. So a better candidate would be a variant of (23b) in which [e] is replaced by a retracted variant, [e̱], with [F2 *4*]. However, this is probably an artifact of the crude quantization of the vowel space, which fails to adequately represent the slope of the front edge of the vowel space. That is, [i] actually has higher F2 than [e]—perhaps [F2 *5.5*] for [i] and [F2 *4.5*] for [e], which would be a sufficient difference to satisfy the MINDIST constraint. Certainly it is a long-standing observation that this asymmetry in the vowel space—the front edge slopes whereas the back edge is more vertical—has the consequence that there is less room to distinguish vowels along the back edge of the vowel space (e.g. Martinet 1952). The consequent pressure on [o-u] contrasts may also explain the fact that vowels transcribed as [u] are often somewhat fronted in languages like English that lack front rounded [y].

Returning to (21), the additional constraint, MINDIST = F1:2 & F2:1, must be ranked below MINDIST = F2:4 in order to derive the five vowel inventory with [u]—i.e. a maximally distinct F2 contrast must be more important than an enhanced contrast between high and mid back vowels. This re-ranking of MINDIST constraints raises the important question of the extent to which the ranking of the expanded inventory of MINDIST constraints is language-specific. Language-specific differences in the ranking of MINDIST imply language-specific differences in the distinctiveness of acoustic differences. These could result from differences in the distribution of attention between dimensions in different languages. Such differences in the allocation of attention are often hypothesized to be a component of perceptual learning (e.g. Jusczyk 1993, Guenther, Husain, Cohen, and Shinn-Cunningham 1999), and are often modeled as stretching and shrinking perceived distances on a dimension (e.g. Guenther et al 1999, Nosofsky 1986). The extent of this variation is presumably limited, but it is far from clear what those limits are (cf. Lindblom 1986:137f.).

2.2.4.2 Analysis of Words

So far we have only considered the selection of inventories of contrasting sounds but a phonology must characterize the set of well-formed possible words in a language. The implication of dispersion theory is that words must be evaluated with respect to the familiar syntagmatic markedness constraints, e.g. syllabification and effort minimization constraints, but they must also be evaluated by constraints on contrast, i.e. words must be sufficiently distinct from other minimally contrasting possible words (MINDIST), and there must be a sufficient number of such contrasting words (MAXIMIZE CONTRASTS). Essentially, each sound in a word must be a member of the optimal inventory for its particular context. We will see in §2.4 that implementing these basic ideas raises some technical issues, but we will postpone that discussion until we have more thoroughly motivated the constraints on contrast.

2.2.5. The Status of Faithfulness Constraints

In standard optimality-theoretic analyses, the constraints evaluate candidate outputs for a given input. So far the analyses we have considered include multiple surface forms or ‘outputs’, but no inputs and no constraints on faithfulness to inputs. In fact the dispersion theoretic constraints require a fundamental revision of faithfulness constraints which probably makes inputs unnecessary.

Standard faithfulness constraints require that the output be as similar as possible to the input—i.e. segments should not be inserted or deleted, feature values should not be changed, etc. These constraints play two conceptually distinct roles: They play a central role in determining the distribution of contrasts in a language, and they also serve to regulate alternations.

The role of faithfulness constraints in determining contrasts is discussed by Prince and Smolensky (1993, chapter 9) and Kirchner (1997), and can be illustrated as follows. Essentially, a constraint PARSE F (or IDENT F), where F is a feature, favors preserving underlying differences—i.e. if the input contains [+F], the output should contain [+F], if the input contains [-F], the output should contain [-F]. So, if PARSE F is satisfied, an underlying difference between [+F] and [-F] is preserved on the surface and we have a contrast in F.

In dispersion theory, this function of faithfulness constraints is taken over by MAXIMIZE CONTRASTS, so faithfulness constraints are not needed to play this role, and we will see that they are actually incompatible with dispersion theoretic constraints. However, MAXIMIZE CONTRASTS cannot simply replace faithfulness constraints because faithfulness constraints also regulate alternations, requiring allomorphs of a given morpheme to be similar. The standard analysis of similarities between allomorphs involves proposing a unique underlying form of the morpheme from which all surface allomorphs are derived, as exemplified in (24). A second component of the analysis must be some requirement that outputs be similar to inputs, otherwise an output need bear no resemblance to the input, and derivation from a common underlying form would in no way guarantee allomorphic similarity. Faithfulness fulfills this function.

(24) /ætɑm/ 'atom' /-z/ '(pl.)'

↓ ↓ ↓ ↓ ↓

[ǽɾəm] [ətʰɑ́m-ɪk] [-s] [-z] [-əz]

The Dispersion theory offers no account of allomorphic similarity, but it is not possible to adopt faithfulness constraints for this purpose because there is a fundamental incompatibility between the constraints on contrast proposed here, and input-output faithfulness constraints. This is illustrated in (25) and (26), which repeat the ranking used in (18) to derive three contrasting vowel heights, with the addition of a top-ranked faithfulness constraint IDENT[F1], which requires that output segments have the same [F1] value as the corresponding input segment—i.e. input values of [F1] must be preserved in the output. Accordingly, an input form is specified—/pɪt/ in (25) and /pit/ in (26). Although the input is a complete word, we only consider the evaluation of F1 (vowel height)—i.e. the contrast constraints are evaluated relative to a set of forms differing only in vowel height. The underlined form is the selected output, whereas the other forms are the set of contrasting forms required for the evaluation of constraints on contrast.

What these two tableaux demonstrate is that inclusion of faithfulness constraints subverts the intended effect of the MINDIST and MAXIMIZE CONTRASTS constraints, because they make the selected inventory of vowel height contrasts dependent on the input under consideration—i.e. the same constraints yield two vowel heights [ɪ-a] in (25), but three [i-e-a] in (26). The second inventory is what we expect in the absence of faithfulness constraints, but this inventory is blocked in (25) because it doesn't contain [ɪ], and consequently would violate the high-ranked faithfulness constraint IDENT[F1].

(25)

	/pɪt/	IDENT [F1]	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	<u>pit</u>-pet-pat	*!		✓✓✓	**
b.	<u>pɪt</u>-pet-pat		*!	✓✓✓	**
c.	☞ <u>pɪt</u>-pat			✓✓	
d.	<u>pit</u>-pat	*!		✓✓	

(26)	/pit/	IDENT [F1]	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	☞ pit-pet-pat			✓✓✓	**
b.	pɪt-pet-pat	*!	*	✓✓✓	**
c.	pɪt-pat	*!		✓✓	
d.	pit-pat			✓✓!	

It is essential to the proper operation of the constraints on contrast that they evaluate the contrasting sounds that can be used to distinguish words—i.e. they generalize across possible words, and so cannot be evaluated relative to a single word as in the standard OT model.

So given the dispersion theory of contrast, we need to provide an account of allomorphic similarity which is independent of the theory of contrast, rather than inextricably combined with it as is the case with faithfulness to an input. In chapter 6 an account is proposed in terms of a direct requirement of similarity between the surface forms of a morpheme (i.e. 'Paradigm Uniformity' or 'Output-Output Correspondence'), thus eliminating any role for an input. But most of the cases considered here concern distribution rather than alternations, and consequently the issue does not arise.

2.3. EVIDENCE FOR THE DISPERSION THEORY

In this section we will show how dispersion theory accounts for phonological phenomena relating to contrast, and provide evidence favoring these analyses over previous accounts.

2.3.1. Inventory Structure

Inventory structure is usually described in terms of cooccurrence constraints. For example the absence of front rounded and back unrounded vowels from the inventory in (27) would be accounted for in terms of the pair of cooccurrence constraints in (28).

(27)
```
i     u
e     o
   a
```

(28) *[-back, +round], *[+back, -round]

According to the Dispersion theory, inventory structure is the result of a compromise between maximization of the number of contrasts, maximization of the distinctiveness of contrasts, and minimization of effort. Thus the analysis of the vowel inventory in (27) is that this language prefers a large minimum distance for F2 contrasts over multiple F2 contrasts (30). As discussed above, front and back vowels differ primarily in the frequency of the second formant with front vowels having a high F2, and back vowels having a low F2. Lip-rounding lowers F2 so the maximally distinct F2 contrast is between front unrounded and back rounded vowels, as indicated in the F2 feature specifications in (4), repeated here in (29) (arranged horizontally to conserve space):

(29) F2 dimension:

5	4	3	2	1
i	y	ɨ	ɯ	u

(30) MINDIST = F2:4 >> MAXIMIZE F2 CONTRASTS

Inclusion of front rounded vowels or back unrounded vowels would result in sub-optimal F2 contrasts such as [y-u] and [i-ɯ], as shown in the tableau in (31).

(31)

	MINDIST = F2:3	MINDIST = F2:4	MAXIMIZE F2 CONTRASTS
> i-u			✓✓
i-ɯ		*!	✓✓
y-u		*!	✓✓
i-ɨ-u	*!*	**	✓✓✓

These two accounts of inventory structure make very different predictions. Cooccurrence constraints imply that markedness is a property of segments, not contrasts. They forbid cooccurrence of a particular combination of features within a single segment. No restrictions are imposed on contrasts per se, so the markedness of a contrast should depend simply on the markedness of the contrasting segments. On the other hand, dispersion theory claims that markedness is a property of contrasts as well as of segments. Given the goal of maximizing the distinctiveness of contrasts, a contrast is marked to the extent that it is not auditorily distinct. Individual segments are marked to the extent that they are articulatorily difficult to produce.

The analysis in terms of cooccurrence constraints (28) claims that front rounded vowels are inherently marked, whereas the dispersion theory claims that it is the contrast between front rounded and back vowels that is marked (because it is less distinct than a contrast between a front unrounded vowel and a back vowel). In general, dispersion theory predicts that the markedness of a sound depends on the contrasts it enters into. We will see here that this prediction is confirmed.

The evidence involve cases in a which a sound is common in the absence of contrast but uncommon in contrasts. A straightforward example involves dental and alveolar stops. Both dental and alveolar stops are cross-linguistically common, and thus would appear to be unmarked segment-types, but alveolar stops rarely contrast with dentals. We cannot account for these facts in terms of cooccurrence constraints: both sounds involve unmarked feature combinations, so the contrast between them should be unmarked. In terms of dispersion theory a contrast between an alveolar and a dental stop is marked because these sounds are auditorily similar, but each individually can form distinct contrasts with other stops such as labials and velars.

A second case of this type involves central vowels. Central vowels are relatively uncommon in front-back contrasts: most languages contrast front and back vowels, but comparatively few contrast front, central and back vowels. But in the absence of front-back contrasts, central vowels are the unmarked case, other things being equal. So-called 'vertical' vowel systems without backness contrasts are found in the Caucasian languages (Colarusso 1988, Choi 1991), Margi (Maddieson 1987), Marshallese (Bender 1968, Choi 1992). In all cases such vowel systems consist of high and low, or high, mid and low central vowels, with contextual variation. The nature of this contextual variation can be illustrated from Kabardian, a Caucasian language studied acoustically by Choi (1991). This language contrasts three short vowels, realized as [ɨ, ə, ɐ] in 'neutral' environments, i.e. adjacent to labials, alveolars and plain laryngeals. Realizations vary from front to back rounded, or diphthongal combinations of these, depending on the consonant context, as summarized in (32) based on data from Choi (1991). Crucially, there are no vertical vowel inventories containing invariant [i] or [u], which are otherwise ubiquitous—i.e. there are no inventories such as [i, e, a] or [u, o, a].

(32)

_j	palatal C, post-alveolars	labials, alveolars, laryngeals	velars	uvulars	labialized Cs, _w
front	partially fronted	central	partially backed	back (and lowered)	back and rounded

Again, in terms of cooccurrence constraints, there is no account of the fact that the markedness of vowels like [i] and [u] depends on the contrasts that they are involved in. Dispersion theory predicts this pattern. Central vowels yield sub-optimal F2 contrasts, thus are not frequent in front-back contrasts. However, in the absence of contrast, effort minimization dictates adopting the tongue position of neighboring consonants, hence the contextual variation. In the absence of contextual demands, extreme articulations are avoided, so central vowels are preferred.

In summary, we have seen that we need to impose restrictions on contrasts to account for cross-linguistic generalizations about inventory structure; it is not adequate to simply place restrictions on individual segments, as cooccurrence constraints do. Specifically, we have seen that contrasts are subject to a requirement that they be maximally distinct, formalized here in terms of MINDIST constraints.

2.3.2. Enhancement

Another contrast-related phenomenon closely related to the issue of inventory structure is enhancement (Stevens, Keyser, and Kawasaki 1986; Stevens and Keyser 1989). We shall see that dispersion theory offers a very straightforward account of enhancement phenomena, whereas theories that do not refer to contrast cannot provide any adequate account.

Stevens et al (1986) observe that 'basic' distinctive features are often accompanied by 'redundant' features which 'strengthen the acoustic representation of distinctive features and contribute additional properties which help the listener to perceive the distinction' (p.426). For example, they describe the relationship between [round] and [back] contrasts, discussed in §2.3.1, as one of enhancement—[round] enhances distinctive [back]. In our terms, this can be reformulated as the observation that independent articulations often combine to yield more distinct contrasts[4], which is a direct consequence of the maximization of the auditory distinctiveness of contrasts. We have already analyzed the enhancement of backness by rounding in these terms as maximization of the distinctiveness of F2 contrasts.

In theories which do not explicitly represent contrasts, enhancement relations have been formulated in terms of redundancy rules (e.g. Stevens et al 1986:462f.) or implicational statements (e.g. Archangeli and Pulleyblank 1994) of the general form shown in (33).

(33) [+back] → [+round]

These approaches to enhancement avoid reference to contrast by making enhancement independent of contrast. The rule in (33) states that [+back] vowels must be rounded regardless of whether they contrast with [-back] vowels. The dispersion theory, on the other hand, predicts that enhancement should only apply to contrasts since it is motivated by maximization of the distinctiveness of contrasts.

The facts are consistent with the dispersion hypothesis: in all cases of enhancement discussed in Stevens et al (1986) and Stevens and Keyser (1989) it is contrasts that are enhanced. Indeed this is implicit in the notion that enhancement applies to *distinctive* features. However it is not always easy to find cases in which the redundancy rule formulation would predict the possibility of enhancement, but where there is no contrast. For example, it is not possible to test the validity of (33) against basic vowel inventories because, as noted in §2.3.1, we do not find back vowels in the absence of backness contrasts, except as a result of assimilation. However, the existence of a redundancy rule like (33) would lead us to expect that assimilatory backing could be followed by rounding, due to the application of this redundancy rule. As indicated in (32), assimilation of central vowels to back is attested in Kabardian, where vowels are back adjacent to uvulars. A similar pattern is observed in other Caucasian languages with vertical vowel inventories

(Colarusso 1988, chapter 8), and in Marshallese the short central vowels become back between velarized consonants (Bender 1968, Choi 1992). In none of these cases is this non-contrastive backing ‘enhanced’ by rounding.

Another test case is provided by patterns of enhancement of voicing. Voicing is difficult to maintain in stops because pressure builds up behind the closure until there is no longer a pressure drop across the glottis. Without a sufficient pressure drop there is no airflow through the glottis, so voicing ceases (Westbury and Keating 1986). Lowering the velum allows air to be vented from the vocal tract, mitigating the pressure build-up, and thus facilitating voicing. In addition, greater amplitude at low frequencies can be transmitted due to the nasal airflow, and low frequency energy is a primary correlate of voicing (Stevens et al 1986:439). Thus nasalization enhances voicing in stop consonants.

Pre-nasalization is employed as an enhancement of contrasts between voiced and voiceless stops in Guaraní, Barasano and Rotokas, among other languages (cf. Herbert 1986, Piggott 1992, Steriade 1993a)—that is voiceless stops contrast with pre-nasalized voiced stops rather than plain voiced stops. However, ‘enhancement’ of voiced stops by nasalization is not observed in the absence of a contrast. We do not find pre-nasalization of inter-vocalically voiced stops, for example.

A parallel argument can be made with respect to implosion. The larynx lowering associated with implosion prevents the build-up of pressure in the oral cavity, and thus facilitates voicing, consequently implosives are characteristically strongly voiced (Ladefoged and Maddieson 1996:84f.). Like pre-nasalization, implosion is employed as an enhancement of stop voicing contrasts in Nyangi and Maasai (Maddieson 1984), and is not found in the absence of contrast, e.g. accompanying intervocalic voicing. So to determine the applicability of enhancement, we must consider contrasts—i.e. pairs of forms—not individual sounds.

It might be thought that contrastive underspecification (e.g. Steriade 1987) would allow us to account for the fact that only contrasts are enhanced, while retaining an analysis of enhancement relations in terms of redundancy rules. With contrastive underspecification only contrastive features are present in underlying representation. If an enhancement rule such as (33) applies before redundant features are filled in, then only contrasts will be enhanced.

Certainly contrastive underspecification allows us to describe this situation, but it provides no explanation why enhancement only applies to contrasts. If pre-nasalization can apply prior to the insertion of redundant voicing, then there is no reason why it should not apply after voicing-specification in some other language. An account in terms of contrastive underspecification does not forge any connection between contrast and enhancement, and thus cannot adequately account for the facts.

More generally, appeals to contrastive underspecification are self-defeating in any attempt to account for inventories of contrasts because contrastive underspecification takes the inventory of a language as given, and determines which features are underspecified on the basis of the observed contrasts. Here we are concerned to derive inventories of contrasts and typological generalizations about them. It is obviously not appropriate to take inventories of contrasts as given when attempting to derive those inventories.

2.3.3. Neutralization

Neutralization, as the name suggests, involves loss of a contrast in some environment, but in theories that do not directly represent contrast, it is not actually possible to analyze loss of contrast as essential to the phenomenon. On the other hand, dispersion theory allows a clear representation of loss of contrast. Steriade (1993b) has shown that there are neutralization phenomena that must be characterized as loss of a contrast per se. These cases cannot be properly analyzed without an explicit representation of contrast.

In standard analyses of neutralization, loss of contrast is a by-product of a distributional restriction. For example, coda devoicing neutralizes voicing contrasts, and is often analyzed in terms of a restriction on the appearance of [+voice] in coda, e.g. (34).

(34) *C]$_\sigma$
|
[+voice]

In this analysis no reference is made to the fact that a contrast is neutralized, we simply observe that if [+voice] cannot appear in coda, then no contrast between [+/- voice] can occur in this position.

In dispersion theory, neutralization of a contrast results when constraints prevent it from achieving sufficient distinctiveness in some environment. That is, in a ranking of the form shown in (35) where *EFFORT is an effort minimization constraint penalizing some articulation, a contrast will be neutralized in some context if it cannot be realized with a distinctiveness of *d* without violating *EFFORT in that context. Note that other constraints will typically be involved in making the realization of a distinct contrast more effortful—e.g. metrical constraints on unstressed vowel duration may make distinct vowel contrasts more difficult to realize in unstressed syllables (cf. §2.3.3.1).

(35) MINDIST = *d*, *EFFORT >> MAXIMIZE CONTRASTS

Thus dispersion theory provides an alternative formalization of Steriade's (1995, 1997) generalization that contrasts are neutralized first in environments where 'the *cues* to the relevant contrast would be diminished or obtainable only at the cost of additional articulatory maneuvers' (1997:1).

Specific evidence for this account of neutralization over the standard analysis in terms of distributional restrictions derives from cases of neutralization in which the result is free variation, a phenomenon discussed in

Steriade (1993b). One of Steriade's examples comes from Gooniyandi, an Australian language (McGregor 1990, Hamilton 1993). In this language the contrast between retroflex and apical alveolar stops is permitted only post-vocalically; it is neutralized word-initially and post-consonantally. In positions of neutralization there is free variation between retroflex and alveolar, as well as intermediate articulations.

As Steriade points out, this neutralization cannot be analyzed in terms of a restriction on the distribution of retroflexes or alveolars, since both can appear in the neutralizing environment. It must be analyzed as the suspension of the contrast per se. A similar situation obtains in Walmatjari (Hudson and Richards 1969), although it is not clear whether neutralization results in free variation or a specific intermediate articulation.

Another case where neutralization yields free variation is found in Danish. In Danish, the contrast between aspirated and unaspirated stops is neutralized word-finally, but there is free variation between the two sounds in this position (Fischer-Jørgenson 1954). A final case is Mong Njua (Lyman 1974), where velars and labials are in free variation preceding laterals, although they contrast elsewhere (§5.3).

To show how these phenomena can be analyzed in terms of dispersion theory, we will first consider the case of coda voicing neutralization, which involves a determinate output, then show how the analysis can naturally be extended to cases like Gooniyandi.

As summarized above, neutralization is a consequence of constraints which prevent a contrast from achieving sufficient distinctiveness. Steriade (1997) provides an analysis of neutralization of voicing among obstruents based on a demonstration that neutralization applies first in environments where there are fewer cues to voicing. We will reformulate part of Steriade's analysis in terms of dispersion-theoretic constraints[5]. Steriade shows that coda devoicing is in fact neutralization of obstruent voicing contrasts where no sonorant follows—i.e. finally or before another obstruent. These are precisely the environments in which there is no VOT, because VOT can only be realized on a following voiced sonorant. Thus if a VOT difference is required for an adequately distinct voicing contrast (i.e. MINDIST = VOT:1 >> MAXIMIZE CONTRASTS), obstruent voicing contrasts are not acceptable in these positions, and neutralization results.

Note that these constraints only motivate suspension of contrast, they do not specify whether stops should neutralize to voiced or voiceless. This is determined by lower-ranked constraints. In this case, it seems that the deciding factor is the difficulty involved in producing voicing in obstruents. As discussed in the previous section, obstructing airflow out of the vocal tract makes it difficult to maintain voicing, a fact we can formalize as a constraint against voiced obstruents: *[+voice, -sonorant]. Given this constraint, we expect stops to neutralize to voiceless, which they do in final position:

(36)

		MINDIST = voice:1	MINDIST = VOT:1	MAXIMIZE CONTRASTS	*[+voice, -son]
a.	ad#-at#		*!	✓	*
b.	ad#				*!
c.	☞ at#				

However it is not true that stop voicing neutralization always results in voiceless stops: before voiced obstruents, neutralization typically yields voiced obstruents. A plausible analysis of this assimilation effect is that it is especially difficult to initiate voicing during an obstruent—due to hysteresis effects it is easier to maintain voicing from a sonorant into a following obstruent than it is to initiate voicing during an obstruent following a voiceless sound (Westbury and Keating 1986). Thus we can posit the following constraint, named *TD for brevity, universally ranked above *[+voice, -son]:

(37) *TD: *[-voice] [+voice,-sonorant]

This constraint is decisive in obstruent sequences, as shown in the following tableau:

(38)

		MINDIST = voice:1	MINDIST = VOT:1	MAXIMIZE CONTRASTS	*TD	*[+voice, -son]
a.	adga-atga		*!	✓✓	*	*
b.	☞ adga			✓		*
c.	atga			✓	*!	

*TD is satisfied by voicing the first obstruent rather than devoicing the second. This alternative is not viable because it eliminates a perfectly distinct pre-vocalic voicing distinction. This can be seen more clearly in the fuller tableau in (39), which evaluates the voicing contrasts in both obstruent positions. Candidate (d) devoices the second obstruent, avoiding any voiced obstruents, but loses to (b) on MAXIMIZE CONTRASTS.

(39)

		MINDIST = voice:1	MINDIST = VOT:1	MAXIMIZE CONTRASTS	*TD	*[+voice, -son]
a.	adka-atka adga-atga		*!	✓✓✓✓	*	*
b.	☞ adga-atka			✓✓		*
c.	atga-atka			✓✓	*!	
d.	atka			✓!		

The crucial point for the analysis of neutralization resulting in free variation is that the suspension of contrast (violation of MAXIMIZE CONTRASTS) is distinguished from the determination of a particular realization under neutralization, here determined by effort minimization. If the remaining constraints do not yield a unique outcome, then the result is neutralization with free variation. This situation can be exemplified from the analysis of Gooniyandi.

Steriade (1995) provides a detailed analysis of the fact that the distinction between apical alveolar and retroflex stops is neutralized in non-post-vocalic positions. The core of the explanation is as follows: Retroflexes are differentiated from apical alveolars by low F3 transitions at closure (Stevens and Blumstein 1975). However, the tongue tip moves forward during the closure of a retroflex and is released from the alveolar ridge, so these sounds are articulatorily and acoustically very similar at release (Dave 1977, Anderson and Maddieson 1994, Spajić, Ladefoged, and Bhaskararao 1994). Thus neutralization occurs in initial and post-consonantal positions because the closure transitions which distinguish the sounds are not present.

We can formulate this analysis in terms of the constraint ranking in (40). Retroflexes are primarily distinguished from other coronals by lower F3 approach transitions (41).

(40) MINDIST = F3:2 >> MAXIMIZE CONTRASTS

(41)

	ʈ		t̺, t̪, t̠	
	approach	release	approach	release
F3:	2	4	5	5

In post-consonantal position, approach transitions are not available, and release transitions are not sufficiently distinct to satisfy MINDIST = F3:2, so neutralization results (42).

(42)

	MINDIST = F3:1	MAXIMIZE CONTRASTS
Ct̺V-CʈV	*!	✓✓
☞ Ct̺V		✓
☞ CʈV		✓

While these constraints are sufficient to derive neutralization, they do not favor any particular realization of the neutralized contrast. The realization of the neutralized contrast is determined by other constraints—e.g. effort minimization in the case of stop voicing neutralization. A simple approach to the analysis of free variation is to allow variation in the ranking of constraints (Anttila 1997, Reynolds 1994)—i.e. there are two constraints that favor different outputs, but their relative ranking is variable, so both outputs are possible. It is likely that producing retroflexion is more effortful than producing the unretroflexed tongue shape of the apical alveolar because other sounds in the environment will generally not be produced with a retroflex tongue tip. Where there are other retroflex consonants in the vicinity, McGregor (1990) observes a tendency to assimilation, otherwise effort minimization favors the alveolar variant.

We hypothesize that a conflicting preference for the retroflex variant derives from the greater distinctiveness of the retroflex from the other coronals, namely laminal dentals and post-alveolars. While F3 lowering is much greater at the closure of a retroflex, it is generally still lower than in other coronals at release (e.g. Spajić et al 1994), as represented in (40), so this property would help to differentiate a retroflex from the other coronals better than an apical alveolar. Some support for this suggestion can be derived from the fact that Anderson and Maddieson (1994) found it difficult to reliably distinguish apical alveolars from other coronals in a study of similar contrasts in Tiwi (p.158). The retroflex (or apical post-alveolar), was distinguished from other coronals by duration, burst amplitude, burst spectrum and F3 onset.

It is not clear what the primary cues differentiating the other coronals are (Anderson and Maddieson 1994), so we will formulate the distinctiveness constraint as MINDIST = d & F3:1 to indicate that the neutralized stop is distinguished from the other coronals by an F3 difference in addition to other unspecified cues. This constraint is then unranked with respect to the effort minimization constraint *RETROFLEX, yielding two equally optimal outputs (43).

(43)

	MINDIST = F3:2	MAXIMIZE CONTRASTS	*RETRO-FLEX	MINDIST = d&F3:1
Ct̺V-CʈV-Ct̪V	*!	✓✓✓	*	
☞ Ct̺V-Ct̪V		✓✓		*
☞ CʈV-Ct̪V		✓✓	*	

The Danish free variation between aspirated and unaspirated stops in final position can be analyzed as a result of the aspirated stop being both more effortful and supporting more distinct place contrasts, since the formant transitions present in the aspirated release provide place cues. The free variation can then be seen as resulting from variation in the ranking of minimization of effort and maximization of distinctiveness. We can represent this in terms of a pair of unranked constraints, informally specified in (44). Favoring effort minimization will result in the unaspirated output, whereas favoring distinctiveness of place cues will result in the aspirated output.

(44) *Aspiration, ‘Maximize distinctiveness of place cues’

To summarize, neutralization with free variation is problematic for standard analyses of neutralization because both sounds that contrast elsewhere are permitted in the environment of neutralization. This makes it impossible to analyze neutralization as a consequence of a constraint against the appearance of one sound type in the context of neutralization. The dispersion theoretic analysis of neutralization, on the other hand, distinguishes suspension of contrast from the realization of the suspended contrast, allowing analysis of these cases.

2.3.3.1. Parallels Between Neutralization and Inventory Selection

The account of neutralization developed here is precisely parallel to the account of inventory structure given in §2.3.1. The connection lies in the fact that the constraints on contrast operate to select an inventory of contrasts in a particular context. For example, syllabification places constraints on possible sequences of segments, so in a language with only CV syllables, the constraints on contrast can only select an inventory of vowel contrasts following a consonant. From this perspective, neutralization occurs when a contrast that is selected in one context is not selected in another (which otherwise permits similar sounds). The difference between a contrast which does not occur in a language and one that is contextually neutralized is that the former is not selected in any context whereas the latter is selected only in certain contexts.

This association between inventory selection and neutralization is supported by the observation that vowel reduction generally produces reduced inventories which are similar to typologically common stressed vowel inventories. E.g. The standard Italian seven vowel system /i, e, ɛ, a, ɔ, o, u/ reduces to the canonical five vowel system, /i, e, a, o, u/ in unstressed syllables, and a five vowel system frequently reduces to a three vowel system, loosely transcribed as /i, a, u/ (e.g. Sicilian, Russian, etc). According to the present account this follows from the fact that essentially the same selectional forces apply in stressed and unstressed syllables, but effort minimization has stronger consequences in short unstressed syllables.

We will exemplify this point with an analysis of Sicilian vowel reduction, in which a five vowel system, /i, e, a, o, u/, reduces to three vowels /i, a, u/ ([ɪ, ɐ, ʊ]) in unstressed syllables. The data in (45) are from the dialect of Mistretta (Mazzola 1976:41).

(45)	vínni	'he sells'	vinnímu	'we sell'
	véni	'he comes'	vinímu	'we come'
	ávi	'he has'	avíti	'you have'
	móri	'he dies'	murímu	'we die'
	úggyi	'he boils'	uggyímu	'we boil'

This is a reduction in height contrasts, so we need only consider the F1 dimension, which is shown in (46).

(46) F1 dimension:	1	2	3	4	5
	i	ɪ	e	ɛ	a

The reduction can be analyzed in terms of the constraint ranking shown in (45). This ranking is basically the same as that in (18), which yields three vowel heights. The only addition is a constraint against short peripheral vowels (particularly [ĭ, ŭ, ă]). This constraint is assumed to be motivated by effort minimization: achieving a peripheral vowel position in a short duration requires rapid movement, and avoidance of the effort involved has been hypothesized to play an important role in the centralization of short vowels (Lindblom 1963b).

(47) *SHORT PERIPHERAL V >> 'Avoid peripheral short vowels [ĭ, ŭ, ă]'
MINDIST = F1:2 >>
MAXIMIZE F1 CONTRASTS >>
MINDIST = F1:3

In stressed syllables, *SHORT PERIPHERAL V is irrelevant, so the ranking yields three vowel heights, as shown in (48). However, in short syllables, this effort minimization constraint penalizes peripheral vowels, so the candidate [i-e-a] is now ruled out because it contains two peripheral vowels (49). Attempting to maintain three contrasts while avoiding peripheral vowels, as in (b), results in violations of the minimal distance requirement because [ɪ-e] and [e-ɐ] differ by only F1:1. The winning candidate (c) has only two vowel heights, which is evaluated as worse by MAXIMIZE F1 CONTRASTS, but satisfies the higher-ranked minimal distance requirement.

(48) Vowels in stressed syllables

		*SHORT PERIPHERAL V	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	í-á			✓✓!	
b.	☞ í-é-á			✓✓✓	**
c.	í-é-ɛ́-á		*!*	✓✓✓✓	***

(49) Vowels in unstressed syllables

		*SHORT PERIPHERAL V	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	ĭ-ĕ-ă	*!*		✓✓✓	**
b.	ɪ̆-ĕ-ɐ̆		*!*	✓✓✓	**
c.	☞ ɪ̆-ɐ̆			✓✓	*

This analysis illustrates the fact that contrasts can really only be selected in a specified context, because the effect of constraints like *SHORT PERIPHERAL V depends on context. We also see that differences in context, in this case involving stress, can result in neutralization of contrasts through the selection of different inventories.

2.3.4. Contrast Preservation in English Stop Voicing

Direct evidence for constraints favoring the maintenance of contrasts is provided by phenomena in which languages take measures to preserve contrasts. One case is the realization of the voicing contrast in English stops. As the table in (50) shows, a stop voicing contrast is maintained in all positions in English, but with varying realizations:

(50) English stop voicing contrasts

	'voiceless'	'voiced'
Initial	voiceless aspirated	voiceless unaspirated
Medial (unstressed)	voiceless unaspirated	voiced

We can explain this distribution as follows (cf. Kingston and Diehl 1994:428f.): Voicing is marked in initial position because it is difficult to start vocal cord vibration during an obstruent, so it is preferable to devoice stops in this position, as English does. But if the 'voiced' stop is devoiced, then, to maintain a contrast, the voiceless stop must be aspirated. In medial position, voicing a stop is not as difficult because it is only necessary to maintain vocal cord vibration (Westbury and Keating 1986), so the contrast can be maintained without aspirating the voiceless stop.

According to this analysis, the realization of the stops depends on the requirement that a distinct VOT contrast be maintained. This point can be made explicit by formalizing the analysis in terms of the constraint ranking in (51). The top-ranked constraints require the maintenance of a VOT contrast with distinctiveness of 1. These are ranked above the constraints *INITIAL VOICED STOP and *ASPIRATION. *INITIAL VOICED STOP is motivated by minimization of effort. Aspiration might be disfavored because of the effort involved, or because of the devoicing effect on a following vowel.

(51) MINDIST = VOT:1,
MAXIMIZE VOT CONTRASTS >>
*INITIAL VOICED STOP >> 'Avoid initial voiced stops'
*ASPIRATION 'Avoid aspirated stops'

(52) VOT:

2	1	0
t^h	t	d

The tableau in (53) illustrates the selection of VOT contrasts in initial position. A contrast between voiced and voiceless unaspirated stops is rejected because it violates *INITIAL VOICED STOP (candidate a). Satisfying this constraint by simply devoicing the voiced stop results in neutralization, violating

MAXIMIZE VOT CONTRASTS. The optimal candidate devoices the voiced stop, but maintains a contrast by aspirating the voiceless stop.

In medial position *INITIAL VOICED STOP is not relevant, so a contrast can be maintained without aspirating the voiceless stop (54).

(53)

		MINDIST = VOT:1	MAXIMIZE VOT CONTRASTS	*INITIAL VOICED STOP	*ASPIRATION
a.	#t-d		✓✓	*!	
b.	☞ #tʰ-t		✓✓		*
c.	#t		✓!		

(54)

		MINDIST = VOT:1	MAXIMIZE VOT CONTRASTS	*INITIAL VOICED STOP	*ASPIRATION
a.	☞ VtV-VdV		✓✓		
b.	VtʰV-VdV		✓✓		*!

The constraint MAXIMIZE VOT CONTRASTS plays an essential role in this analysis. The devoicing of initial stops is explained in terms of minimization of effort, but the aspiration of initial voiceless stops is explained in terms of the need to maintain a contrast. Without this constraint, the result would be neutralization.

Generally, this analysis demonstrates the necessity for comparative constraints. The fact that the voiceless stop needs to be aspirated in initial position depends on the devoicing of the voiced stop, but the voiced stop also cannot devoice unless the voiceless stop is aspirated. The realizations of the stops thus cannot be determined independently, they must be fixed simultaneously through comparison of contrasting forms.

Note that we have not accounted for aspiration of voiceless stops in stressed medial syllables. In this case, aspiration applies even though it is not necessary for maintenance of contrast. There are a couple of possible explanations for this distribution. Possibly stressed syllables permit the greater effort involved in achieving the maximal contrast between fully voiced and aspirated stops. Alternatively, it was suggested above that aspiration might be dispreferred because it tends to devoice following vowels. This would be more problematic before short vowels where total devoicing could result (as in English [pʰə̥tʰeɪɾoʊ] 'potato'), but would not be problematic before long, stressed vowels.

2.4. WORKING WITH CONSTRAINTS ON CONTRAST

It is important to emphasize that the dispersion theory of contrasts is not a theory of inventories operating somehow outside of conventional phonological analyses. It is central to the analysis of neutralization, for example, that inventories of contrasting sounds are selected in context, so the set of contrasting vowels in stressed syllables may be different from the set of contrasting vowels in unstressed syllables (§2.3.3.1). Or stop place contrasts may be different in post-vocalic and non-post-vocalic environments (§2.3.3).

That is, a phonology must characterize the set of possible words in a language, and this requires combining paradigmatic constraints on contrast with the more familiar syntagmatic constraints on sound sequences. Incorporating constraints on contrasts into a grammar of possible words faces technical difficulties for the following reason: Constraints on the distinctiveness of contrasts evaluate a relationship between forms, so if we want to determine whether a putative word is well-formed, we must consider whether it is sufficiently distinct from neighboring words. But these words must also be well-formed, which implies assessing their distinctiveness from neighboring words, and so on. Thus it seems that we cannot evaluate the well-formedness of a single word without determining the set of all possible words.

This problem is circumvented in the preceding analyses by considering only the evaluation of inventories of contrasting sounds (or short strings of sounds) in a particular context rather than evaluating complete words. For example, in evaluating vowel inventories, we are effectively determining the set of contrasting sounds that are permitted in a syllable nucleus. This makes the evaluation of MINDIST and MAXIMIZE CONTRASTS straightforward since only a small number of contrasting sounds are possible in a given context. This simplification is valid given some assumptions. First, the context must be well-formed. E.g. if we are evaluating the set of vowels that can appear before a retroflex stop, it must be true that retroflex stops are part of an inventory of consonant contrasts that can occur in post-vocalic position. Second, nothing outside of the specified context should be relevant. I.e. no constraint that is ranked high enough to affect the well-formedness of the inventory should refer to material outside of the specified context.

More generally, the strategy for avoiding the problem of mass comparisons is to derive generalizations about the set of possible words in a language—e.g. stressed vowels are all drawn from a certain set—rather than deriving particular words. But this strategy is not actually novel, it is the usual approach to phonological analysis. Even if it is possible to determine whether an individual word is well-formed with respect to a constraint ranking, the result of such an exercise is usually not very significant. Showing that a grammar can derive an individual word is not the goal of phonological analysis of a language, the goal is to devise a grammar that derives all and only the possible words of that language. The usual intermediate goal is to derive generalizations about all the possible words of the language, exactly as in the analyses here.

For example, in analyzing a language it is common to restrict attention to a single process, e.g. place assimilation between nasals and stops, ignoring stress assignment, distribution of vowels, etc. Such an analysis may be illustrated by deriving complete words, e.g. /kanpa/ → [kampa], but in itself this is uninteresting. The real goal is to derive the generalization that nasals are always homorganic to following stops. Establishing such a generalization properly requires showing that no contrary output is derived if all possible inputs are passed through the grammar (Prince and Smolensky 1993:91). So, with or without paradigmatic constraints, there is an important distinction between deriving individual words using a grammar and reasoning about the properties of the set of words derived by that grammar. Constraints on contrast make complete derivation of individual words difficult, but that does not preclude deriving generalizations about possible words.

To approach the derivation of complete words, it is necessary to derive increasingly comprehensive descriptions of the set of possible words. Such a description need not be a list of possible words, it could be a grammar that generates the possible words. That is, one way to deal with the need to evaluate all words simultaneously could be to evaluate candidate grammars which provide compact characterizations of candidate sets of possible words[6].

2.5. THE ANALYSIS OF AUDITORILY-BASED PHENOMENA

Having developed and supported the dispersion theory of contrast, the next three chapters apply it to the analysis of the phonological phenomena introduced in §1.3. In this chapter we have seen some evidence that distinctiveness of contrasts must be assessed in auditory terms, but the main focus has been on evidence that there are constraints that evaluate contrasts. The analyses in the following chapters provide much more evidence for the auditory nature of distinctiveness constraints, and for the relevance of these constraints to a variety of phonological processes. With these goals in mind, we consider phenomena that are problematic for most articulatorily-based feature theories in that they involve interactions between sounds that do not seem to have any articulatory basis, e.g. rounding of high front vowels before retroflexes. We will see that maximization of the auditory distinctiveness of contrasts plays a central role in most of these phenomena. In the next chapter we explore enhancement in more detail, chapter 4 presents analyses of assimilation between consonants and vowels, and chapter 5 covers neutralization.

NOTES

1. There may be other cues to this distinction, such as closure duration. The important point is that the closure transitions do not always redundantly co-vary with release transitions.

2. Richey (2000) demonstrates that Russian palatalized labial and coronal stops are distinguished exclusively by their bursts, since their formant transitions are essentially identical.

3. [e-ɯ] also violates this constraint (while [e-u] does not) because neither the F1 nor the F2 difference between these vowels is sufficient. However, it is likely that the combined differences of F1:2 and F2:3 should be as distinct as F2:4. Combining differences on distinct dimensions is the topic of the remainder of this section.

4. This formulation has the advantage of avoiding the vexed problem of deciding which features are distinctive and which are redundant (Stevens, Keyser and Kawasaki 1986:460ff.).

5. Steriade's original analysis is based on ranking positional markedness constraints against voicing contrasts according to the richness of cues to voicing available in that position. E.g. *[αvoice]/_# >> *[αvoice]/_[+sonorant]. These constraints are replaced here by MINDIST constraints. The main difference from Steriade's analysis is that she assumes that neutralization results in phonetic underspecification (i.e. *[αvoice] constraints are only satisfied by absence of a voicing specification), so the realization of neutralized segments is assumed to be determined by phonetic interpolation. It is crucial to the analysis of free variation proposed here that the realization of neutralized segments should be determined by conflicting constraints.

6. Adopting this strategy implies generalizing the MAXIMIZE CONTRASTS constraint. In the evaluation of sets of contrasting sounds, we have simply counted the number of sounds, but it is not appropriate to count sets of possible words because it is possible to generate an infinite number of words with a single consonant and a single vowel if there is no limit on word length. As stated in §2.1, 'The number of phonological contrasts should be maximized in order to enable a language to differentiate a substantial vocabulary of words without words becoming excessively long'. More specifically, we could say that the goal is to differentiate words as fast as possible, i.e. the number of possible words should increase as fast as possible with word length. So one measure that could be used to evaluate MAXIMIZE CONTRASTS is the per-segment perplexity of a candidate grammar—essentially the average number of contrasting segments allowed at any point in a string (Bahl, Jelinek, and Mercer 1983:188).

CHAPTER 3

Ways of Maximizing Distinctiveness

In the previous chapter we argued for a model of contrast that incorporated the requirement that the auditory distinctiveness of contrasts should be maximized. This requirement places constraints on auditory representations, and thus provides a basis for their involvement in phonology. In this and the next two chapters we will see that many of the auditorily-based phenomena identified in chapter 1 involve maximization of distinctiveness as a central motivation.

In the next section we will consider cases of enhancement that involve relationships that cannot be given an articulatory basis, and show that they can be analyzed in terms of maximizing the auditory distinctiveness of contrasts. These cases are all analyzed as involving a single auditory dimension—i.e. they involve increasing the difference between contrasting forms along the primary dimension of contrast. In the remainder of the chapter we will consider other ways in which the distinctiveness of contrasts can be maximized, namely by differences on multiple auditory dimensions, and by extending the duration of auditory differences.

3.1. ENHANCEMENT

Enhancement phenomena involve straightforward maximization of the auditory difference between contrasting sounds. In this section we will show that the phenomena in (1), which involve relationships between articulatorily diverse features, can all be analyzed in terms of the MINDIST constraints introduced in chapter 2.

(1) Enhancement relationships

Front vowels are unrounded	[-back] → [-round]	Many examples (§3.1.1)
Back vowels are rounded	[+back] → [+round]	Many examples (§3.1.1)
Pharyngealized consonants are labialized	$d^{ʕ}$ → $d^{ʕw}$	Modern Aramaic, Modern Syriac (§3.1.2)
[-anterior] sibilants are rounded	ʃ → $ʃ^{w}$ ʂ → $ʂ^{w}$	English, French. Polish (§3.1.3)
Retroflex approximants are rounded	ɹ → $ɹ^{w}$	English (§3.1.4)

3.1.1. F2: Backness and Rounding

As we have already noted several times, in most languages, front vowels are unrounded and back vowels are rounded. We saw in §2.3.1 that this pattern yields maximally distinct F2 contrasts, and thus follows from maximization of distinctiveness. This enhancement relation not only provides clear evidence for maximization of the distinctiveness of contrasts, but also shows that the relevant notion of distinctiveness must be auditory. It is hard to imagine any articulatory basis for the correlation of tongue backing with lip-rounding. The tongue and the lips are articulatorily independent, so it would appear to be as easy to round the lips with the tongue body forward as with it retracted. It also seems unlikely that the relevant notion of distinctiveness could be given an articulatory basis. For example a feature-counting distance metric based on articulatory features would predict that a contrast such as [y-ɯ] should be as distinct as [i-u] since both pairs differ in both [back] and [round], and would not explain why it is back and round, as opposed to say, [back] and [nasal], which are combined to produce more distinct contrasts.

3.1.2. Low F2: Pharyngealization and Labialization

The existence of an enhancement relationship between pharyngealization and lip-rounding is suggested by the fact that pharyngealized consonants are realized with lip-rounding in a number of Semitic languages. Lehn (1963) reports that pharyngealized consonants can be labialized in Cairene Arabic. Garbell (1965:33) describes Modern Aramaic pharyngealized labials as being ‘produced with a marked protrusion and rounding of the lips’ (p.33) in the dialect spoken in Jewish areas of Azerbaijan. Hetzron (1969) describes pervasive lip-rounding as part of the realization of emphasis (pharyngealization) in Modern Syriac (a Christian dialect of modern Aramaic).

This relationship between labialization and pharyngealization can be understood as maximization of the distinctiveness of contrasts because a low F2 at consonant release is an important cue to pharyngealization in Arabic (Card 1983), and lip-rounding further lowers F2, so rounding enhances the distinction between plain and pharyngealized consonants by increasing the difference in F2 at release (2).

(2)

	t	t^{ʕ}	t^{ʕw}
release F2	4	2	1

It is possible that in some cases labialization is used not so much to enhance pharyngealization as to compensate for reduced pharyngealization. That is, both pharyngealization and lip-rounding serve to lower F2, so a given level of F2 can be achieved by more tongue retraction and less lip-rounding, or vice versa. This possibility is suggested by the contrast between the description of Modern Syriac by Hertzron (1969), which implies that labialization is a primary component of emphasis, and descriptions of most Arabic dialects, which emphasize the role of pharyngealization (e.g. al-Ani 1970).

3.1.3. Lowering Noise Frequency: [-anterior] and Rounding

Non-anterior coronal fricatives are often produced with lip-rounding, for example post-alveolar fricatives in English and French and retroflex fricatives in Polish are all produced in this way (Ladefoged and Maddieson 1996:148, Puppel, Nawrocka-Fisiak, and Krassowska 1977:157). Again, there is no articulatory basis for this relationship. From an auditory point of view, however, we can see that rounding serves to enhance the distinctiveness of these sounds. This point can be made most simply for languages like English and French which contrast two sets of sibilants, [+anterior] [s, z] and [-anterior] [ʃ, ʒ]. These sounds are differentiated primarily by the frequencies at which noise is concentrated (the Noise Frequency dimension). This depends on the size of the resonating cavity in front of the noise source: the larger the cavity, the lower its resonant frequency, and thus the lower the frequency of the first intensity peak in the fricative spectrum. [-Anterior] fricatives have a larger front cavity, and thus a lower intensity peak, than [+anterior] fricatives. Lip-rounding increases this difference by lowering the resonant frequency of the front cavity.

This situation is represented in the specifications of various sibilants for Noise Frequency (NF) in (3). Rounding the palato-alveolar fricative [ʃ^{w}] and unrounding the alveolar [s] yields a greater distinction in NF than unrounded [ʃ] vs. [s].

(3) Noise Frequency dimension:

6	5	4	3	2
s	s^{w}	ʃ	ʃ^{w}	ʂ^{w}
		ɕ	ɕ^{w}	
			ʂ	

The situation in Polish is a little more complex because there are sibilants at three contrasting places: dental [s̪], alveolo-palatal (palatalized post-alveolar) [ɕ], and retroflex (apical post-alveolar) [ʂ]. Only the retroflex is produced with lip-rounding (Puppel et al 1977). This situation is also predicted by considerations of maximization of distinctiveness. The retroflex has the lowest Noise Frequency, so lowering it further through lip-rounding increases its difference from the alveolo-palatal. Rounding any other sibilant makes it more similar to a sound with otherwise lower NF. This is illustrated in (4).

(4)

		MINDIST = NF:1	MINDIST = NF:2	MINDIST = NF:3
a.	s-ɕ-ʂ		*!	**
b.	☞ s-ɕ-ʂʷ			**
c.	s-ɕʷ-ʂʷ		*!	*
d.	s-ɕʷ-ʂ	*!	*	*

This case shows that rounding does not simply apply to [-anterior] fricatives, in which case it would apply to the alveolo-palatal. Rounding serves to enhance a contrast in Noise Frequency. In each case the sibilant with the lowest noise frequency is rounded: the palato-alveolar in English and French, and the retroflex in Polish, thereby enhancing the contrast with the higher sibilant or sibilants.

3.1.4. Low F3: Retroflexion and Rounding

Lip-rounding also serves to enhance retroflexion in approximants, as in English, where retroflex [ɹ] is often produced with lip-rounding (Delattre and Freeman 1968). Retroflexes are characterized by a low F3 (Stevens and Blumstein 1975), and lip-rounding and/or protrusion serve to further lower F3 (Johnson 1997:101f.), thus enhancing contrasts on this dimension. Again, there is no articulatory basis for a relationship between lip-rounding and retroflexion.

3.1.5. Other Cases of Enhancement

Enhancement is regarded as inherently perceptual in nature by Stevens, Keyser, and Kawasaki (1986). It is described as the ‘use of... redundant features in order to enhance acoustic properties associated with distinctive feature oppositions’ (p.447). So all the cases of enhancement discussed in Stevens et al (1986) and Stevens and Keyser (1989) are accounted for in auditory/acoustic terms. Thus the full range of enhancement relations can be accounted for in terms of maximization of the distinctiveness of contrasts, the cases discussed above are simply those which dramatically demonstrate that enhancement relations cannot have an articulatory basis. Other enhancement relations are less transparently based on auditory representations. For example, the enhancement relation between voicing and nasalization (§2.3.2) is an instance of what might be called enhancement by facilitation: nasalization facilitates the production of strong voicing. Voicing contrasts in stops can be enhanced by taking measures to reduce oral pressure, such as increasing the volume of the oral cavity by expanding the pharynx, lowering the larynx etc (Westbury 1983). Oral pressure can also be reduced by lowering the velum, thus allowing air to be vented through the nasal cavity. These measures enhance the voicing contrast by facilitating the production of vocal cord vibration, but do not directly affect the primary dimension of contrast, the presence of low frequency periodicity. (Although nasalization has some direct effect because transmission via nasal airflow results in greater amplitude of low-frequency sound than transmission through the neck tissues, as in a fully oral stop (Stevens et al 1986:439)). This differs from enhancement of backness by rounding, for example. In that case the primary dimension of contrast is F2, and rounding has a direct effect on this dimension, lowering F2.

Enhancement by facilitation can be described without reference to acoustics: velum-lowering creates the aerodynamic conditions that permit vocal cord vibration. However, there are two observations to be made. Firstly, the goal of maximizing the auditory distinctiveness of contrasts accounts for the incidence of enhancement by facilitation. Without vocal cord vibration there will be no contrast in low frequency periodicity. Secondly, any articulatorily based account of these cases would have to be stated in terms of articulatory states rather than gestures. That is, voicing would have to be defined in terms of the state of vocal cord vibration rather than any gesture such as vocal cord adduction to account for the need for enhancement. This is a major step towards an analysis in auditory terms since it is obviously the articulatory state that is relevant to the acoustic signal. Without vibration, adduction of the vocal cords during a stop closure is acoustically indistinguishable from abduction.

Another type of enhancement relation discussed in Stevens et al (1986), but not so far exemplified here involves enhancement of a basic contrast by differences on additional auditory dimensions, as in the case of enhancement of palato-alveolars by affrication. This pattern of enhancement is addressed in the next section.

3.2. CONTRASTS ON MULTIPLE DIMENSIONS

So far we have mainly discussed maximizing the distinctiveness of contrasts on individual auditory dimensions. In this section we will return to the observation made in §2.2.4.1 that contrasts are typically realized by differences on several dimensions, and can thus be enhanced by increasing any of these differences.

In chapter 2 we discussed the fact that vowels differ in the frequencies of more than one formant, but an even more striking example is provided by stop voicing contrasts. Vibration of the vocal folds during closure gives rise to what might be regarded as the defining property of voiced stops, namely the 'presence of low-frequency spectral energy or periodicity' (Stevens and Blumstein 1981:29). However, voiced and voiceless stops in English are also differentiated by voice onset time, closure duration, duration of the preceding vowel, frequency of F1 and f_0 adjacent to the closure, and amplitude of F1 at release (Lisker 1986).

All of these differences have been shown to influence voicing judgements in perception (f_0: Haggard, Ambler, and Callow 1970, closure duration: Lisker 1957, VOT and F1 onset: Lisker 1975, Summerfield and Haggard 1977, periodicity during closure: Stevens and Blumstein 1981, F1 offset: Kingston and Diehl 1995, vowel duration: Massaro and Cohen 1983). Thus increasing any of the differences will enhance the voicing contrast. In general, any difference between contrasting forms contributes to the distinctiveness of the contrast. Other prime examples of contrasts on multiple dimensions are provided by place contrasts in obstruents. Fricatives that contrast in place can differ in formant transitions and in the properties of their frication noise. Place in stops is marked by formant transitions and burst properties, among other differences.

The case of stop place contrasts illustrates another important point: the various differences that mark a contrast need not be simultaneous, they may be distributed over an interval of time. For example, place contrasts in intervocalic stops are marked by two differences on the F2 dimension; one at the approach, and one at the release. We will return to the temporal dimension of contrast in §3.4, below.

A simple illustration of an enhancement relationship involving distinct dimensions is provided by palato-alveolar affricates. In many respects, the palato-alveolar can be regarded as a member of a series of contrasting plosives, together with the stops (cf. Steriade 1994a). It differs from the other plosives in place, and thus is differentiated by formant transitions—palato-alveolars generally have a higher F2 than labials or alveolars. However it also differs in the loudness of frication at release. Affricates prolong the brief period of affrication that inevitably accompanies the release of a stop closure, and that results in a louder percept of frication (cf. §2.2.2.9). This difference can be represented in terms of the dimension of Noise Loudness (NL). Since palato-alveolars are laminal coronals, the area of contact between tongue and roof of the mouth is relatively large in these sounds, resulting in a slow release, and thus a natural tendency to affrication. Even so-called palato-alveolar stops (IPA [t̲]) in languages such as Eastern Arrernte are somewhat affricated (Ladefoged and Maddieson 1996:28ff.). This partial affrication is specified [NL *3*]. We will assume that alveolars and palato-alveolars are also differentiated by F2 transitions as in (5).

(5)

	t	t̲	tʃ
burst NL	2	3	5
transition F2	4	5	5

The contrast [t - t̲] is then distinguished by F2:1 & NL:1, whereas [t - tʃ] differ by F2:1 & NL:3. So affrication of the palato-aveolar enhances the contrast with alveolar stops.

3.3. CONSTRAINING THE GROUPING OF DIMENSIONS IN CONTRASTS

The proposed generalization of minimum distance requirements to allow for differences on multiple dimensions permits contrasts realized on arbitrary groups of dimensions, but this is not generally observed. E.g. we do not find VOT contrasts enhanced by differences in F2 at release. In this section we will consider generalizations about the sets of dimensions that realize contrasts, and the basis of these patterns.

In general, differences associated with a contrast are articulatorily related. The articulations that implement a contrast on one dimension inevitably have effects on other auditory dimensions. For example producing the low intensity interval characteristic of a stop by occluding the vocal tract also results in a burst when the closure is released. Similarly, producing the different release transitions that distinguish place contrasts in stops requires making the closure at different places of articulation, which also affects the properties of the accompanying release burst, and of any closure transitions. No priority for release transitions is implied here: the point is that the burst and the transitions are liable to co-vary, so a contrast realized by differences in one will generally also be marked by differences in the other. Differences in formant values also co-vary because it is not physically possible to vary the resonances of the vocal tract in complete independence. For example, producing a high F2 requires a relatively low F1.

The articulatory connections between the cluster of differences that mark stop voicing in English are more complex. Implementing low frequency periodicity requires vocal fold vibration. Maintaining voicing during a stop is difficult (as discussed in §2.3.2), so voiced stop closures are shorter to facilitate maintenance of voicing throughout the closure. The basis of the length difference in the preceding vowel is unclear[1]. A positive VOT results from maintaining the glottal abduction gesture beyond the release of the stop, although this particular coordination is presumably motivated by enhancement of the voicing contrast (Kingston 1990). The mechanism by which voicelessness is connected with raised f_0 is a matter of considerable dispute. Most hypotheses suggest that the effect is a by-product of laryngeal adjustments required for the voicing distinction (see Ohala 1978b for a review), although Kingston and Diehl (1994) propose that the f_0 difference is produced to enhance the difference in F1 onset. The differences in F1 onset appear to be connected to VOT. F1 has very low amplitude after the release of an aspirated stop because the aspiration noise does not excite the first formant. As a result, the effective onset of F1 is later in an aspirated stop, and thus is higher than in the voiced stop where it has its onset immediately after release, where F1 is still low due to the constriction for the stop (Harrington and Cassidy 1999:91ff.).

This is not to say that the grouping of dimensions that differentiate contrasts are an automatic consequence of articulatory considerations. This is evident from the fact that the various cues to stop place which typically group together can be independently contrastive (§2.2.2.9). For example, place is marked only by closure transitions in an unreleased stop, and the burst and transitions are independently contrastive in contrastively palatalized stops.

Furthermore, languages differ in the extent to which they draw upon various dimensions in realizing a contrast. For example, in most languages voicing contrasts in obstruents are marked by differences in the duration of a preceding vowel, with vowels being shorter before voiceless obstruents (Chen 1970). But, as Keating (1985) shows, the magnitude of this effect varies across languages, ranging from large in English to completely absent in Polish, Czech and Saudi Arabic. The fact that the general pattern is so widespread, suggests that it is a natural consequence of the voicing contrast, but the fact that the effect varies shows it is not an automatic consequence. The degree of length difference required must thus emerge from the constraint rankings of each language.

Restrictions on the grouping of dimensions in contrasts probably derive from two main sources: limits on the degree of distinctiveness required by languages, and minimization of effort. As noted in §2.2.3.3, it is apparent that not all possible rankings of the constraints on contrast are attested. The balance between maximization of the number of contrasts and maximization of the distinctiveness of contrasts is determined by the ranking of MAXIMIZE CONTRASTS relative to the MINDIST constraints. If all rankings were possible, we would expect to find languages which value the number of contrasts very highly, resulting in a huge number of very fine contrasts, and languages which value distinctiveness very highly, resulting in a handful of maximally distinct contrasts. Neither of these extremes is attested. It seems that there is a lower bound on the distinctiveness required for a contrast to be functional, and that there is an upper bound beyond which additional distinctiveness provides a poor return on the effort expended. The latter consideration is of importance here because it implies that we will not find dimensions bundled together to provide extremes of distinctiveness, e.g. co-varying voicing and place in stops to yield a system such as /b, t, k^h/, because the associated MINDIST constraints will always be ranked low relative to MAXIMIZE CONTRASTS. Thus we are not likely to find high-ranked minimum distance requirements of large differences on articulatorily independent dimensions.

Where a difference on one dimension is employed to enhance a difference on another, minimization of effort favors the use of articulatorily associated differences. As observed above, the articulations that implement a contrast on one dimension inevitably have effects on other auditory dimensions, so these concomitant differences add to the distinctiveness of a contrast without any additional effort. For example, the production of a contrast in F2 transitions by means of an alveolar closure contrasted with a palato-alveolar closure is liable to be accompanied by a difference in duration of frication noise. As noted above post-alveolars, being laminal, have a large area of constriction, resulting in a slow release of the constriction, and thus a natural tendency to affrication. So a difference in Noise Loudness of the release burst is produced without any additional effort. In fact, it would require considerable effort to minimize this difference.

If further enhancement is required, minimization of effort and maximization of distinctiveness favor exaggerating these articulatory concomitants of the basic contrast. For example, the easiest way to enhance the contrast between the alveolar and palato-alveolar is to increase the difference in Noise Loudness through full affrication. Affricating the alveolar would yield a less distinct contrast for the same effort, because the result would be a contrast between a partial affricate and a full affricate. In terms of the feature specifications in (6), a contrast between [t - tʃ] involves a distance of F2:1 & NL:3, whereas [ts - t̲] are distinguished by the smaller distance F2:1 & NL:2.

(6)

	t	t̲	tʃ	ts
burst NL	2	3	5	5
transition F2	4	5	5	4

Similarly, a voicing contrast in obstruents can be enhanced by increasing the f_0 difference that accompanies the difference in low frequency amplitude. It would be counter-productive to attempt to enhance this contrast by lowering f_0 following a voiceless stop and raising it following a voiced stop, because producing the same magnitude of difference would require greater effort to overcome the contrary effect of voicing.

So it is expected that the limits on the sets of dimensions that are combined to realize contrasts should be derivable from limits on variation in ranking of MAINTAIN CONTRASTS and MINDIST constraints, which rule out grouping large differences on independent dimensions, and minimization of effort constraints, which lead to a preference for articulatorily synergetic combinations of dimensions.

3.4. DURATIONAL ENHANCEMENT

The magnitude of the distinction between two contrasting forms cannot depend solely on the magnitude of a difference along some spectral parameter, but must also depend on the duration of that difference. So the total difference between two forms is some integration of the auditory difference between them over time (Lindblom 1990a, Kawasaki 1982). For example, consider the contrast between the forms [pe] and [po]. These forms are primarily differentiated by the height of F2 during the vowel, but typically they will also be differentiated by F2 transitions after the release of the stop because labials typically assimilate the tongue body position of the following vowel. The contrast can be enhanced by increasing this difference in release transitions through allophonic palatalization and labio-velarization. That is, [p^{j}e] and [p^{w}o] are more distinct than [pe] and [po] because the contrast is signaled by a larger difference in formant transitions in addition to the vowel F2 difference. This pattern of enhancement is observed in Nupe, for example (Hyman 1970).

These considerations imply that a MINDIST constraint such as MINDIST = F2:2 should include some specification of the required duration of this difference. We will not attempt to develop a general approach to the effects of duration on distinctiveness since these are so poorly understood, rather we will tailor our approach to the cases that concern us, i.e. formant differences distributed over the vocalic interval of a syllable (a vowel together with preceding and following transitions). We will assume that the distinctiveness of a formant difference depends on the kind of segment it is associated with, vowel or transition, and on the number of segments which differ on that formant dimension. So, a difference of F2:2 in a vowel segment alone is less distinct than a difference of F2:2 in a vowel segment accompanied by a difference in F2:1 in the preceding release transitions, for example. This difference can be referred to in MINDIST constraints using the '&' notation introduced in §2.2.4.1:

(7) MINDIST = V F2:2 >> MINDIST = V F2:2 & trans F2:1

More generally, a larger formant difference during any segment yields a larger overall difference. So constraint (8b) requires a larger difference than (8a) because both mandate the same difference in Vowel F2, but (8b) requires this to be accompanied by a larger difference in F2 transitions. (8c) also requires a larger difference than (8a), but in this case because it demands a larger difference in the vowel. We will not attempt to establish a universal ranking between (8b) and (8c) since it is unclear what general principles govern the trade-off between the larger vowel difference in (8c) and the larger transition difference in (8b).

(8) a. MINDIST = V F2:2 & trans F2:1
b. MINDIST = V F2:2 & trans F2:2
c. MINDIST = V F2:3 & trans F2:1

This approach makes duration effects notationally parallel to the effect of differences on multiple dimensions—i.e. F2 differences during vowel and transition are treated as separate dimensions, so increasing either difference increases the overall distinctiveness of the contrast.

A simple example of durational enhancement is provided by allophonic palatalization and labio-velarization of consonants, as in Nupe. In this language, consonants are palatalized before front vowels (e.g. [p^je]) and labio-velarized before back rounded vowels (e.g. [p^wo]). This pattern is analyzed in more detail in §4.2.1.2, but we can illustrate the role of constraints of the kind shown in (7) here. F2 specification for the release transitions of relevant consonants are given in (9), and for relevant vowels in (10). The tongue body position during the 'plain' labials is indicated by a superscript vowel symbol. E.g. [p^e] is intended to represent a labial stop produced with the tongue in position for the vowel [e], which is assumed to be the usual realization of a labial stop before [e]. As shown in (11), palatalizing labials before front vowels results in a more distinct contrast between front and back vowels because the difference in vowel F2 is supplemented by a larger difference in F2 release transitions. This enhancement is required by the lower-ranked MINDIST constraint.

(9)

	p^e	p^j	p^o	p^w
trans F2	4	5	1	1

(10)

	e	o
Vowel F2	5	1

(11)

		MINDIST = V F2:4 & trans F2:3	MINDIST = V F2:4 & trans F2:4
a.	p^ee-p^oo		*!
b.	☞ p^je-p^wo		

We will also see that neutralization can arise where durational requirements on differences cannot be met in a particular context. For example, in Cantonese back rounded vowels neutralize with front rounded vowels between coronals because the coronals do not allow sufficient differences in formant transitions to support a distinct contrast (§4.1.1.5).

NOTES

1. Kluender, Diehl and Wright (1988) hypothesize that lengthening the vowel before a voiced stop reduces the perceived duration of the stop closure due to a contrast effect, but see Fowler (1992) for counter-evidence. Maddieson (1997) suggests that the difference in vowel duration compensates for the difference in duration between voiced and voiceless stops, resulting in a more constant total duration for vowel plus following stop.

CHAPTER 4

Consonant-Vowel Assimilation

In articulatory assimilation one segment becomes articulatorily more similar to a nearby segment, for example, a nasal may become labial before a labial consonant. This can be understood straightforwardly as the extension of an articulation, e.g. labial closure, from the conditioning segment into the target. This process is represented autosegmentally as spreading of an articulatory feature from the conditioning segment onto the target. Many of the patterns discussed in this chapter have treated as assimilatory (e.g. Clements 1991), but they cannot be analyzed as simple feature spreading given a strictly articulatory feature set. For example, coronals can condition vowel fronting, but coronals and front vowels do not share any feature that could account for this process in feature theories like those of Sagey (1986) or Chomsky and Halle (1968). These patterns are listed in (1–2).

(1) Assimilation of vowels to consonants

coronal conditions fronting	to → tø	Cantonese, Lahu, Lhasa Tibetan (§4.1.1)
plain labial conditions rounding	pɯ → pu	Tulu, Acehnese, Turkish (§4.1.2)
retroflex conditions rounding	iɖ → yɖ	Wembawemba, Wergaia (§4.1.3)

(2) Assimilation of consonants to vowels

front vowels condition coronality	pi → tʃi, tsi ki → tʃi, tsi	ChiMwi:ni, Slavic, Romance (§4.2.1)
round vowels condition labiality	ku → fu tu → fu	Luganda (§4.2.2)

We will analyze most of these phenomena as involving articulatory assimilation, but assimilation interacts with distinctiveness constraints to yield various patterns of contextual neutralization and enhancement. There are two basic patterns of interaction. In the first, articulatory assimilation makes it difficult to maintain a distinct contrast in some context. This problem can be resolved by neutralization or by compensatory enhancement. For example, assimilation results in neutralization of the contrast between back rounded and unrounded vowels [u] and [ɯ] next to labials in Mapila Malayalam and Acehnese (§4.1.2). The vowels partially assimilate to the labial constriction of the consonant, which would make unrounded vowels auditorily similar to their rounded counterparts. The contrast would thus be insufficiently distinct in this context and is neutralized. Compensatory enhancement is exemplified by the rounding of high front vowels before retroflexes in Wembawemba (§4.1.3). Assimilation of a retroflex to the tongue body position of a high front vowel results in loss of retroflexion because retroflexion requires a lower, more retracted tongue body position to allow room for the tongue tip to be curled back towards the palate. This reduction in retroflexion would make the contrast with apical alveolars insufficiently distinct, but the contrast is rescued by compensatory enhancement: the lips are rounded, enhancing the auditory effects of retroflexion.

The other basic pattern involves enhancement of a contrast by exploiting the auditory side-effects of articulatory assimilation, along the lines discussed in §3.4 and §3.5, above. For example, palatalization of preceding consonants can enhance vowel F2 contrasts by exaggerating a difference in F2 transitions that arises through assimilation of the consonant to the following vowel (§4.3.1.2). We will argue that coronalization of velars before front vowels involves enhancing a difference in affrication that arises through assimilation of the velar to the vowel (§4.3.1.3).

4.1. ASSIMILATION OF VOWELS TO CONSONANTS

We will first consider cases in which vowels assimilate to consonants. In most of these examples, assimilation results in an indistinct vowel contrast, which is rescued by compensatory enhancement (Wembawemba, §4.1.3.), or neutralized (most other cases).

4.1.1. Fronting of Vowels Adjacent to Coronals

Coronal consonants can condition fronting of vowels, and front vowels can condition coronalization of consonants. These interactions are problematic for a feature theory in which front vowels are [-back] dorsals and plain coronals have no dorsal features leaving the two with no place features in common. It has been suggested that front vowels are in fact coronal (Clements 1976, 1991, Hume 1992). This proposal establishes a direct relationship between coronals and front vowels, but yields phonological representations that gloss over the considerable phonetic differences between front vowels and coronals—i.e. front vowels primarily involve a constriction between the tongue body and the hard palate, and do not typically involve any coronal constriction (cf. Keating 1993). We will argue that there is an articulatory basis to the fronting of vowels by coronals, but it involves the physiological linkage between tip of the tongue and the tongue body rather than a shared primary articulator. This less direct approach to the relationship between coronals and front vowels better accounts for the limited conditions under which coronals condition fronting and vice versa, and for the fact that fronting can be partial, as in the English example considered next.

We will develop the basic analysis of the fronting effect of coronals with reference to allophonic fronting of back vowels in English. This case will be discussed in considerable detail because it illustrates many factors that are relevant to the analysis of consonant-vowel interactions in general. The constraints developed in the analysis of English will then be applied to cases of neutralizing fronting in other languages. Finally, we will discuss a sound change in Lhasa Tibetan in which phonemic front vowels developed through the influence of coronals.

4.1.1.1. Articulatory Factors in the Fronting Effect of Coronals

English exhibits allophonic fronting of back vowels adjacent to coronals, so /u/ in 'two' is fronted compared to /u/ in 'who' or 'coo', for example. In many dialects, the effect is strong enough that it would not be unreasonable to transcribe the vowel of 'two' as central [tʰʉ], or even further forward (cf. Ladefoged 1999). This fronting effect of coronals will be analyzed as fundamentally articulatory—that is vowels are fronted due to articulatory assimilation to the front tongue body of the coronal. However, not all coronals are produced with a fronted tongue body, and it will be argued that considerations of auditory distinctiveness are central to understanding which coronals are fronted.

The essential basis of the relationship between coronals and tongue body fronting is the fact that the tongue tip is attached to the tongue body. As a result, it is easiest to form constrictions with the tip of the tongue in the front of the mouth (i.e. close to the teeth) if the tongue body is also in a relatively forward position, otherwise considerable stretching of the tongue is required. Anterior coronals (dentals and alveolars) obviously require the tip of the tongue to be close to the front teeth, but laminal [-anterior] coronals (palato-alveolars) involve a similar requirement because the tongue blade forms a constriction just behind the alveolar ridge, and the tip is in front of the blade. In retroflexes, however, the tip of the tongue is farther back, behind the alveolar ridge (apical post-alveolars) or even on the hard palate ('sub-apical palatals' in the terminology of Ladefoged and Maddieson 1996).

While these considerations imply a dispreference for producing alveolars, and dentals with a retracted tongue body, it is clearly possible to do so, as indicated by the existence of velarized coronals, e.g. the 'dark' [ɫ] of English, or contrastively velarized coronals in Marshallese (Bender 1968, Choi 1992). However even these examples provide evidence that full tongue body retraction is difficult without tongue-tip retraction. In Marshallese, Choi's measurements of F2 at consonant onset and offset show that the velarized coronal [tˠ] involves a much fronter tongue body than the velarized labial [pˠ] (p.49)—i.e. F2 is much higher adjacent to [tˠ] (about 1650 Hz) than adjacent to [pˠ] (about 1100 Hz). In English, velarized [ɫ] commonly vocalizes, suggesting that it is difficult to keep the tip of the tongue in contact with the alveolar ridge while retracting the tongue body. A related pattern is observed in Ponapean: Rehg (1973) divides Ponapean consonants into 'front' and 'back' series which appear to be palatalized and velarized since the front consonants have a fronting effect on back vowels, and the back consonants have a backing effect on front vowels. Corresponding members of the two series, e.g. front [p] and back [pʷ], cannot cooccur in a morpheme. The velarized counterpart of the front dental stop is a retroflex affricate—i.e. the velarized coronal has a retracted tongue tip which can be understood as a consequence of the hypothesized dispreference for velarized dentals. In a similar vein, Gnanadesikan (1994) presents evidence that back vowels can condition retroflexion of adjacent coronals in Walmatjari (Hudson and Richards 1969) and other Australian languages.

So effort minimization favors producing non-retroflex coronals with a fronted tongue body. Given a coronal with a front tongue body, fronting of adjacent back vowels is then hypothesized to result from another aspect of effort minimization, specifically a dispreference for exerting the effort required to move the tongue body from front to back between a consonant and an adjacent vowel. Fronting back vowels is one obvious strategy for reducing this movement-related effort.

The analysis outlined so far can be formalized using three effort minimization constraints. The first two constraints express the dispreference for velarizing anterior or non-anterior laminal ([+distributed][1]) coronals (3). We will assume that the features [anterior] and [distributed] are only relevant to coronals, so it is not necessary to specify [coronal] in these constraints. The second constraint may well be inviolable, i.e. it may be essentially impossible to fully velarize a distributed palato-alveolar.

(3) *[+anterior, back]
*[-anterior, +distributed, back]

The constraint against moving the tongue body from front to back (or vice versa) between adjacent segments is part of a general class of effort minimization constraints against making rapid articulator movements. Faster movements involve greater effort according to most models of articulatory effort (e.g. Nelson 1983, Lindblom 1990b, Kirchner 1998). For present purposes we will formulate this preference as a set of constraints against movement along articulatory dimensions between adjacent segments (cf. Lombardi's (1999) 'AGREE' constraints). So the constraint in (4) is violated by a sequence of a front segment followed by a back segment, or the opposite sequence.

(4) *FRONT-BACK: [front] and [back] segments should not be adjacent.

The analysis of partial fronting requires that we distinguish the larger, more effortful movements of the tongue body from front to back from the smaller, less effortful movement from front to central. Thus we need a scalar articulatory dimension of tongue body position, comparable to the auditory dimensions already proposed, rather than a single, binary [+/-back] feature. For the moment we will distinguish three tongue body positions on the articulatory front-back dimension: front, central and back. Moving all the way from front to back involves greater effort than moving from front to central, or central to back. So we add the constraints in (5), which are universally ranked below *FRONT-BACK.

(5) *FRONT-CENTRAL: [front] and [central] segments should not be adjacent.
*CENTRAL-BACK: [central] and [back] segments should not be adjacent.

The operation of these constraints in English is illustrated in (6). The position of the tongue body at the release of a consonant is indicated using superscripted vowel symbols, [$t^{ɪ}$] for [front] , [t^{u}] for [back], and [$t^{ɨ}$] for [central], but we initially consider only candidates with [front] and [back] coronals. We use superscript [ɪ] rather than [i] for the [front] tongue body position because the tongue body is generally not as high and forward during a coronal as in the vowel [i][2]. A truly high front tongue body is found in palatalized coronals, so we can posit an additional position [palatalized] preceding [front] on the articulatory front-back dimension. This finer division of the scale is discussed further in §4.1.1.3, below. We will ignore constraints on lip-movement for the moment, and assume that lip-rounding is partially anticipated on a consonant preceding a rounded vowel.

Candidates (a)-(d) satisfy *[cor, +ant, back] since they have [front] coronals. However, this results in progressively greater violations of the constraints against rapid movement where central and back vowels follow (b) and (c) respectively. If movement to a following back vowel is reduced by backing the coronal, then *[cor, +ant, back] is violated. So, if unopposed, the effort constraints would require that coronals should be followed by front vowels (a)-(b).

(6)

		*[+anterior, back]	*FRONT-BACK	*FRONT-CENTRAL
a.	$t^{ɪ}$i			
b.	$t^{ɪ}$y			
c.	$t^{ɪ}$ʉ			*
d.	$t^{ɪ}$u		*	*
e.	t^{u}u	*		

The desired outcome for most English accents is partial fronting of back vowels, as in candidate (c), so some constraints must oppose complete fronting. Complete fronting of back vowels is blocked by the need to realize sufficiently distinct vowel F2 contrasts adjacent to alveolars—i.e. MAXIMIZE CONTRASTS and MINDIST constraints. The ranking including these constraints is shown in (7).

The winning candidate is (b) with a contrast between front unrounded [i] and central rounded [ʉ] after alveolars. Candidate (b) defeats (e) because MINDIST = F2:3 is ranked above *FRONT-CENTRAL so it is worth making the movement from front to central to achieve a distinctiveness of F2:3 (satisfied by [i-ʉ], but violated by [i-y]). The other candidate which fully satisfies the effort constraints, (a), is eliminated because MAXIMIZE F2 CONTRASTS is also ranked above *FRONT-CENTRAL, so it is preferable to violate this effort minimization constraint to contrast front and back vowels. Moving to the other extreme, candidates (c) and (d) maximize the distinctiveness of the vowel contrast, satisfying MINDIST = F2:4, but at the cost of violating high-ranked effort constraints. Thus the winning candidate represents a compromise between effort minimization and vowel distinctiveness, exchanging a reduction in the distinctiveness of vowel F2 contrasts for a reduction in the effort of moving from consonant to vowel.

(7) English vowel fronting

		*[+ant, back]	*FRONT-BACK	MAX F2 CONTRASTS	MINDIST = F2:3	*FRONT-CENTRAL	MINDIST = F2:4
a.	t^{ɪ}i			✓!			
b.	☞ t^{ɪ}ʉ-t^{ɪ}i			✓✓		*	*
c.	t^{ɪ}u-t^{ɪ}i		*!	✓✓			
d.	t^{ʊ}u-t^{ɪ}i	*!		✓✓			
e.	t^{ɪ}y-t^{ɪ}i			✓✓	*!		*

4.1.1.2. Auditory Factors in the Fronting Effect of Coronals

The preceding analysis formalizes the effort factors considered so far, and shows how they can conflict with vowel distinctiveness, but it is incomplete because we have not considered candidates including [central] coronals. The constraint against retracting the tongue body during coronals is currently formulated to apply strictly to [back] anterior coronals, so it is not violated by [central] coronals. Thus the winning candidate in (7) should be [t^{ɨ}ʉ-t^{ɪ}i] because it performs as well as (b) on the top-ranked block of constraints, but it involves no tongue body movement, satisfying *FRONT-CENTRAL.

This candidate could be eliminated by refining the effort constraints as in (8). I.e. we could hypothesize that the optimal tongue body position during an alveolar is front, and central and back tongue positions involve increasing difficulty. Ranking *[cor, +ant, central] above *FRONT-CENTRAL would make candidate (b) optimal again.

(8) *[+anterior, back] >> *[+anterior, central]
*[-anterior, +distributed, back] >> *[-anterior, +distributed, central]

This approach is not implausible, but it seems likely that central coronals are also dispreferred here because they yield less distinct consonant place contrasts. This alternative is worth developing because it illustrates one of the themes of this chapter: movement minimization constraints often create conflicts between maximizing the distinctiveness of adjacent contrasts. In this case, we will argue that retracting the tongue body during a coronal to make it easier to produce a more distinct back vowel results in less distinct consonant place contrasts. I.e. consonant place distinctiveness is best served by a front tongue body, vowel F2 distinctiveness is best served by a back tongue body, and these two preferences are brought into conflict because following both results in an effortful transition between consonant and vowel.

One of the primary dimensions that distinguishes consonant place is F2 at closure and release (F2 transitions) (§2.2.2.8). In the environment of back vowels, coronals are distinguished from labials and velars by having higher F2 transitions. This general pattern seems to arise out of effort minimization considerations: the dispreference for the effort involved in rapid articulator movements favors moving towards the articulatory position of the following vowel during a preceding consonant. In labials there is no articulatory difficulty in anticipating any tongue body shape during the stop, and so this is generally what occurs. In velars, the same effort minimization considerations favor forming a constriction at whichever point on the palate requires least movement from the adjacent vowel. Articulatory studies have found essentially this predicted pattern of variation (e.g. Öhman 1966, Houde 1967). Tongue body position at release is a primary determinant of F2 transitions, so labials and velars generally have F2 transitions at similar frequencies to adjacent vowels—particularly they are low before back vowels, the context relevant to a discussion of the fronting effect of coronals[3].

In anterior coronals, on the other hand, the articulatory linkage between tongue tip and tongue body makes anticipation of a back vowel difficult, as was discussed above. Furthermore, as in labials and velars, it is the position of the tongue body that determines F2 at release of a coronal since the coronal constriction per se has little effect on formant transitions (Manuel and Stevens 1995). So the fronted tongue body that articulatorily facilitates formation of an anterior coronal constriction also yields a high F2, maximizing the distinctiveness of the coronal from non-coronal stops. Centralizing the tongue body lowers F2 transitions, resulting in a less distinct contrast. So even if a central tongue body would not make the alveolar closure articulatorily difficult, distinctiveness considerations make it undesirable.

In other words, effort constraints create a conflict between maximizing the distinctiveness of consonant place contrasts, and maximizing the distinctiveness of vowel contrasts. Fronting back vowels adjacent to coronals is motivated by minimization of effort when the coronal is produced with a front tongue body, but the coronal is produced with a front tongue body in order to maximize its distinctiveness from other places of articulation.

This analysis is easily implemented by adding MINDIST constraints relevant to consonant place contrasts into consideration. In fact MINDIST = F2:3 will serve as the relevant distinctiveness requirement on both consonants and vowels if we assume that it applies to F2 in both 'transition' and 'vowel' segments. Relevant F2 specifications are given in (9). The tableau in (10) shows the crucial candidates, namely (a) the intended winner of (7) with a front alveolar and a central vowel, and (b) the actual winner with a central alveolar and a central vowel. We have added a contrasting [p$^{\text{u}}$u] to each candidate, as a representative non-coronal. It is assumed that the coronal-velar contrast is sufficiently distinct by virtue of the large difference in burst quality, so it is the coronal-labial contrast that is in need of enhancement in this context[4].

As noted above, candidate (b) satisfies *FRONT-CENTRAL while candidate (a), with the fronted coronal violates it. However, this is no longer decisive because the central alveolar has release [F2 *3*] whereas the front alveolar [t$^{\text{ɪ}}$] has release [F2 *4*], yielding a better contrast with the labial release of [F2 *1*].

(9)

	i	y	ɨ	ʉ	u
vowel F2	5	4	3	2	1
	t$^{\text{ɪ}}$	t$^{\text{ɨ}}$	p$^{\text{u}}$		
transition F2	4	3	1		

(10) Comparison of front and central alveolars.

		*[cor, +ant, back]	*FRONT-BACK	MAX CONTRASTS	MINDIST = F2:3	*FRONT-CENTRAL	MINDIST = F2:4
a.	☞ t$^{\text{ɪ}}$ʉ-t$^{\text{ɪ}}$i p$^{\text{u}}$u			✓✓✓		*	*
b.	t$^{\text{ɨ}}$ʉ-t$^{\text{ɪ}}$i p$^{\text{u}}$u			✓✓✓	*!		*

Similar considerations apply to coronal fricatives and approximants. F2 transitions may be less important to place contrasts involving sibilant fricatives than they are to stop place contrasts because fricative place contrasts may be distinguished by Noise Frequency and Noise Intensity as well. However, a high F2 will still enhance contrasts such as [s-f]. Sibilant fricatives such as [s] also require rather precise placement of the tongue tip because a jet of air must be directed at the teeth to generate the high intensity noise characteristic of these sounds (Shadle 1991), so this in turn may result in more stringent requirements on tongue body position. The coronal approximant /l/ does not consistently condition fronting across English dialects. Many dialects of American English velarize [l] to some extent even in onset, and these partially velarized laterals do not condition vowel fronting. However, the plain [l] of most British dialects does condition fronting. In these latter dialects, a high F2 helps to distinguish [l] from [w], but it is not clear what countervailing constraint causes the 'velarizing' dialects to forgo maximizing distinctiveness along this dimension[5].

Finally, distinctiveness of consonant place contrasts is relevant to explaining why languages like English do not adopt an alternative route to satisfying [coronal, +anterior, back], i.e. retracting the coronal to a [-anterior] retroflex. We noted above that this strategy seems to be adopted in Ponapean and Walmatjari. Stop places are distinguished by properties of the stop burst as well as by formant transitions. The typical [p, t, k] system seems to be well-dispersed because the burst spectra of the stops are quite distinct (cf. §2.2.2.9): Labials have low intensity, diffuse bursts, coronals have high intensity bursts with energy concentrated at high frequencies, and velar bursts are characterized by a well-defined spectral peak whose frequency varies depending on vowel context, but is generally well below the peak of a coronal burst spectrum (Stevens and Blumstein 1978, Harrington and Cassidy 1999:83ff.). Any retraction of the place of the coronal is liable to result in a lowering of the Noise Frequency of its burst, making it less distinct from the other stops.

In languages with palato-alveolar affricates, as in English, distinctiveness of the contrast between these sounds and the coronal stops is probably a significant factor also. Retracting the coronal stop would result in a burst which is less distinct from the palato-alveolar frication. Retraction of anterior coronal fricative [s] is obviously problematic where there is a contrast with a non-anterior sibilant such as [ʃ] since this will bring the point of articulation of the contrasting fricatives close together, which is liable to yield similar fricative noise properties. And, in English at least, retraction of [l] would reduce the distinctiveness of its contrast with [ɹ].

4.1.1.3. Articulatory Dimensions

As already noted, the articulatory front-back dimension proposed here is formally similar to the auditory dimensions introduced in §2.2.2. The use of scalar dimensions in auditory representations is motivated primarily by the need to provide a direct representation of auditory distance for evaluation of MINDIST constraints. A similar motivation applies in the case of articulatory dimensions: we have suggested that a class of effort minimization constraints penalizes articulatory movement between segments, with larger movements violating higher-ranked constraints—e.g. moving the tongue body from front to back is more effortful than moving it from front to central, or central to back. Magnitude of movement along a dimension is more easily represented with scalar dimensions, just as distinctiveness of contrasts is more easily represented with scalar dimensions. We have not fully exploited this potential by, e.g., formulating constraints against moving *n* steps on an articulatory dimension, with constraints ranked according to the size of the movement, instead we have formulated rather specific constraint such as *FRONT-BACK, *FRONT-CENTRAL. We have adopted the latter approach to keep the constraint names interpretable, and in recognition of the fact that the articulatory dimensions are more tentative and ad hoc than the auditory dimensions proposed here. That is, we will make no attempt to construct a general set of articulatory dimensions, and some of the dimensions proposed might be decomposed into multiple dimensions in a more general framework (e.g. in §4.1.2 we propose a dimension of 'lip-opening' which might be better decomposed into jaw height, lower-lip raising, and lip protrusion).

The scalar representation of tongue body position also makes finer distinctions than the standard binary feature [+/-back]. We have already motivated the differentiation of front, central, and back positions to allow for the analysis of partial fronting of vowels by coronals. Here we will briefly discuss some evidence for distinguishing a fourth, more fronted position [palatalized], a distinction which is also important to analyses of English coronals in §5.1. The most basic consideration is the need to distinguish plain coronals with a fronted tongue body from palatalized coronals. In auditory terms, the former generally have [F2 *4*] transitions, whereas palatalized coronals have [F2 *5*]. This difference arises because the tongue body is not as high and forward in the plain coronal. We propose to label this more forward tongue body position [palatalized], yielding a scale with four points (not necessarily evenly distributed) (11).

(11) palatalized – front – central – back

There are dialects of American English in which alveolars are often realized with [F2 *5*] release transitions, but this is by no means universal. Before back vowels, part of the reason is the difficulty of moving from a [palatalized] coronal to a vowel which is back enough to be distinct from front vowels—i.e. *PALATALIZED-CENTRAL >> *FRONT-CENTRAL. But there is also evidence that palatalizing coronals can create articulatory difficulties, regardless of the vowel context. Forming a dorso-palatal constriction requires curving the front of the tongue body to bring it close to the hard palate, and this curvature seems difficult to combine with the upward orientation of the tongue tip required to make contact between the tip and the teeth or the alveolar ridge. In Russian the palatalization of dental stops results in a shift to a laminal alveolar closure, and in Polish the palatalized counterparts of dental stops are alveo-palatals (Keating 1991:39). Palatalization of retroflexes is particularly problematic as discussed in §4.1.3 below.

4.1.1.4. Lahu

Lahu (Matisoff 1973) exhibits cooccurrence restrictions which can be analyzed as resulting from fronting of vowels adjacent to coronals, although there do not appear to be any phonological alternations involved. Lahu has front, central and back vowels (12), but coronal consonants (alveolars and palato-alveolars) cannot be followed by non-low central vowels[6] (13). Note that the palatal glide patterns with the coronals in this respect.

(12) Lahu vowels

i	ɨ	u
e	ə	o
ɛ		ɔ
	a	

(13)	ni	'look at, try doing'	*nɨ	*nə
	tʃʰi	'this'	*tʃʰɨ	*tʃʰə
	tí	'only'	*tɨ	*tə
	ʃì	'yellow, golden'	*ʃɨ	*ʃə
	tsê	'quotative'	*tsɨ	*tsə
	dê	'something useless'	*dɨ	*də
	le	'substance questions'	*lɨ	*lə
	gú-jîʔ	'mat'	*jɨ	*jə

The absence of central vowels following palatals and coronals can be explained in terms of a process that fronts central vowels in this context, neutralizing the contrast between front and central vowels. The basic fronting effect is analyzed exactly as for English, resulting in back vowels being fronted to central. But this makes it impossible to maintain a sufficiently distinct three-way contrast, so neutralization to a two-way contrast between front unrounded and central rounded vowels results.

The contrast between front, central and back vowels in non-coronal contexts derives from the constraint ranking shown in (15).

(14) F2 Dimension:	5	4	3	2	1
	i	y	ɨ	ʉ	u

(15) Vowel F2 contrasts in non-coronal contexts.

		MINDIST = F2:2	MAX CONTRASTS	MINDIST = F2:3
a.	☞ i-ɨ-u		✓✓✓	**
b.	i-u		✓✓!	

After anterior coronals, and other sounds with a front tongue body, the situation is rather different because the constraint *FRONT-BACK becomes relevant. To simplify the analysis, we will assume the effort constraint suggested in (8), *[+anterior, central] which penalizes anterior coronals with either central or back tongue body position. As in English, central coronals could instead be excluded by constraints on the distinctiveness of consonant place contrasts.

These effort constraints are ranked above MAXIMIZE CONTRASTS (16). The high ranking of *[+ant, central] excludes candidates with coronals not facilitated by a front tongue body position, i.e. (b) and (c). However, if this constraint is satisfied by making all coronals front, then a following back vowel, as in (a), becomes unacceptable since it violates *FRONT-BACK. Consequently back vowels must be replaced by central vowels. This makes it impossible to maintain the three-way F2 contrasts found in other environments, because central rounded and unrounded vowels differ only by F2:1, in violation of MINDIST = F2:2. Since all of these constraints rank above MAINTAIN CONTRASTS, it is preferable to neutralize to a two-way vowel F2 contrast. Low-ranked distinctiveness constraints prefer neutralizing to [i-ʉ] (e) rather than the less-distinct [i-ɨ] (f).

(16) Vowel F2 contrasts after a coronal.

		*[+ant, central]	*Δ[front] & Δ[back]	MINDIST = F2:2	MAX CON-TRASTS	MINDIST = F2:3
a.	t^{I}i-t^{I}ɨ-t^{I}u		*!		✓✓✓	**
b.	t^{I}i-t^{I}ɨ-t^{ɨ}u	*!			✓✓✓	**
c.	t^{I}i-t^{I}ɨ-t^{u}u	*!			✓✓✓	**
d.	t^{I}i-t^{I}ɨ-t^{I}ʉ			*!	✓✓✓	**
e.	☞ t^{I}i-t^{I}ʉ				✓✓	
f.	t^{I}i-t^{I}ɨ				✓✓	*!

In other words, the fronting effect of coronals in Lahu is analyzed as being fundamentally the same as in English. The difference is that Lahu has contrastive central vowels which must be neutralized in fronting contexts to avoid an indistinct contrast, so the fronting is neutralizing rather than allophonic.

The palato-alveolars and palatal glide also condition fronting (13). Palatal glides are [palatalized], so are expected to condition fronting also. Palato-alveolars are [-anterior] coronals, but they are laminal, and consequently subject to the constraint *[-anterior, +distributed, central] (8). As noted above, this constraint is probably universally high-ranked (at least above *[+anterior, central]) so palato-alveolars pattern just like alveolars here.

Note that the low central vowel can appear following coronal and palatal consonants:

(17)

(17)	ʃā	'animal, game'	nâʔ	'bullet'
	lâhū	'Lahu'	jàʔ	'go down, descend'
	tʃā	'to sprout'	tâʔ	'to go down, descend'

This is expected if the restriction against the non-low central vowels is due to neutralization which results from fronting of contrasting back vowels. I.e. the problem is not with realizing central vowels after coronals and palatals, rather the problem is with maintaining a contrast between central and back vowels in those environments. There are no front-back contrasts amongst low vowels, so no problem arises.

4.1.1.5. Cantonese

Comparable distributional evidence for a fronting effect of coronals can be observed in Cantonese. In Cantonese, back vowels do not appear between dentals, only front vowels can appear in this position (Cheng 1991, Kao 1971). Thus the contrasts between front and back rounded vowels is neutralized. Examples are given in (19) and the vowel phonemes of Cantonese are shown in (18)[7].

(18)	i	y	u
	e	ø	o
		a,aː	

(19)	k^hyt	'decide'	k^hut	'bracket'		
	hø	'boots'	ho	'river'		
	t^hyt	'to take off'	*t^hut		t^hʊk	'bald head'
	t^høn	'a shield'	*t^hon		t^hok	'to carry (on shoulders)'

As Cheng (1991) argues, this distributional restriction can be understood as resulting from fronting of vowels between coronals. The analysis is thus very similar to that proposed for Lahu: assimilation to the front tongue body position of the coronals results in fronting of back vowels, which would yield an insufficiently distinct contrast with the front rounded vowels, so these contrasts are neutralized. However, the Cantonese vowel-fronting differs interestingly in that it occurs only if the vowel is flanked by coronals (19).

Doubly-conditioned assimilation processes are problematic for standard autosegmental approaches. Spreading a feature from two sources onto a target achieves the same as spreading the feature from one source (20), so the role of the second source is unexplained.

```
(20)    x    x    x                  x    x    x
        |  .·'    |                  |  .·'·.   |
     [-back]  [-back]             [-back]   [-back]
```

In the present analysis of fronting by coronals, two coronals have a cumulative effect on the distinctiveness of the contrast between front and back rounded vowels, resulting in a less distinct contrast in this environment. That is, in the contrast [k^{y}y^{y}t]-[k^{u}ʉ^{y}t], the distinction between /y/ and /u/ is realized during the release transitions and the vowel, whereas between coronals [t^{y}y^{y}t]-[t^{y}ʉ^{y}t] it would be realized in the vowel only. That is, as discussed in §3.4, the distinctiveness of a contrast depends on the duration of differences as well as on the magnitude of the differences at a particular point in time. We have transcribed lip-rounding on transitions here, a factor which we ignored in the transcriptions and analyses of English and Lahu. Lip-rounding is more important here because the distinctions between transitions are central to the analysis, whereas in English and Lahu it was the position of the tongue body that was relevant to the analysis of the fronting effects. Transcribing rounding on transitions also emphasizes the continuity of vowel and transitions, making the duration of vowel differences clearer. In terms of auditory representations, [k^{y}y^{y}t]-[k^{u}ʉ^{y}t] are distinguished by V F2:2 and trans F2:3 (from the velar transitions), whereas [t^{y}y^{y}t]-[t^{y}ʉ^{y}t] are distinguished by V F2:2 only. The [y-u] contrast is not found adjacent to labials because separate cooccurrence constraints prevent front rounded vowels from occurring in that environment (see §5.2 for an analysis).

This analysis can be formalized in terms of the constraint ranking illustrated in (22). Note that it is assumed that the contrast between front unrounded and rounded vowels (e.g. [i-y]) is primarily in F3, the rounded vowels being [F3 *1*] and the unrounded vowels [F3 *4*] ([e]) or [F3 *5*] ([i]). This means that the only minimal F2 contrasts in vowels are between front and back rounded vowels (e.g. [y-u]). Front unrounded vowels are more distinct from back vowels, so if back rounded vowels are sufficiently distinct from front rounded vowels, then they are necessarily sufficiently distinct from front unrounded vowels also. Thus in the tableaux below, we only need to consider the F2 contrast between rounded vowels.

Again, the basic analysis of the fronting effect of coronals is as in English: the high ranking of *[+ant, back], *[+ant, central] and *FRONT-BACK makes it impossible for coronals to appear adjacent to back vowels—only front and central vowels are acceptable. However, a velar can accommodate to the back tongue position of [u] and to the front tongue position of [y], so between a velar and a coronal it is possible to realize an adequate contrast between front and back vowels because they are distinguished by the large difference at onset as well as the smaller difference at the vowel center (c)[8].

(21) F2 Dimension:

5	4	3	2	1
i	y	ɨ	ʉ	u
e	ø	ə	ɵ	o
	t^{y}			t^{u}
	k^{y}			k^{u}

(22)

		*[+ant, back]	*FRONT -BACK	MINDIST = V F2:2 & trans F2:3	MAX CON-TRASTS	*FRONT-CENTRAL
a.	k^{y}y^{y}t-k^{u}u^{u}t	*!			✓✓	
b.	k^{y}y^{y}t-k^{u}u^{y}t		*!		✓✓	*
c.	☞ k^{y}y^{y}t -k^{u}ʉ^{y}t				✓✓	*
d.	k^{y}y^{y}t				✓!	

But in the environment between two coronals, both transitions are required to be front, so a front-back contrast cannot be realized by a difference in transitions. The distinction between front and central at the mid-point of the vowel is not sufficiently distinct (V F2:2) to maintain a contrast (i.e. MINDIST = V F2:2 & trans F2:3 outranks MAINTAIN CONTRAST), so neutralization is preferable. The low-ranked effort minimization constraint *FRONT-CENTRAL favors neutralizing to a front vowel, since this means minimal movement between the vowel and adjacent coronals.

(23)

		*[+ant, back]	*FRONT -BACK	MINDIST = V F2:2 & trans F2:3	MAX CON-TRASTS	*FRONT-CENTRAL
a.	t^{y}y^{y}t-t^{u}u^{u}t	*!			✓✓	
b.	t^{y}y^{y}t-t^{y}u^{y}t		*!*		✓✓	
c.	t^{y}y^{y}t-t^{y}ʉ^{y}t			*!	✓✓	
d.	☞ t^{y}y^{y}t				✓	
e.	t^{y}ʉ^{y}t				✓	*!

Vowel fronting also applies between an onset palatal glide and a coronal coda (24a), as would be expected given the fully front tongue position of the palatal. However the back vowel [ɔ] can appear between a coronal onset and a palatal off-glide in the diphthong [ɔi] (24b) (there is no [oi]). It is not clear whether fronting occurs in this context. Zee's (1999) acoustic study shows a little fronting of the nucleus of [ɔi] in a non-coronal context, relative to open syllable [o], but in the same environment, the nucleus of [øy] is actually retracted. These diphthongs are quite long, and a substantial proportion of their duration is occupied by transition, so it is plausible that a larger movement from front to back is possible without greater effort if the transitions between stops and vowels are shorter. Finally, Zee shows that the contrast between [øy] and [ɔi] is realized by large temporal differences in addition to the differences in vowel and glide quality: in [øy] the duration of the first part of the diphthong is shorter than the second, whereas the reverse is true in [ɔi], and [ɔi] is longer overall (in fact it is often transcribed as [ɔ:i]). So the contrast could probably be adequately maintained even if fronting rendered the nuclei of the diphthongs rather similar.

Note that although there is a diphthong [ui], it does not appear after a coronal onset. However, the diphthongs [ui] and [ɔi] are generally in complementary distribution, contrasting only after velars (Bauer and Benedict 1997:63f.), so it appears this gap is due to a height neutralization process rather than any fronting effect of the coronal.

(24) a.	jyt	'moon'	*jut		
	jøt	'weak'	*jot		
b.	løy	'woman'	lɔi	'come here'	
	tʰøy	'calf'	tɔi	'generation'	

4.1.1.6. Lhasa Tibetan

Fronting of vowels adjacent to coronals can be observed in the diachronic development of Lhasa Tibetan (Michailovsky 1975). The earlier language had the vowels [i, e, a, o, u]. Then certain final consonants were lost, and back vowels which had preceded dental consonants became front (25a). The quality of vowels preceding labials and velars was unaffected (25b).

(25)	8th Century Tibetan	>	Lhasa Tibetan	
a.	lus		lyː	'body'
	jul		jyː	'country'
	bod		phøː	'Tibet'
	spos		pøː	'incense'
	sman		mɛ̃ː	'medicine'
	skad		qɛː	'language'
b.	goŋ		qhõː	'price'
	gjag		jaː	'yak'
	nub		nuː	'west'

Similar, if less consistent, developments can be observed in other Tibeto-Burman languages (Michailovsky 1975). These developments provide further evidence for the fronting effect of coronals on back vowels, and Michailovsky (1975) and Ohala (1981) both argue that perceptual considerations are central to understanding this change. However, it is not entirely clear exactly how this fronting effect should be characterized during the various synchronic states passed through in the course of this sound change. Ohala (1981) argues that the loss of final consonants and the fronting of vowels were essentially simultaneous developments: the vowel fronting is argued to have been a result of misinterpretation of the F2 raising effect of a following coronal as inherent to the vowel when the final consonant was not perceived. This implies a change from a state comparable to English, in which vowel fronting is an allophonic effect of coronals, to a language with a contrast between front and back rounded vowels. Once the consonant place contrast was replaced by a vowel contrast, this contrast was presumably enhanced by fully fronting the newly fronted round vowels.

If this scenario is correct then the only synchronic fronting effect of coronals can be analyzed in essentially the same way as English (§4.1.1.1). However it is also possible that Lhasa Tibetan passed through an intermediate stage in which vowel fronting was exaggerated to provide a better cue to the coronal-non-coronal contrast among final consonants. This enhancement of the difference in vowel F2 could have been in compensation for the loss of other place cues as lenition of final consonants progressed. So this account posits a more gradual shift in the relative importance of the various cues to the final place contrast. If this sequence of events is accurate, then the intermediate stage is an example of enhancement of a contrast by increasing a difference that arises as an articulatorily-motivated side-effect of realizing the primary cues to the contrast, a pattern discussed in §3.3 above.

4.1.1.7. Summary

In summary, we have seen three cases in which coronals, or coronals and palatals, condition fronting of vowels. The observed natural class of coronals and palatals and their effect on vowels can be understood in terms of the shared property of a front tongue body position. However, not all coronals have a front tongue body—most obviously velarized coronals do not, and retroflexes generally do not. These coronals do not condition fronting, on the contrary they can condition backing of vowels.

The link between anterior and laminal coronals and a front tongue body position is argued to be the result of the physiological connection between tongue tip and tongue body. It is easier to produce sounds which require an advanced tongue tip if the tongue body is front. However, this physiological connection results in a violable preference (formalized as an OT constraint) for an association between anterior and laminal coronals and a front tongue body rather than a fixed cooccurrence. For example, velarization contrasts on dentals represent a case in which this constraint is violated in order to realize an additional contrast.

Although the connection between front vowels and this class of coronals is articulatory, distinctiveness constraints play a role in explaining why effort minimization is not satisfied by retracting the coronal (§4.1.1.2), and why neutralization is restricted to the position between coronals in Cantonese (§4.1.1.5).

4.1.2. Rounding of Vowels Adjacent to Labials

A labial constriction typically results in a lowering of the second and third formants, whether or not the lips are rounded. Thus the labial constriction at the release of a labial has similar acoustic effects to lip-rounding, so extension of a labial constriction from a labial consonant onto a vowel can result in a sound which is acoustically indistinct from a rounded vowel. Rounding can then arise through neutralization of rounding contrasts. So the basic connection between plain labials and lip-rounding lies in the similarity of the auditory effects of these articulations.

4.1.2.1. Mapila Malayalam

It has long been observed that plain labial consonants can condition rounding of vowels, diachronically and synchronically (Campbell 1974, Sagey 1986, etc). One such case is found in Mapila Malayalam, a Dravidian language (Bright 1972). In many Dravidian languages epenthesis applies to break up consonant clusters, and to syllabify final consonants. In Mapila Malayalam, the epenthetic vowel is high, central, and unrounded, except following a round vowel or labial consonant, where it is realized as rounded [u] (26). Essentially the same pattern is observed in Tulu, which is spoken in the same area (Bright 1972).

(26)	/pal/	palɨ	'milk'	/pand/	pandɨ	'shake'
	/onn/	onnu	'one'	/moːn/	moːnu	'son'
	/nuːr/	nuːru	'hundred'	/unn/	unnu	'dine!'
	/caːv/	caːvu	'death'	/japp/	jappu	'pound'
	/islaːm/	islaːmu	'Islam'	/ʈripp/	ʈrippu	'trip'

The non-epenthetic vowel inventory of Mapila Malayalam is [i, e, a, o, u] (plus length contrasts). There are words with non-epenthetic final short [u], as can be observed from the fact that these vowels are not lost upon addition of a vowel-initial suffix (27a), cf. (27b) with epenthetic [u]. There are no words with non-epenthetic [ɨ].

(27) a.	/naɖu/	naɖu	'hip'	/naɖu+aː/	naɖuvaː	'is it the hip?'
b.	/oːɖ/	oːɖu	'run!'	/oːɖ+ije/	oːɖije	'I ran'

As in the case of fronting by coronals, this process is analyzed as involving both articulatory and auditory factors. The articulatory factor is the same dispreference for rapid movements discussed above, but in this case we are concerned with movements of the lips rather than of the tongue body. This dispreference for rapid movement results in the lips remaining somewhat approximated after the release of a labial. Lip constriction has the same acoustic effects, whether it is achieved by lip rounding or simple vertical approximation of the lips. So the result of slowly releasing a labial into the central unrounded vowel is acoustically very similar to the back rounded vowel /u/. Consequently, the distinction between [ɨ] and [u] is neutralized in this context.

To formalize this analysis, we need to represent at least three degrees of lip opening: close, approximated, and open. Lips are ‘close’ in labial stops and fricatives, ‘open’ in most non-labial sounds, and ‘approximated’ in sounds produced with a labial constriction of less than fricative degree (rounded or vertically compressed—cf. Ladefoged and Maddieson’s (1996:296) feature [compressed]). We can then formulate a constraint against rapid lip movement (28), which is violated by movement from close to open between adjacent segments.

(28) *LIPS CLOSE-LIPS OPEN

As with tongue body position, lip aperture can be thought of as a scalar articulatory dimension, but it is possible that a full articulatory analysis would decompose lip aperture into multiple articulatory dimensions, e.g. lip protrusion, lower-lip position, and jaw position (see below and §4.1.2.3).

The articulatory features of the release of a consonant specify the articulatory position just before release, so a labial stop is specified [lips close] at release, but the auditory features of the release generally reflect the auditory consequences of moving from the articulatory position just before release to the position for the vowel. Specifically, release formant specifications reflect the frequency of formants around onset of audible formants, which obviously occurs only after the lips have opened to some extent. This approach is adopted to avoid proliferating representations of intermediate articulatory positions.

F2 specifications for relevant sounds are shown in (29). A superscript [$^{\beta}$] is used to indicate an unrounded approximant constriction of the lips. As mentioned above, the acoustic effects of an unrounded lip constriction are essentially the same as the effects of lip-rounding. (The only differences arise from the fact that rounding is typically accompanied by protrusion of the lips, which results in further lowering of formants, since it lengthens the vocal tract, but this difference is generally too small to represent here). Specifically, both will lower F2 of the central vowel, making it more similar to back rounded [u].

(29) F2 dimension:

5	4	3	2	1
i	y	ɨ	ɨ$^{\beta}$	u

Articulatory feature specifications for degree of lip constriction in relevant sounds are as follows:

(30)

lips close	p	
lips approximated	ɨ$^{\beta}$	u
lips open	ɨ	

Rounding after labial consonants can then be analyzed in terms of the constraint ranking in (31). Neutralization is to the rounded vowel [u] rather than [ɨ$^{\beta}$] because this yields a better contrast with [i].

(31)		*LIPS CLOSE-LIPS OPEN	MINDIST = F2:2	MAXIMIZE CONTRASTS
a.	jappɨ-jappu	*!		✓✓
b.	jappɨ$^{\beta}$-jappu		*!	✓✓
c.	☞ jappu			✓

A full analysis of Malayalam epenthesis would take us too far from our main concern here, which is the alternation between unrounded and rounded vowels in the context of plain labials. However it is worth saying a little more about the derivation of the epenthetic vowel quality—i.e. that the epenthetic vowel is always high and is central in non-labial contexts. It is assumed that the height of this vowel results from effort minimization constraints, that is the vowel must be high to minimize lowering from the high jaw position associated with consonants, particularly given the extra short duration of the vowel. This is another 'movement minimization' constraint, applying to jaw position, so we can dub it *JAW LOWERING. A high jaw position is probably also relevant to the extension of labial constriction into a following vowel because jaw lowering results in lip opening unless the lips move to counteract the jaw motion. So lip opening for a low vowel can be produced without much movement of the lips relative to the jaw, but opening the lips into a vowel with a high jaw position may require more movement of the lips themselves. The epenthetic vowel is central (in non-labial environments) to remain distinct from the non-epenthetic [i] and [u] (32).

(32) Epenthetic vowel quality in non-labial environments.

		*JAW LOWERING	*LIPS CLOSE-LIPS OPEN	MINDIST = F2:2	MAXIMIZE CONTRASTS
a.	pali-palə-palu	*!			✓✓✓
b.	☞ pali-palɨ-palu				✓✓✓
c.	pali-palu				✓✓!

The rounding effect of preceding round vowels is susceptible to a similar analysis—articulatory extension of rounding (or partial rounding) from the round vowel onto the epenthetic vowel results in a sound which is insufficiently distinct from [u] so neutralization results. However, the constraint *LIPS CLOSE-LIPS OPEN cannot easily be adapted to account for extension of rounding since geminate consonants and consonant clusters can intervene between the two vowels. This suggests that more stringent constraints apply to the rate of unrounding movements—e.g. we might need constraints on longer vowel-to-vowel movements as well as on short C-to-V movements—or else that this rounding harmony is not motivated by effort minimization.

4.1.2.2. Acehnese

Another case in which plain labials condition rounding of vowels is found in Acehnese (Durie 1985). Acehnese has the vowel inventory shown in (33), plus diphthongs with schwa off-glides[9]. The high central unrounded vowel is rounded between labials in unstressed syllables, giving rise to the alternations shown in (34). The basic form of the verbal prefix /pɨ-/ surfaces preceding non-labials (34a). When prefixed to a labial stem, the prefix vowel is flanked by labials, and thus rounds to [u] (34b).

(33)

i	ɨ	u
e	ə	o
ɛ	ɐ	ɔ
	a	

(34)

a.	nan	'name'	pɨ-nan	'to name'
	abɛɛ	'dust'	pɨ-abɛɛ	'to dust'
b.	bɨt	'work'	pu-bɨt	'to do; make a deed of'
	pagɨ^{ə}	'fence'	pu-pagɨ^{ə}	'to fence'

Like Cantonese vowel fronting, rounding in Acehnese is a case of doubly-conditioned assimilation: it applies only to vowels preceded and followed by labials. We will thus propose a parallel analysis, according to which a single labial conditions partial lowering of F2. The combined effect of flanking labials reduces the F2 contrast with back rounded vowels to the point where it is not adequate for contrast, and neutralization results. This analysis is formulated as shown in (36) and (37). With a single labial, it is possible to maintain an [ɨ-u] contrast because F2 can rise through the second part of the vowel, as indicated by the transcribed 'transitions' in (36). Between labials, this is not possible, so the contrast would be insufficiently distinct, and neutralization is preferred (37). The back rounded vowel surfaces under neutralization because this yields a more distinct contrast with front [i].

(35) F2 dimension:

5	4	3	2	1
i	y	ɨ	ɨ^{β}	u
			p^{ɨ}	p^{u}

(36)

		*LIPS CLOSE- LIPS OPEN	MINDIST = V F2:1 & trans F2:2	MAX CON-TRASTS	MINDIST = V F2:2 & trans F2:2
a.	p^{ɨ}ɨ^{ɨ}-p^{u}u^{u}	*!		✓✓	
b.	☞ p^{ɨ}ɨ^{βɨ}-p^{u}u^{u}			✓✓	*
c.	p^{u}u^{u}			✓!	
d.	p^{ɨ}ɨ^{βɨ}			✓!	

(37)

		*LIPS CLOSE- LIPS OPEN	MINDIST = V F2:1 & trans F2:2	MAX CON-TRASTS	MINDIST = V F2:4
a.	p^{ɨ}ɨ^{ɨ}p-p^{u}u^{u}p	*!		✓✓	*
b.	p^{ɨ}ɨ^{βɨ}p-p^{u}u^{u}p		*!	✓✓	*
c.	☞ p^{u}u^{u}p			✓	
d.	p^{ɨ}ɨ^{βɨ}p			✓	*!

Note that we have assumed that articulatory effort is a relevant factor here, i.e. the contrast between [ɨ-u] is problematic in labial environments in part because effort avoidance requires maintaining a labial constriction into the vowel. This makes the analysis parallel to that proposed for Cantonese, but this assumption is not essential to the analysis. The lowering effect of labial consonants on the F2 transitions alone would make the contrast less distinct between labials than in other environments: [p^{ɨ}ɨ^{ɨ}-p^{u}u^{u}] differ by V F2:2 and trans F2:2, whereas [p^{ɨ}ɨ^{ɨ}p-p^{u}u^{u}p] differ by V F2:2 and trans F2:1. So neutralization would still follow if MINDIST = V F2:2 & trans F2:2 were ranked above MAINTAIN CONTRASTS. What is crucial is that the contrast is less distinct between labials than in other environments.

The restriction of this pattern of neutralization to unstressed syllables presumably follows from the shorter duration of unstressed vowels, which makes the impact of the transitions on the distinctiveness of vowel contrasts greater, since the transitions occupy more of the vowel. However, we will not attempt to represent this difference. Finally, the non-high central vowels [ə, ɐ] do not occur in unstressed syllables (Durie 1985:21), so it is not possible to determine whether these vowels would undergo the same rounding process.

4.1.2.3. Turkish Labial Attraction

Another well known case of rounding conditioned by labials is Turkish ‘labial attraction’ (Lightner 1972). Turkish has the vowel inventory shown in (38). Rounding usually can only appear in non-initial syllables as a result of harmony conditioned by a preceding round vowel. But in a morpheme-internal sequence of an unrounded low vowel and a labial consonant followed by a high back vowel, the high vowel is usually round (39). This phenomenon has been dubbed 'labial attraction'.

(38) Turkish vowels

i	y	ɯ	u
e	ø		o
	a		

(39)

armud	'pear'	kabuk	'rind'
karpuz	'watermelon'	avlu	'courtyard'
javuklu	'engaged'	samsun	'mastiff'

This phenomenon superficially appears similar to Mapila Malayalam, but it is not obviously a case of neutralization because, as a result of rounding harmony, rounding is not independently contrastive in these contexts. That is, without labial attraction, we would expect only [armɯd], not a contrast between [armɯd] and [armud], because the latter violates rounding harmony. So labial attraction will instead be analyzed as an enhancement of the word-level contrast between front and back vowels.

It is hard to develop a full analysis of labial attraction without also developing an analysis of contrast in vowel harmony languages, which we will not attempt here, but the following is suggested as an outline consistent with the present framework. The basic assumption we will make is that the neutralization of rounding contrasts beyond the first syllable is a precondition for rounding harmony, rather than being the result of rounding harmony—i.e. rounding assimilation doesn't force the neutralization of rounding contrasts, rather rounding assimilation occurs as a result of choosing the lowest effort realization for the neutralized contrasts between rounded and unrounded vowels.

Rounding harmony spreads rounding onto high vowels, while all other vowels remain unrounded. The tendency to assimilation can be analyzed as the result of a dispreference for changing lip position, so if one vowel is rounded, adjacent vowels (and intervening consonants) should be rounded also. Following Kirchner (1993) and Kaun (1995), we analyze the fact that rounding harmony does not target non-high vowels as a consequence of a higher-ranked dispreference for expending the effort to round the lips during a non-high vowel—i.e. rounding the lips involves bringing the lips close together which is facilitated if the jaw is high, but made more difficult if the jaw is low.

Thus the basic pattern of rounding harmony is analyzed as a result of effort minimization, but the other factor that can influence the realization of neutralized contrasts is maximizing distinctiveness of remaining contrasts—i.e. enhancing the F2 distinctions between vowels in the first syllable by maximizing differences between vowels in subsequent syllables. The result of labial attraction, [apu] is more distinct from contrasting front-harmonic [øpy] and [epi] than the harmonic alternative [apɯ] because the difference in the second vowel is larger—this is hypothesized to be the motivation for labial attraction.

The questions raised by this line of analysis are: (i) Why does this enhancement only apply after labials? (ii) Why does it only apply after [a]? (iii) Doesn't this enhancement actually make the contrast with [opu] less distinct? The first question concerns the basis of the relationship between plain labials and lip rounding in this process. We suggest that it is articulatory rather than auditory: enhancement by rounding occurs only after labials because articulatory similarities between a plain labial constriction and lip-rounding make lip-rounding less effort after a labial than after other consonants. That is, the change from close to approximated lips involved in producing a round vowel after a labial stop or fricative (e.g. [pu]) is less effort than moving from open to approximated in producing a round vowel after a non-labial (e.g. [tu]). Articulatory specifications for lip positions of relevant sounds are as in (40).

(40)

	p	u	ɯ	a
lips close	+	-	-	-
lips approximated	-	+	-	-
lips open	-	-	+	+

The analysis so far can then be formulated as follows. The ranking in (41) derives the basic pattern of rounding harmony: the lower ranked constraint promotes harmony by requiring that lip position should not change, but the extension of rounding onto non-high vowels is blocked by the higher-ranked constraint, *[-high, -lips open], which expresses the dispreference for constricting the lips (as in rounding) during a non-high vowel. Note that all of these constraints are ranked below MAXIMIZE CONTRASTS, so they will not cause neutralization—i.e. *[-high, -lips open] does not prevent [e-ø] contrasts in the first syllable of a word.

(41) *[-high, -lips open] >> *LIPS APPROXIMATED-LIPS OPEN

Two lower-ranked constraints must be added to this ranking to account for rounding after labials (42). The MINDIST constraint favors enhancement of vowel F2 contrasts in the first syllable by differences in F2 of vowels in subsequent syllables. The disjunction of minimum distances that determine vowel contrasts in initial syllables is symbolized by *d*—our concern is the preference for enhancement by differences in additional vowels. This constraint would be satisfied by an [y-u] difference in the second syllable, but not by an [y-ɯ] difference.

This preference is outranked by the two effort minimization constraints from (41), so a contrast like [øty]-[atɯ] will not be enhanced by rounding (*[atu]) because this would violate the higher-ranked constraint against changing lip position, *LIPS APPROX-LIPS OPEN. However, following a labial the lips are constricted anyway, so rounding may be produced by violating only low-ranked *LIPS CLOSE-LIPS APPROX. Consequently enhancement by rounding is preferred following a labial.

(42) *[-high, -lips open] >>
*LIPS APPROX-LIPS OPEN >>
MINDIST = *d* & V F2:3 >>
*LIPS CLOSE-LIPS APPROX

The fact that labial attraction applies only after [a], and the fact that it enhances front-back contrasts between [epi, øpy] and [apu] at the cost of the distinctiveness of the rounding contrast [opu-apu] are probably related. The requirements of back and round harmony imply that the only vowels that could precede back unrounded [ɯ] are other back unrounded vowels, i.e. [a] and [ɯ]. So it is only the absence of labial attraction in the context [ɯpɯ] (*[ɯpu]) that is in need of explanation. A possible basis for this pattern lies in the fact that the contrasts among the high vowels [i, y, ɯ, u] are quite different from those among the non-high vowels [e, ø, a, o]. The vowel [a] is low and central, not back (e.g. Zimmer and Orgun 1992), so it is quite distinct from mid, back, rounded [o], and probably closer acoustically to [ø]. Consequently the [a-ø] contrast is more in need of enhancement by second syllable differences than [a-o]. The high back unrounded vowel [ɯ], on the other hand, is close to its rounded counterpart [u], distinguished by relatively small differences in F2 and F3. So the [ɯ-y] contrast cannot be enhanced at the expense of the [ɯ-u] contrast, and the more distinct contrast [ɯpɯ-upu] is to be preferred.

A final interesting point concerning labial attraction is that it does not apply to front vowels in spite of the existence of front rounded vowels in Turkish. This is expected given the proposed analysis, because rounding front vowels would not enhance any contrasts, i.e. *[epy] is less distinct from both [øpy] and [apu] than [epi].

4.1.3. Rounding of Vowels Adjacent to Retroflexes

Wembawemba (Hercus 1986) is an aboriginal Australian language spoken in Victoria. It has the basic vowel inventory shown in (43).

(43)
i u
e o
a

The high front vowel /i/ is rounded preceding retroflexes (44a), but not elsewhere (44b). The evidence for this process is distributional: [i] does not appear before retroflex consonants, and [y] only appears in this position. It has not been possible to identify any alternations in Hercus (1986). The rounding effect is described as more pronounced where /i/ is preceded by a labial (Hercus 1986:17)

(44)	a.	t̪ʲyɳd̪ʲyɳ	‘poker’	myɽkuk	‘egg’
		tyɭənaiuk	‘new, fresh’	pyɽpin̪ʲ	‘waddy’
	b.	tir	‘tomahawk’	pili	‘stomach’
		mim	‘grandparents’	mitetʲa	‘to lick’

A similar rounding effect is observed in Wergaia, a closely related language with the same vowel inventory as Wembawemba (Hercus 1986):

(45)	gyɽəm	‘spear shield’	d̪ʲyɭuk	‘end’

These phenomena are highly problematic for articulatorily-based feature theories because no such theory relates rounding and retroflexion. Rounding is a lip gesture, whereas retroflexion is a coronal articulation, so articulatorily there is no connection between them. In auditory-acoustic terms, lip-rounding and retroflexion are both ways to achieve a low third formant frequency, so rounding vowels before retroflexes can be analyzed as a way of enhancing a contrast in F3. It is interesting to note here the parallel with Jakobson, Fant, and Halle's (1952) acoustically-defined feature [+flat] which is applied to round vowels and retroflexes, however [+flat] is also used to specify velarization and pharyngealization.

Specifically, we propose that high front vowels are rounded before retroflexes to realize a contrast based on F3 in a context where retroflexion is articulatorily problematic. The articulatory difficulty arises from an articulatory incompatibility between tongue tip retroflexion and a high front tongue body. A retroflex involves a constriction formed by the tongue tip against the hard palate, but the tongue body approximates to the palate when it is high and front, so it is not possible to form both constrictions simultaneously. So the tongue body must be retracted and lowered during a retroflex, consequently rapid tongue body movement is required where a high front vowel precedes a retroflex. More generally, it appears that any front tongue body position is problematic during a retroflex, even if non-high, and that a high tongue body position is problematic, unless it is also back (i.e. it is problematic for the front of the tongue to be high).

The effort involved in making rapid tongue body movements from front and high front vowels to a position compatible with retroflexion is dispreferred, and languages with retroflexes find a wide variety of way of avoiding it. In many Dravidian languages, including Irula (Zvelebil 1970) and Kodagu (Emeneau 1970), the consonant dominates, so front vowels are retracted preceding retroflexes. Languages such as Gugada (Platt 1972) lengthen the transition from vowel to retroflex, resulting in partial backing and lowering of the vowel transcribed by Platt as [ɪə]. English also generally shows retraction of high front vowels before [ɹ]. Alternatively, the consonant may accommodate to the tongue body position of the vowel, which makes full retroflexion impossible. This strategy appears to be adopted in Mantjiltjara where retroflexion is ‘very weak’ after [i] (Marsh 1969). Reduction in the degree of retroflexion following [i] can be observed in the palatographic study of Gujarati retroflexes presented in Dave (1977).

A further reflex of the incompatibility of retroflexion and a high/front tongue body can be observed in Acoma, where retroflexes palatalize to alveolar or palato-alveolar before front vowels (Miller 1965). That is, retroflexion is lost because it is inconsistent with the palatalizing effect of front vowels. A similar pattern is observed in Molinos Mixtec (Hunter and Pike 1969).

Returning to the case of Wembawemba, retroflex consonants are distinguished from their alveolar counterparts primarily by low F3 transitions into the consonant. This low F3 is usually realized by retroflexion, but after high front vowels it is realized by rounding instead to avoid lowering and retracting the vowel, which would endanger vowel contrasts. I.e. Wembawemba is like Mantjiltjara in resisting lowering of [i], but differs in that the F3 contrast is preserved through rounding.

The relevance of vowel height to the realization of a low F3 can be observed from the fact that in Wembawemba the mid front vowel, /e/, is not rounded before retroflex consonants. Hercus describes it as retracted to a more central quality, transcribed as [ɜ] (p.17). That is, low F3 can be realized following a mid-vowel without any effect on the height of the vowel, because the tongue body is already low enough to accommodate retroflexion, however some retraction does result.

(46)	pɜɳɜɽ	‘teal duck’	tʲɜʈama	‘to hinder’
	mɜʈmɜɽil	‘large black cormorant’	wɜɽpuk	‘tree trunk’

It is vowels preceding retroflexes that are affected because retroflex consonants are typically only truly retroflex at the beginning of the consonant closure. It appears that the tongue tip moves forward in the course of the retroflex, and the constriction is released from an essentially alveolar position (Anderson and Maddieson 1994, Spajić, Ladefoged, and Bhaskararao 1994). This articulatory fact is reflected in the fact that F3 is much lower at closure than at release (Dave 1977, Ladefoged and Maddieson 1996:28). It is not clear what motivates this movement, but it has been observed consistently across diverse languages, so we will assume that it is not feasible to realize a retroflex contrast via F3 at release.

The formalization of this analysis requires the effort constraints in (47) and (48). The constraints in (47) express the dispreference for producing retroflexes ([+anterior, -distributed] coronals) with a high central or front tongue body position. It is not possible to collapse these constraints together using standard tongue body features—the proper generalization is probably a requirement that the front of the tongue body (i.e. the area behind the blade) should be central and non-high, providing room for the tip to be curled up to contact the palate. This is compatible with a high back tongue position because only the back of the tongue is high, allowing the front to be non-high. The constraints in (48) penalize tongue body movements from high to non-high and from front to central between vowel and consonant closure.

(47) *[+high, -back, -anterior, -distributed]   * ${}^{\text{i}}$ɖ, * ${}^{\text{ɨ}}$ɖ
         *[+front, -anterior, -distributed]   * ${}^{\text{i}}$ɖ, * ${}^{\text{e}}$ɖ

(48) *HIGH-MID
         *FRONT-CENTRAL

To simplify the analysis, we will initially assume that retroflexion is lost following a high front vowel, so the contrast with alveolars is realized by rounding only. It is more likely that retroflexion is reduced in this context and this reduction is compensated by rounding. Certainly retroflexes are transcribed in these forms, and Hercus describes the front rounded vowel as being somewhat 'centralized', which suggests some accommodation to partial retroflexion. Deriving this state of affairs requires finer differentiation in articulatory representations and in effort constraints, a point which we will return to after illustrating the basic form of the analysis with the current simplified constraints.

A partial constraint ranking is shown in (50) which derives loss of retroflexion with concomitant rounding after a high front vowel. Transition qualities are represented with superscript vowels as usual, [${}^{\text{i}}$] for a high front tongue body, and [${}^{\text{ə}}$] for a mid central tongue body. Realizing an F3 transition contrast through retroflexion is not possible following a high front vowel because it requires either producing retroflexion with a high front tongue body, in violation of high-ranked *[+high, -back, -ant, -dist] (candidate a), or a rapid transition from high to mid, violating *HIGH-MID (candidate b). So, assuming the vowel is not lowered or backed (alternatives considered in the next tableau), retroflexion must be lost. This results in neutralization of contrasts with alveolars (50d), unless the F3 contrast is realized by lip rounding instead (50c). The latter candidate wins because it contains more contrasts. Rounding of the vowel in addition to the closure transitions is assumed to be motivated by a constraint against a rapid transition from unrounded to rounded, e.g. *LIPS PROTRUDED-LIPS RETRACTED.

(49)

	${}^{\text{ə}}$ʈ	${}^{\text{i}}$ʈ	${}^{\text{y}}$t	${}^{\text{i}}$t
F3:	2	2	2	5

(50)

		*[+hi, -bk, -ant, -dist]	*HIGH-MID	MINDIST = trans F3:3	MAX CON-TRASTS
a.	iⁱʈ-iⁱt	*!			✓✓
b.	iᵊʈ-iⁱt		*!		✓✓
c.	☞ yʸʈ-iⁱt				✓✓
d.	iⁱt				✓!

Tableau (52) shows that lowering the high front vowel is not viable as a way to satisfy *[+high, -back, -ant, -dist] because this would make the contrast between high and mid vowels insufficiently distinct. The vowel [ɨ] is assumed to be low enough to satisfy *[+high, -back, -ant, -dist], but higher than [ɜ], to illustrate that partial lowering of /i/ results in an insufficiently distinct height contrast (51b)—the relevant MINDIST constraint requires vowel F1 contrasts to be distinguished by F1:2. So the alternatives are neutralizing the height contrast, or rounding the high vowel, and the latter is preferred.

(51)

	y	ɨ	ɜ
F1:	1	2	3

(52)

		*[+hi, -bk, -ant, -dist]	*[+front, -ant, -dist]	MINDIST = trans F3:3 or V F1:2	MAX CON-TRASTS
a.	☞ yʸʈ-ɜᵊʈ				✓✓
b.	ɨᵊʈ-ɜᵊʈ			*!	✓✓
c.	ɜᵊʈ				✓!

The derivation of retraction in mid vowels is shown in (53). A front vowel is not possible before a retroflex because this results in either a front tongue body during the retroflex, in violation of *[+front, -ant, -dist] (53a), or a rapid transition from front to central in violation of *FRONT-CENTRAL (53b). However, with a mid vowel, *[+high, -back, -ant, -dist] is satisfied without modification of the vowel since it is not high. It is only *[+front, -ant, -dist] and *FRONT-CENTRAL that need to be satisfied. This is achieved by retracting the vowel (53c), avoiding neutralization of the retroflexion contrast (53d).

(53)

		*[+hi, -bk, -ant, -dist]	*[+front, -ant, -dist]	*FRONT-CENTRAL	MINDIST = trans F3:3	MAX CONTRASTS
a.	e^{e}ʈ-e^{e}t		*!			✓✓
b.	e^{ə}ʈ-e^{e}t			*!		✓✓
c.	☞ ɜ^{ə}ʈ-e^{e}t					✓✓
d.	e^{e}t					✓!

The full ranking so far is:

(54) *[+high, -back, -anterior, -distributed]
*[+front, -anterior, -distributed]
*FRONT-CENTRAL
*HIGH-MID
MINDIST = trans F3:3 or V F1:2
>>
MAXIMIZE CONTRASTS

We have not yet explained why mid vowels are not rounded, and more broadly, what opposes rounding of vowels before retroflexes in other languages. Rounding a front vowel will in general reduce its distinctiveness from back vowels, and therefore is undesirable. However, this explanation does not go through easily in the current formulation of the analysis. If [ɜ] is sufficiently retracted to have [F2 *3*] (55), then it would be less distinct from back [o] in F2 than a front rounded vowel [ø]. Two factors might still favor centralization over rounding: first, [ɜ-o] is more distinct in F3 than [ø-o] (55), and second, a dispreference for the effort involved in lip-rounding might out-rank the preference for any slight improvement in distinctiveness gained by the rounded realization.

(55) F2 dimension:

5	4	3	2	1
i	y	ɜ	ɯ	u
	ø			o

F3 dimension:

1	2	3	4	5
ɹ	o	ɯ	ɜ	i
	ø			

But in any case, it is unlikely that [ø] is really the most viable alternative to [ɜ] here. As noted above, it is inaccurate to assume that retroflexion is completely lost after the high front vowel. Presumably it is desirable to retain some degree of retroflexion in order to realize burst and release transition cues to retroflexion. This in turn requires some degree of retraction of front vowels, as described for [y] by Hercus (1986:17). This retraction would also provide additional cues to retroflexion from the difference in vowel F2. So the viable alternatives are probably [ø̠t̠], with a partially retracted front rounded vowel and a partially retroflexed consonant, and [ɜʈ] with a central vowel and a fully retroflexed consonant. These vowels would not differ much in F2 (presumably both would be [F2 *3*]), so the greater F3 distinctiveness and lower effort of [ɜʈ-oʈ] is decisive.

This fuller analysis requires us to distinguish full and partial retroflexion, a tongue body position between front and central, and distinct effort constraints pertaining to the tongue body requirements of full and partial retroflexes. To sketch such an analysis, we will use an articulatory dimension of anteriority: [+1ant] for anterior coronals, [-1ant] for full retroflexion, and [0ant] for partial retroflexion. We will also use a backness dimension: [-2back] for a front tongue body, [0back] for central, and [-1back] for an intermediate position (positive values would represent a back tongue body position).

The revised effort constraints pertaining to retroflexes are given in (56): Full retroflexion is easiest with a central tongue body ([0back] or further back), and there are increasing penalties for attempting to combine full retroflexion with a more fronted tongue body (56a). Partial retroflexion ([0ant]) is consistent with a retracted tongue body [-1back], but is also problematic with a front ([-2back]) vowel (56b). As in (47) above, full retroflexion is also incompatible with a high central tongue body ([0back]) (56c). Constraints against rapid tongue body movement, *Δ[back] and *Δ[high], penalize any change on the height or backness dimension between a vowel and following consonant closure. All of these constraints are ranked above MAXIMIZE CONTRASTS, and so are unviolated.

(56) a. *[-2back, -1anterior, -distributed] >>
*[-1back, -1anterior, -distributed]

b. *[-2back, 0anterior, -distributed]

c. *[+high, 0back, -1anterior, -distributed]

d. *Δ[back],
*Δ[high]

Relevant articulatory and auditory specifications are given in (57). A ‘retraction’ diacritic is used to mark partial retroflexion on consonants (e.g. [t̠]), and partial retraction ([-1back]) on vowels (although [ʏ] is used for the partially retracted counterpart of [y] to avoid placing a retraction diacritic under a ‘y’).

(57)

	ʈ	ʸʈ	t̠	ʸt̠	t	ʸt
ant	-1	-1	0	0	1	1
F3	2	1	4	2	5	2

	i,e	y,ø	i̠,e̠	ʏ,ø̠	ɜ
back	-2	-2	-1	-1	0
F2	5	4	4	3	3
F3	5	2	4	2	4

The effects of the effort constraints are illustrated in (58–59). These tables show all combinations of degrees of retroflexion (full, partial, alveolar) with front, retracted, and central vowels, for high and mid vowels respectively. Shading marks sequences which violate effort constraints, assuming the tongue body position of the vowel persists into the consonant closure, satisfying the movement constraints, *Δ[back], *Δ[high]. Since these effort constraints outrank MAXIMIZE CONTRASTS, these sequences are ruled out[10]. The crucial difference between high and mid vowels is that mid central vowels are compatible with full retroflexion, whereas high central vowels are not.

(58)

		-2back i, y	-1back i̠, ʏ	Øback ɨ, ʉ
-1ant	ʈ	iʈ	i̠ʈ	ɨʈ
Øant	t̠	it̠	i̠t̠	ɨt̠
+1ant	t	it	i̠t	ɨt

(59)

		-2back e, ø	-1back e̠, ø̠	Øback ɜ, ɵ
-1ant	ʈ	eʈ	e̠ʈ	ɜʈ
Øant	t̠	et̠	e̠t̠	ɜt̠
+1ant	t	et	e̠t	ɜt

Retroflexion contrasts must satisfy the effort constraint, and balance distinctiveness of the consonant contrast with distinctiveness of the vowel contrasts. This results in the following conflict: the retroflex should be fully retroflexed to make this consonant place contrast maximally distinct, but the more retroflexed the consonant is, the more retracted and lowered the vowel must be, and this endangers vowel F1 and F2 contrasts. Rounding can make the consonant contrast more distinct but also reduces the distinctiveness of vowel F2 contrasts. We have already seen that lowering high vowels is not possible without yielding inadequate F1 contrasts (52, above)—this part of the analysis remains essentially unchanged. So at most partial retroflexion is possible with high vowels, leaving the candidates shown in (60). This tableau shows the evaluation of these forms, assuming they must contrast with an apical alveolar consonant (in [it]) and a back rounded vowel (in [uʈ]). A sixth possibility, neutralizing the retroflexion contrast in this environment (i.e. selecting none of the candidates), is eliminated by MAXIMIZE CONTRASTS since it yields one contrast less than the winning candidate (c), which does not violate any higher-ranked constraint.

Only two of these candidates that satisfy the effort constraints also satisfy the top-ranked minimum distinctiveness requirements on both the vowel and consonant contrasts. To facilitate interpretation of the tableau, violations of the MINDIST constraint are marked according to whether the violating contrast involves the consonant contrast with apical alveolar [t] (C) or the vowel contrast with back [u] (V). A contrast between a partial retroflex and an apical alveolar (60 b, d) is insufficiently distinct (trans F3:1) unless enhanced by lip-rounding (c, e). A rounded central vowel, as in (e), is insufficiently distinct from the back rounded vowel (V F2:1).

(60)	uʈ- _ -it	MINDIST = trans F3:3 or V F2:2	MAX CON-TRASTS	MINDIST = trans F3:3 & F2:2
a.	yt		✓	*!
b.	i̲t̲	*!(C)	✓	*
c.	☞ ʏt̲		✓	
d.	ɨt̲	*!(C)	✓	*
e.	ʉt̲	*!(V)	✓	

That leaves two viable candidates, (a) with a front-rounded vowel and no retroflexion, and (c) with a retracted rounded vowel and partial retroflexion. Candidate (c) involves a more distinct consonant contrast since it combines rounding with partial retroflexion. This should yield a lower F3 than rounding alone (cf. Spajić, Ladefoged, and Bhaskararao 1994), although the difference might be small, and is not reflected in the specifications shown in (57). In addition, partial retroflexion could result in some differences from alveolars in burst quality and F3 at the release of stops, and persistence of F3 differences during trills/taps. Finally, retraction of the tongue body during the vowel and the retroflex results in a lower F2 during vowel and closure transitions, compared to the apical alveolar. Since this last difference is the most consistent, we have taken it as representative, and proposed that low-ranked MINDIST = trans F3:3 & F2:2 distinguishes the two candidates. Note that candidate (a) yields a more distinct vowel contrast—F2:3 vs. F2:2—so the constraint requiring more distinct vowel F2 contrasts, MINDIST = V F2:3, must be lower-ranked.

Following a mid vowel, full retroflexion is possible with a central vowel, so there are additional candidates for realization of a retroflexion contrast in this context, as shown in (61). The evaluation of candidates (a-e) is exactly as in (60), so the best of these candidates is [ø̲t̲], with partial retroflexion and a retracted rounded vowel. However candidate (f) also satisfies the basic distinctiveness requirements on both consonant and vowel contrasts, since the consonant is fully retroflexed, and the vowel is unrounded. The decision between these two candidates falls to lower-ranked MINDIST constraints. We assume that [ɜʈ] is preferred because this yields a more distinct vowel contrast, since unrounded [ɜ] differs from back rounded [o] in F3, whereas [ø̲] does not, although both have the same V F2 value.

(61)	oʈ- _ -et	MINDIST = trans F3:3 or V F2:2	MAX CONTRASTS	MINDIST = trans F3:3 & F2:2	MINDIST = V F2:2 & V F3:2
a.	øt			*!	
b.	e̲t̲	*!(C)	✓		
c.	ø̲t̲		✓		*!
d.	ɜt̲	*!(C)	✓		
e.	ɵt̲	*!(V)	✓	*	
f.	☞ ɜʈ		✓		
g.	ɵʈ	*!(V)	✓	*	

So the difference in behavior between high and mid front vowels is a consequence of the compatibility of mid vowels with full retroflexion of a following consonant. Full retroflexion is not possible after high front vowels, so the only way to realize a sufficiently distinct consonant contrast is through lip-rounding. After mid vowels, full retroflexion proves preferable to lip-rounding as a way to realize a distinct consonant contrast because it yields a more distinct vowel contrast.

Finally the constraints proposed here strictly only require that the closure transitions be rounded, since the retroflexion contrast can be adequately realized by a difference in F3 transitions (as noted above). Deriving rounding throughout the vowel requires the addition of effort constraints favoring a gradual onset of rounding. As suggested above, the simplest account is to assume a constraint against a rapid change from open, unprotruded lips to close, protruded lips, e.g. *Δ[lips open]&Δ[lips protruded]. This must be ranked above maintaining a slightly more distinct vowel contrast (e.g. MINDIST = V F2:2 & V F3:3). This analysis predicts partial rounding during the vowel, which isn't precisely what Hercus transcribes, but might be a reasonable interpretation of the statement that lip-rounding is more pronounced following a labial. This could be taken to indicate that a retroflex does not condition full rounding through a preceding vowel, but that producing full rounding at vowel offset and a lip constriction for a preceding labial does result in the acoustic effects of rounding throughout the vowel.

Wergaia differs from Wembawemba in that mid front vowels are rounded between a labial and a retroflex (62).

(62) møɽpi 'maybe' bøɳɜɽ 'teal duck'

There are two possible analyses of this pattern. The first possibility is that rounding of mid vowels is an enhancement of retroflexion, increasing the magnitude and duration of the F3 difference associated with the retroflexion contrast. As with Turkish labial attraction, this enhancement is restricted to the post-labial environment because it is less effort to produce lip-rounding following a labial constriction. The second possibility is that retroflexion is always enhanced by partial rounding of the retroflex transitions, and that this combines with extension of a preceding labial constriction to yield the impression of a fully rounded vowel.

Rounding conditioned by retroflexes seems less common than rounding by labials or fronting by coronals, but the phenomenon observed in Wembawemba and Wergaia is related to the more familiar enhancement of retroflexion by rounding as observed in English, where retroflex approximants are realized with lip rounding. In both cases the connection is that both articulations serve to lower F3. There is even a case in which the English retroflexion contrast has developed historically into a contrast based partly on rounding: In New Zealand English the mid vowels of words such as ‘bird’ and ‘nurse’, which correspond to syllabic [ɹ] in American English, are pronounced as a centralized rounded vowel, e.g. [nœ̠s] ‘nurse’ (Wells 1982:607). Another possible case comes from Brahmin dialects of Tamil in which word-final [m, n, j, ɭ] have been lost, with concomitant rounding of [a] to [o] where the deleted consonant is the retroflex lateral [ɭ] or labial [m] (Schiffman and Eastman 1975).

4.2. ASSIMILATION OF CONSONANTS TO VOWELS

4.2.1. Front Vowels Condition Coronalization

In many cases there is some degree of symmetry between assimilation of vowels to consonants and vice versa. We saw above that coronals can condition fronting in vowels, and in this section we will see that front vowels can condition coronality in consonants. Similarly, round vowels occasionally condition the appearance of plain labial consonants. But in each case we will also see that there are important asymmetries between the two directions of interaction which make it clear that the basis of these patterns is more complex than spreading a shared feature from consonant to vowel and vice versa. In the case of coronalization by front vowels, the crucial asymmetry is that this process almost always yields affricates or fricatives, whereas all manners of coronals can condition vowel fronting. We will argue that this generalization arises because most cases of coronalization arise by the following route: palatalization results in partial affrication due to articulatory factors and this affrication is then enhanced by making it sibilant, which is only possible with a coronal place of articulation. This proposal is developed in detail in this section.

4.2.1.1. Coronalization of Velars

Palatalization of velars by front vowels/glides can have a range of outputs, some of which are shown in (63). Palatalization of a velar to a palatal is expected articulatorily, since this essentially involves fronting the dorsal constriction to a palatal position, but where the output is a palato-alveolar or alveolar, the major articulator has changed from dorsal to coronal. This type of change is hard to explain in articulatory terms because front vowels are not generally articulated with the tongue blade.

(63)	k →	c	palatal	dorsal
		tʃ	palato-alveolar	coronal
		ts	alveolar / dental	

Examples of processes in which velars become palato-alveolars before front vowels are found in Slovak (64) and Acadian French (65).

(64) Slovak (Rubach 1993)

tʃlovek	'man'	tʃlovetʃ-iː	'human'
bok	'side'	botʃ-i-tʲ	'keep away'
strig-a	'witch'	stridʒ-iː	'witch-like'

(65) Acadian French (Hume 1992:161)

ki ~ tʃi	'who'	kyir ~ tʃyir	'leather; to cook'
kɛ ~ tʃɛ	'quay'	kœr ~ tʃœr	'heart'
gete ~ dʒete	'to watch for'	gœl ~ dʒœl	'mouth'

In Kirundi, velars can palatalize to dentals (66) (Broselow and Niyondagara 1990). The same change occurred historically in the development of French, and some Italian dialects.

(66)	-teeka	'cook (inf.)'	/-teek-i-e/	-teetse	'cook (perf.)'
	-oga	'swim (inf.)'	/-og-i-e/	-odze	'swim (perf.)'

Many of these coronalization processes involve complications such as morphological conditioning, limited productivity, or opacity due to independent processes involving vowels. The aim here is not to provide a detailed analysis of a single language, but to account for the cross-linguistic properties of velar coronalization.

In outline, the analysis proposed here is that palatalization involves exaggerating the difference in F2 at the release of consonants preceding front and back vowels in order to enhance the distinctiveness of those vowel contrasts. These differences arise naturally from articulatory assimilation between consonants and adjacent vowels, resulting in higher release F2 preceding vowels with higher F2.

The simplest way to increase F2 at the release of a consonant is usually to produce a secondary palatal constriction with the tongue body—i.e. palatalization. However the primary constriction of a velar is produced with the tongue body, so introducing a dorso-palatal constriction involves shifting the primary constriction of the consonant from velar to palatal[11]. Coronalization results from additional enhancement of the contrast between front and back vowels: palatal stops are invariably somewhat affricated, so a difference in affrication becomes part of the distinction between palatalized and plain stops. This difference can be enhanced by increasing the loudness of affrication by shifting to an otherwise acoustically similar sibilant affricate. Sibilants are all coronal, so assibilation implies coronalization.

The analysis of palatalization is discussed in the next section. We will then turn to palatalization and coronalization of velars.

4.2.1.2. The analysis of Palatalization

The prototypical palatalization process involves addition of a glide-like secondary palatal constriction to the release of consonants preceding front vowels. This may be allophonic, as in Nupe (Hyman 1970), or neutralizing, as in some environments in Russian. That is, in Nupe only palatalized consonants are found before front vowels, and only labio-velarized consonants are found before back vowels (back vowels are all rounded) (67), so there is no palatalization contrast in either context.

(67)	ēɟí	‘child’	*ēgi	*ēg^{w}i
	ēɟē	‘beer’	*ēge	*ēg^{w}e
	ēg^{w}u̿	‘mud’	*ēgu̿	*ēɟu̿
	ēg^{w}ó	‘grass’	*ēgó	*ēɟó

There is a contrast between plain, palatalized, and labio-velarized consonants before low central [a], so we could think of these contrasts as being neutralized in all other contexts, but the point remains that before non-low vowels palatalization and labio-velarization are part of the realization of front-back vowel contrasts, not independent contrasts. In Russian, on the other hand, palatalization can be contrastive before non-front vowels and where no vowel follows (68), so palatalization before front vowels neutralizes this contrast (69)[12].

(68)	tok	‘shock’	t^{j}ok	‘flowed’
	vol	‘ox’	v^{j}ol	‘led’
	luk	‘onion’	l^{j}uk	‘hatch’
	mat	‘curse words’	mat^{j}	‘mother’
(69)	ʒar-a	‘heat’	ʒar^{j}-it^{j}	‘to fry’
	sip	‘hiss’	sip^{j}-et^{j}	‘to speak in a hoarse voice’

The Nupe pattern of palatalization enhances vocalic F2 contrasts at the expense of cues to consonant contrasts since all palatalized consonants have similar high F2 transitions, whereas F2 transitions after plain consonants provide cues to place of articulation. It can be regarded as the exaggeration of the ubiquitous pattern of vowel-dependent variation in formant transitions discussed in §2.2.2.8 and §3.4. That is, F2 at the release of a consonant is generally higher preceding a vowel with higher F2, and lower preceding a vowel with a lower F2.

The ultimate basis of this pattern is minimization of effort—i.e. dispreference for the effort involved in rapid movements favors anticipating the articulatory position of a following vowel at the release of a preceding consonant, as far as possible. Anticipation of the articulatory position of the vowel effectively results in assimilation of the release F2 to the F2 of the vowel. However, these differences in formant transitions also provide cues to vowel identity, and so the vowel contrasts can be enhanced by exaggerating the differences which would be expected based on effort minimization alone. The usual pattern of formant transitions is probably a balance between effort minimization, distinctiveness of vowel contrasts, and distinctiveness of consonant contrasts—for example, it was suggested in §4.1.1.2 that in English, F2 transitions of coronals are kept high before back vowels to enhance the contrast with non-coronals although effort minimization would favor a lower F2 (i.e. more assimilation to the back tongue body position of the vowel). In Nupe, distinctiveness of vowel contrasts dominates, so these vowel-conditioned differences in F2 transitions are exaggerated well beyond what is motivated by effort minimization.

This analysis of the Nupe pattern of allophonic palatalization can be formalized in terms of the relative ranking of MINDIST constraints relevant to vowel and consonant contrasts (70). Palatalization and labio-velarization are required to satisfy 'MINDIST = V F2:3 & trans F2:4', which requires that vowel F2 contrasts also be differentiated by a large difference in F2 transitions. As discussed above, this enhancement conflicts with maximizing the distinctiveness of consonant contrasts because it pre-empts the use of formant transitions to realize consonant contrasts. In the case of stops, this leaves burst properties, such as differences in NF, as the main cues to place. So for palatalization to occur, this MINDIST constraint must be ranked above any MINDIST constraint which requires burst contrasts to be accompanied by differences in formant transitions such as 'MINDIST = burst NF:2 & trans F2:1'. The constraint in (70) is satisfied if burst NF contrasts are accompanied by any difference in either F2 or F3 transitions.

(70) MINDIST = V F2:3 & trans F2:4 >>
MINDIST = burst NF:2 & (trans F2:1 or trans F3:1)

The effect of this type of ranking is illustrated in (72), with specifications for the burst and release of relevant stops in given in (71). (72) shows the selection of realizations for a consonant place contrast between labials and coronals, and of a vowel F2 contrast. For clarity, the column for each MINDIST constraint has been divided into two sub-columns, one for the evaluation of vowel contrasts, and one for the evaluation of consonants, each headed by the relevant disjunct of the MINDIST constraint. Candidate (a) represents the usual coarticulatory variation in stop transitions according to vowel context. The vowel F2 contrasts are not differentiated by a sufficient distinction in F2 transitions, so this candidate is eliminated in favor of (b), in which vowel F2 contrasts are enhanced by a large difference in F2 transitions. The fact that this leads to less distinct stop place contrasts is unimportant, since the MINDIST constraint that these violate is lower ranked.

(71)

	p^e	p^j	p^o	p^w	t^I	t^j	t^Y	t^w
trans F2	4	5	1	1	4	5	3	1
trans F3	3	5	1	1	5	5	1	1
burst NF	2	2	2	2	6	6	5	5

(72)

	MINDIST = V F2:3 & trans F2:4 (V)	or burst NF:2 (C)	MINDIST = V F2:4 & trans F2:4 (V)	or burst NF:2 & (trans F2:1 or trans F3:1) (C)	MAX CONTRASTS
a. p^ee-p^oo t^Ie-t^Yo	*!*		**		✓✓✓✓
b. ☞ p^je-p^wo t^je-t^wo				**	✓✓✓✓

In languages like Russian, palatalization is contrastive, so palatalization by front vowels is neutralizing. Presumably neutralization occurs because plain consonants before front vowels are generally produced with a front tongue body position, as discussed above, so the contrast between plain and palatalized consonants is insufficiently distinct. However, enhancement of vowel contrasts must still be invoked to explain why the result of neutralization is a palatalized consonant rather than a plain one. I.e. the potential contrast between [p^je] and [pe] is neutralized to [p^je] rather than [pe] because this yields a more distinct contrast with [po].

4.2.1.3. Palatalization of Velars

In the case of velars the basic result of palatalization is a palatal stop. That is, the usual strategy for producing a high F2 at consonant release is to add a dorso-palatal constriction at release, but velars are dorsal consonants, so this implies shifting the primary constriction of the consonant from velar to palatal. This is the result of palatalizing velars in Nupe (67, above), Kinyarwanda (Kimenyi 1979:40f.), Margi (Hoffman 1963), and Romanian (Mallinson 1986), for example. A palatal is the expected result of palatalizing a velar whether palatalization is regarded as primarily an articulatory assimilation or an auditory enhancement. The cases that more clearly differentiate the two accounts are those exemplified above in which velars alternate with palato-alveolars or other coronals, which is unexpected from an articulatory point of view

One striking fact about coronalization of velars is that it almost always results in an affricate or fricative, usually a sibilant. The exceptions will be discussed briefly below.

(73) Attested results of historical palatalization of velar stops to coronals[13]

tʃ, dʒ	e.g.	Slavic, Italian dialects, Akan, Kinyarwanda dialects etc
ts, dz		Slavic, Italian dialects
ʃ, ʒ		Slavic, Italian dialects
s, z		Slavic, Italian dialects, French, Kirundi
θ, ð		Italian dialects, Spanish dialects

These sounds are probably not all the direct results of palatalization, there may be additional processes such as lenition involved in their derivation. The fact remains that all the outputs of coronalization are fricated.

To account for the connection between coronalization and frication, we will develop an analysis of the coronalization of velars as a by-product of enhancing contrasts in vowel F2 with a secondary difference in loudness of frication. That is, in the case of simple palatalization, the contrast between /ki/ and /ku/ is realized as the greater difference between [ci] and [ku], where the vowel contrast is enhanced by a difference in formant transitions, which essentially extends the duration of the difference in F2. But palatal stops also differ from velars in being somewhat affricated. Ladefoged (1993:162) states of palatal stops that 'because of the shape of the roof of the mouth, the contact between the front of the tongue and the hard palate often extends over a fairly large area. As a result, the formation and release of a palatal stop is often not as rapid as in the case of other stops, and they tend to become affricates'. Palatalizing the velar to a palato-alveolar, realizing the contrast as [tʃi]-[ku], further enhances the contrast by increasing this difference in duration and amplitude of frication, while still producing a large difference in F2 transitions. It happens that loud, sibilant affrication can only be produced with a coronal constriction, so coronalization is a side-effect of assibilation.

Coronalization is then a case in which a contrast is realized on more than one auditorily unrelated dimension (cf. §3.4), i.e. F2 transitions and burst Noise Loudness. As is usual in such cases, the differences associated with the contrast are articulatorily related: the affrication is a by-product of palatalizing a velar, but this connection is rather indirect after coronalization. We will first analyze coronalization of velars to palato-alveolars, which is probably the most common pattern. The analysis of coronalization to alveolars and dentals will be discussed later.

Coronalization involves an additional enhancement of vowel F2 contrasts, so it is motivated by a MINDIST constraint of the kind shown in (74), which requires vowel F2 contrasts to be accompanied by both a difference in F2 transitions, and in loudness of burst frication (NL).

(74) MINDIST = V F2:3 & trans F2:3 & burst NL:2

(75)

	k^u	c	tʃ	p^u	p^j
Release:					
F2	1	5	5	1	5
Burst:					
NL	2	3	5	1	1
NF	1	4	4	2	2
diffuse	-	-	-	+	+

It is clear from the feature specifications in (75) that [tʃi-ku] is a more distinct contrast than [ci-ku] due to the greater difference in NL (3 vs. 1), and thus is preferred by MINDIST constraints (both have similar F2 transitions). However we must answer two basic questions about such an enhancement: (i) What constraint opposes enhancement by assibilation, i.e. how is simple palatalization of velars derived? (ii) Why should assibilation apply to velars rather than other places of articulation?

Assibilation will generally be opposed by MINDIST constraints pertaining to consonant contrasts because this enhancement of vowel contrasts results in less distinct contrasts between the assibilated consonant and other sibilant affricates and fricatives. Contrasts with other affricates would be most problematic, but contrasts with sibilant fricatives are more widespread. I.e. [tʃ-s] is a less distinct contrast than [c-s]. We will not formulate specific MINDIST constraints here because it is not clear how best to characterize the dimensions that differentiate fricatives and affricates. Several dimensions have been shown to be perceptually relevant. Howell and Rosen (1983) show that the rate of increase of amplitude of frication, or 'rise-time' (Gerstman 1957), is used to distinguish fricatives and affricates, with affricates having shorter rise times. Repp, Liberman, Eccardt, and Pesetsky (1978) demonstrate the relevance of duration of silence (for the stop closure) and duration of frication noise.

As for the second question, the main issue here is why velars are assibilated (and hence coronalized) in preference to labials, since coronals frequently are wholly or partially affricated as a result of palatalization, and the results are sibilant, naturally enough; e.g. Japanese ti → tʃi (Vance 1987), Polish t → tɕ, and Russian, where palatalized [t^j] is partially affricated (Keating 1993). Assibilation of velars is preferred over assibilation of labials because this results in more distinct place contrasts between the palatalized consonants. That is, palatalization of a velar would otherwise result in a palatal stop, which is auditorily similar to a palato-alveolar affricate both in burst Noise Frequency and Noise Loudness (75). So if the labial were assibilated, the result would be a relatively indistinct contrast between a palato-alveolar affricate and a palatal stop [tʃi-ci]. On the other hand, a palatalized labial is quite distinct from a palato-alveolar affricate in both burst quality (Noise Frequency and Diffuse) and burst Noise Loudness (75), so if the velar is assibilated, we derive a much more distinct contrast between a palato-alveolar affricate and an unaffricated palatalized labial [p^ji-tʃi][14].

This is entirely parallel to the analysis of enhancement of alveolar vs. palato-alveolar contrasts by affrication of the latter: In both cases it is easier to enhance a contrast by exaggerating a difference that would be present anyway as an articulatory side-effect, rather than attempting to reverse the articulatorily motivated pattern. The analysis is formalized in (76), which shows the selection of realizations for velar and labial stops before front and back vowels. Both stop place and vowel F2 contrasts are evaluated. The top-ranked MINDIST constraint requires that vowel F2 contrasts be enhanced by palatalization. The bottom-ranked MINDIST constraint requires further enhancement by a difference in burst Noise Loudness—i.e. it requires assibilation. Candidate (a) violates this constraint since the consonants before front vowels are only palatalized. Candidate (d) fully satisfies this constraint, in effect assibilating both labial and velar stops, resulting in neutralization of this place distinction before front vowels. Enhancement by assibilation is ranked below MAXIMIZE CONTRASTS, so (d) is rejected by this constraint. So given this ranking, it is optimal to assibilate either the labial or the velar, but not both (candidates b and c). Assibilation of the velar (candidate b) wins because it results in a more distinct consonant place contrast.

(76)

			MINDIST = (V F2:4 & trans F2:4) (V)	or burst NF:2 (C)	MAX CONTRASTS	MINDIST = V F2:4 & trans F2:4 & burst NL:2 (V)
a.		ci-ku p^ji-pu			✓✓✓✓	**!
b.	☞	tʃi-ku p^ji-pu			✓✓✓✓	*
c.		ci-ku tʃi-pu		*!	✓✓✓✓	*
d.		tʃi-ku pu			✓✓✓!	

Note that the fact that coronals commonly affricate when palatalized fits into the general analysis developed here. Assibilation of velars is essentially exaggeration of affrication, which is an articulatory by-product of palatalizing a velar. Labials are not usually assibilated because palatalizing a labial doesn't automatically yield significant affrication. Affrication of palatalized coronals follows from articulatory factors that make some degree of affrication a common side-effect of adding a palatal constriction to a coronal. As noted in §4.1.1.3, the curvature of the front of the tongue that is required to form a dorso-palatal constriction plausibly makes it easier to form a coronal with a broad, laminal contact rather than an apical contact (Keating 1991, 1993). As discussed in connection with palato-alveolars (§3.2), a broad closure of this kind leads to a slower release, and a tendency to affrication. This situation differs from the palatalization of velars because it is possible to produce a palatalized apical with additional effort, whereas it is impossible to produce a palatal stop without a broad contact between tongue and palate. However, effort minimization makes affrication of palatalized coronals common.

We have proposed here that coronalization is essentially a side-effect of enhancing a difference in frication. Other accounts have analyzed affrication as a side-effect of coronalization (e.g. Lahiri and Blumstein 1984, Gorecka 1989). These analyses essentially propose that dorso-palatal obstruents are marked, and that the unmarked active articulator for a palatal sound is coronal. Translated into constraints, we could propose a constraint against palatal obstruents.

According to this analysis the fact that affrication accompanies coronalization is due to the fact that it is difficult to produce a palato-alveolar stop. This claim is problematic on three counts. Firstly it does not explain why the result of coronalization is always a fricative or affricate, even when alveolar or dental, since stops are much more common than affricates at these places of articulation. Secondly, while Lahiri and Blumstein (1984) argue reasonably that palato-alveolar stops are always affricated, there is variation in the degree of affrication. The sound in Eastern Arrernte that Ladefoged and Maddieson (1996) describe as a palato-alveolar stop is somewhat affricated, but the degree of affrication is substantially less than that found in the palato-alveolar affricate of English, for example. If affrication were simply a side-effect of coronalization, we might expect affrication to be minimized in at least some cases, but this does not seem to be so. Finally, palatal nasals are not replaced by palato-alveolars, in fact they are the usual result of palatalization of nasals in Romance (Calabrese 1993). This is consistent with the view that coronalization is a side-effect of assibilation—palatal nasals are not affricated, so there is no frication to enhance. If coronalization were motivated by a desire to avoid forming a dorso-palatal closure, then it should apply equally to stops and nasals.

4.2.1.4. Coronal Outputs other than Palato-alveolar Affricates

So far we have only considered coronalization resulting in a palato-alveolar affricate, but alveolars and dentals are also possible outputs, as are fricatives. Alveolar and dental sibilants clearly provide the enhancing difference in noise intensity in the same way as a palato-alveolar, and have high F2 at release. So to this extent, they are expected as possible outcomes of palatalization. However, it is unclear what constraint might favor the alveolar/dental outputs over a palato-alveolar. Unpalatalized alveolars and dentals have only [F2 *4*] at release, as opposed to the [F2 5] release of a palato-alveolar. Thus to explain the occurrence of these outputs we must identify some counter-balancing factor which favors them. The nature of this factor will be left open here.

Coronalization of stops also often yields fricatives rather than affricates, as in Russian and Polish where [g] coronalizes to [ʒ]. It is commonly hypothesized that such cases involve lenition in addition to palatalization. In other words, the output of coronalizing a stop is always an affricate, other things being equal, but additional constraints may require spirantization of the output. In the case of Polish there is direct evidence for such a lenition process: the voiced velar coronalizes to a fricative only when preceded by a sonorant (77a); after an obstruent, the result is an affricate (77b) (Rubach 1984). This pattern is naturally accounted for in terms of coronalization combined with a process of inter-sonorant lenition.

(77)	a.	rog	‘horn’	roʒ-ek	‘horn (dim.)’
		ɕnjeg	‘snow’	ɕnjeʒ-ek	‘snow (dim.)’
	b.	drobjazg	‘detail’	drobjaʒdʒ-ek	‘detail (dim.)’

In addition, if only one velar coronalizes to a fricative, it is the voiced velar, as in Polish and Russian where k → tʃ and g → dʒ/ʒ. This accords with the observation that voiced plosives are more prone to lenition than voiceless ones (Foley 1977:101f.). Similarly, we will assume that non-sibilant fricatives [θ, ð] found as the ultimate results of palatalization of velars in some Italian and Spanish dialects are secondary developments from an earlier sibilant.

Finally, a central piece of evidence for the analysis of coronalization as a side-effect of assibilation is the observation that when velars are palatalized to coronals, the result is almost always a sibilant affricate or fricative. However there are one or two cases in which front vowels have conditioned the appearance of plain coronal stops. For example, in the Chaga dialect of Gweno /k/ is realized as [t̺] before ‘super-high’ [i̝] (Hinnebusch and Nurse 1981:57). Another possible case is the historical change of *k to [t] before [i] in Hottentot (Sagey 1986:267). These atypical developments might result from constraints motivating palatalization, in concert with constraints against complex consonants (such as those with secondary articulations), which force neutralization with simple consonants (cf. §5.5).

4.2.1.5. Coronalization of Labials

Coronalization of labials by front vowels is much less common than coronalization of velars, because palatalization of labials does not generally give rise to significant affrication (§4.2.1.3). There are cases of labial coronalization, but only where velars coronalize also. We will analyze these cases as fortition of palatal glides preceded by stops of any place of articulation.

This analysis is suggested by sound changes in the development of French from Latin which have been misinterpreted as exemplifying the development of labials into palato-alveolars by palatalization (e.g. Ohala 1978a). This interpretation is based on words such as those in (78a) in which Latin [b] or [v] followed by a front vowel corresponds to a palato-alveolar fricative in modern French. However, it can be seen from the forms in (78b) that the palatal glide (orthographic *j* in Latin) independently strengthened to a palato-alveolar fricative, via a palato-alveolar affricate in vulgar Latin (79a). In the forms in (78a), the pre-vocalic front vowels became glides which also underwent fortition. The preceding labial was deleted in another regular development (79b) (Brunot and Bruneau 1937:76f.). Thus the apparent coronalization of labials in fact involves fortition of a high front vowel to a coronal fricative.

(78)	Latin >	French	
a.	rabia	ra[ʒ]e	'madness, rage'
	rubeus	rou[ʒ]e	'red'
	tibia	ti[ʒ]e	'stem'
	serviente	ser[ʒ]ent	'sergeant'
b.	jumentu(m)	[ʒ]ument	'mare'
	jocus	[ʒ]eu	'game'
	Junius	[ʒ]uin	'June'

(79) a. j > dʒ > ʒ
b. biV > bjV > bdʒV > dʒV > ʒV

Actual coronalization of labials is attested in Bantu, conditioned by reflexes of the 'super-high' front vowel. For example, in ChiMwi:ni (Kisseberth and Abasheik 1975), labials and velars 'palatalize' to coronals before the perfect suffix /-iɫe/ (80) (vowel harmony results in the vowel height alternations in this suffix). Coronals are fricated in the same environment. The fact that all stops are fricated suggests an analysis according to which this frication developed from the interaction of stops with a following super-high vowel. I.e. much as in the French sound change, coronalization here is essentially fortition of a high vowel to a coronal fricative. The difference is that in ChiMwi:ni this fortition occurs only following stops. This is plausibly a result of the aerodynamic conditions at the release of a stop into super-high vowel [i̭]. This vowel is supposed to have had a very narrow stricture (Hyman 1976), and so might have been prone to frication under conditions of rapid airflow, as at the release of a stop. This palatal frication could have been exaggerated by making it sibilant (and thus more intense) to enhance the contrast with high vowels, whose reflexes do not condition frication. Indeed, the contrast between high and super-high vowels has been lost, leaving frication as the only realization of this erstwhile contrast after stops[15]. In ChiMwi:ni, as in French, the stop closure preceding the frication is lost.

(80)	ku-ɬap-a	'to swear an oath'	ɬas-iɬ-e	'he swore an oath'
	ku-ɬip-a	'to pay'	ɬis-iɬ-e	'he paid'
	x-pik-a	'to cook'	piʃ-iɬ-e	'he cooked'
	x-t̪ek-a	'to hold'	t̪eʃ-eɬ-e	'he held'
	x-pit-a	'to pass'	pis-iɬ-e	'he passed'
	ku-ɬoːt-a	'to dream'	ɬoːs-eɬ-e	'he dreamed'

According to this analysis, coronalization of labials here was also a side-effect of assibilation. But in this case, assibilation enhanced a vowel height contrast by exaggerating frication following a stop release, whereas in the cases of palatalization, the frication is a side-effect of forming a dorso-palatal constriction in combination with a dorsal (or coronal) primary constriction. The former process is independent of the place of articulation of the stop, so we predict the asymmetry alluded to above, whereby velars can coronalize without labials doing so, but labials cannot coronalize without velars doing the same (cf. Foley 1977:94).

Thus ChiMwi:ni coronalization can be analyzed as originally motivated by a MINDIST constraint requiring that F1 contrasts be accompanied by a difference in Noise Loudness, e.g. MINDIST = F1:1 & NL:4. The analysis of current ChiMwi:ni must involve many other factors—it is apparent that the effects of the reflexes of the super-high vowels have become heavily morphologized, e.g. they apply only with certain prefixes, and the development of vowel harmony means that the relevant vowels are not necessarily even high. Analyzing these aspects of the coronalization process is beyond the scope of this dissertation.

4.2.2. Round Vowels Condition Labiality

Just as plain labials condition rounding in vowels (§4.1.2), round vowels can condition the appearance of plain labials, although the latter process is not common. Historical developments in which labialized consonants become plain labials are well attested (see §5.5), but synchronic processes conditioned by round vowels are rare. The primary cases are found in Bantu languages, conditioned by reflexes of the 'super-high' rounded vowel [u̟]. Examples from Luganda are shown in (81) (Hyman 1976).

(81)	-afik-a	'be cracked'	-afif-u	'cracked'
	-ewuk-a	'be light'	-ewuf-u	'light weighted'

Ponelis (1974) argues, on the basis of an examination of such processes in a wide range of languages, that historically they involve labialization which then undergoes 'fricativization', often followed by elision of the stop, as in Luganda, or assimilation of the stop to the fricative (82). Many of these intermediate stages are attested synchronically, as in Swazi, where aspirated alveolars develop labial frication before [u] (83) (Ponelis 1974:51).

(82) *ku̝ > kwu > kʍ̝u > kfu > pfu > fu
*tu̝ > twu > tʍ̝u > tfu > tfu > fu
*du̝ > dwu > dw̝u > dvu > bvu > vu

(83) $t^h \rightarrow$ tf / _ [+round]

-itfu	'ours'
butfongo	'sleepiness'
-tfwala	'carry'

This analysis makes the process of labialization parallel to that sketched above for coronalization conditioned by the super-high front vowel. According to this analysis, the stop does not directly become labial, rather it contributes to the fricativization of the narrow labial constriction as a result of the high rate of airflow at its release (It is not clear that this requires the intermediate stage of labialization assumed by Ponelis, and shown in (82)). Labialization of the stop phase then involves the familiar pattern of place assimilation in clusters (e.g. Jun 1995), or cluster simplification through deletion of the stop. As with coronalization by super high vowels, the change to a labial fricative generally applied to stops at all places of articulation, including labials.

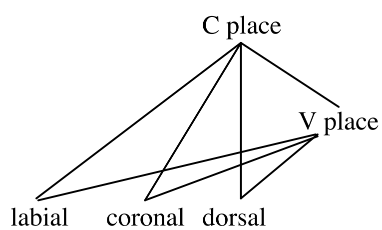
The point at which rounding conditions the appearance of a plain labial is when the fricated labialization ([w̝]) gets reinterpreted as a plain labial fricative (usually a labio-dental [f] or [v]). This development involves auditory similarity. Frication produced by a rounded labial constriction is very similar to that produced by a bilabial or labio-dental constriction, since in all these cases there is effectively no resonating cavity in front of the constriction. The resulting fricative spectrum is low in intensity and diffuse. The shift from rounded fricative to labio-dental fricative could be an enhancement of the super-high vs. high vowel contrast: more intense turbulence noise can be generated by directing a jet of air against an obstacle. In labio-dentals the upper lip provides such an obstacle for the jet of air formed by the constriction between lower lip and teeth. There is no such obstacle in bilabial or rounded fricatives, so they are less intense (Stevens, Keyser, and Kawasaki 1986:440) (we have not made this relatively subtle distinction in the Noise Loudness scale (§2.2.2.4), so further refinement of that scale would be required to formalize this analysis).

4.3. UNIFIED FEATURE THEORY

We have argued here that interactions between coronal consonants and front vowels, labial consonants and round vowels, and retroflex consonants and round vowels provide evidence for auditory representations, and greater detail in articulatory representations. Clements (1991) and Hume (1992) have proposed alternative analyses of some of these interactions, namely those between coronals and front vowels and between labials and round vowels. Their proposals involve substantial modifications of the Sagey-style feature theory, but do not include independent articulatory and auditory features. Their model is intended to account for all interactions between coronals and front vowels, and between labials and round vowels, but much of the evidence considered in Clements (1991) and Hume (1992) involves consonant-vowel interactions of the kind discussed above.

As we pointed out above, phenomena like vowel-fronting conditioned by coronals are problematic for an articulatorily-based feature theory such as Sagey's because these sounds have no feature in common: coronals are [coronal] and front vowels are [-back] dorsals. The Unified Feature Theory (UFT) accounts for the interactions between coronals and front vowels and between labials and round vowels by specifying both as [coronal] and [labial] respectively. The theory also specifies both back vowels and velar consonants as [dorsal], thus predicting interactions between these sounds. As can be seen from the outline of the proposed geometry in (84), Clements and Hume are not simply eliminating [-back] and [round] from Sagey's geometry and subsuming their functions under [coronal] and [labial] respectively, they have also introduced a distinction between 'Consonant place' and 'Vowel place'. This allows consonantal and vocalic place features to be related while preserving a means to distinguish them.

(84)



Clements (1976) adopted the more direct approach to this problem, proposing that front vowels are simply [coronal] rather than [-back], in other words identifying the standard [-back] feature with a revised [+coronal]. Fronting of vowels adjacent to coronals, and coronalization of consonants adjacent to front vowels can then be formulated as an assimilation processes, involving the spread of the feature [coronal]. However, a straightforward identification of traditional [-back] and [coronal] in this way leads to immediate problems. Firstly, coronals are never active in front/back harmony, whereas palatalized consonants are. E.g. in Turkish front/back vowel harmony, palatalized consonants trigger fronting harmony, whereas plain coronals do not (Kenstowicz and Kisseberth 1977:387). If [-back] is replaced by coronal, palatals and coronals should both be specified [coronal], and should pattern together in the harmony process, but they do not. Similarly, front vowels are never active in coronal harmony. For example, in Sanskrit n-retroflexion, /n/

becomes retroflex [ɳ] when preceded by the retroflex continuants [r, ʂ] (Whitney 1889, Schein and Steriade 1986). Retroflexion is blocked by an intervening coronal consonant but is unaffected by an intervening front vowel. Thus front vowels fail to pattern with coronal consonants, contrary to what we would expect if they were both specified as [coronal].

The Hume-Clements model is designed to resolve these problems through a partial segregation of vowel and consonant features. The vowel place features are separated from their consonantal counterparts, and placed under a 'Vowel place' node, subordinated to the Consonant place node (84). The vocalic [coronal] can then spread across an instance of consonantal [coronal] and vice versa[16].

Thus the identification between vowel and consonant place features is made by associating the same feature to different structural positions. So front vowels are specified with [coronal] under the Vplace node and coronal consonants are specified with [coronal] under the CPlace node. The three main identifications between traditional consonant and vowel features made in this way are summarized in (85)[17].

(85)	C-labial = 'labial'	V-labial = 'round'
	C-coronal = 'coronal'	V-coronal = 'front'
	C-dorsal = 'dorsal'	V-dorsal = 'back'

An immediate point of difference between the UFT and the account of consonant-vowel interactions developed here is the prediction made by the UFT that velars should condition backing, and vice versa. This follows from specifying back vowels and velar consonants as [dorsal]. We have not discussed any interactions of this type and would not expect them: back vowels are produced with a retracted tongue body, but the precise place of articulation of a velar typically varies depending on its vocalic context. This is reflected in the usual articulatory analysis of velars according to which they involve a dorsal constriction, unspecified for backness, and in which vowels are all dorsal, with back vowels being differentiated from front vowels by the feature [back] (e.g. Sagey 1986). Only dorsal consonants with specifications for [back] such as palatals, and uvulars, would be expected to have an effect on the backness of vowels.

In fact, support for a connection between dorsal and back is weak. Firstly, as Clements (1976) observes, back vowels do not condition velarity in consonants (86).

(86) pɯ –×→ kɯ
tɯ –×→ kɯ

There are also no clear cases in which plain velars condition backing of vowels. We do find cases of backing conditioned by uvulars, as in Palestinian Arabic, but velars do not condition this process (Herzallah 1990). This is exactly the situation we would expect on the basis of the Sagey model in which uvulars are [+back] but velars are not.

Clements (1991) offers only the case of Maxakali vowel insertion (Gudschinsky, Popovich, and Popovich 1970) as evidence for a backing effect of plain velars. In Maxakali a vowel can be inserted between a vowel and a coda consonant. The quality of the inserted vowel depends on the identity of the coda consonant as summarized in (87):

(87)	Coda	Inserted V
	velar	high back unrounded
	palato-alveolar	high front unrounded
	labial	mid back unrounded
	alveolar	central unrounded, variable height

Clements proposes that a back vowel is inserted before velars because both are back. However, this analysis implies that the quality of the vowel is determined by spreading the place features of the coda consonant onto the vowel, in which case Clements' model incorrectly predicts rounded vowels before labials, and front vowels before alveolars.

The !Xoo Bushman 'back vowel constraint' (Traill 1985:90) has also been suggested as a possible case by Jaye Padgett (p.c.). In !Xoo velars, uvulars and clicks, all of which involve dorsal articulations, are followed only by the non-front vowels [u, o, a]. I.e. they do not appear before [i, e]. This might be analyzed as a backing effect of the dorsal consonants, but the evidence suggests that it is more likely to be related to a coronalizing effect of front vowels. The constraint is violated by a verb particle /kV/ in which /V/ is a copy of the following stem vowel. This particle can surface as [ki] where the stem contains [i], thus violating the back vowel constraint. This violation is often regularized, but by coronalizing [ki] to [ti], not by retracting the vowel (Traill 1985).

Not only is there a lack of cases demonstrating interactions between plain velars and back vowels, but there are cases in which velars pattern with front vowels or glides (Davis 1994). For example, in Swiss-Romansh palatal glides harden to velar stops in pre-consonantal position (Kamprath 1987) (88).

(88)	krej-r	→	krekr̥	'to believe'	cf.	krej-a	'believes'
	rej-r	→	rekr̥	'to laugh'		rej-a	'laughs'

There is also evidence that back vowels can condition retroflexion of coronals, as discussed in §4.1.3 above (see also Gnanadesikan 1994). The cases mentioned there include Ponapean (Rehg 1973), where the velarized counterpart of a dental stop is a retroflex affricate, and Walmatjari (Hudson and Richards 1969) where word-initial apicals are retroflexed after back vowels (the contrast between alveolar and retroflex apicals is neutralized word-initially). In terms of the UFT, this would imply that [+back] should be identified with the feature(s) for retroflexion rather than [dorsal].

Abandoning the identification of [back] and [dorsal] would make the UFT less symmetrical, but it would not be inconsistent with retaining the analysis of coronal/front vowel and labial/round vowel interactions. Turning to these cases, we see a more fundamental difference between the UFT and the approach to consonant-vowel interactions developed here. The UFT establishes a direct and invariant relationship between front vowels and coronals and between round vowels and labials, whereas we have proposed indirect relationships between these articulators, in some cases mediated by violable constraints. This difference can be illustrated by comparing analyses of the fronting effects of coronals. In the UFT, front vowels and coronals share the feature [coronal] so all coronals inherently bear a feature that allows them to condition vowel fronting. Here we have argued that the fronting effect of coronals is fundamentally based on the physical linkage between tongue tip and tongue body. As a result of this linkage, it is easier to place the tongue tip in the front of the mouth if the tongue body is also fronted. Where this preference is observed, there is then a very direct relationship between coronals and front vowels: they are both produced with a front tongue body. However, this preference only applies to certain coronals (e.g. it doesn't apply to retroflexes), and it can be violated at the cost of greater effort (as in the case of velarized coronals). It is also unidirectional: anterior coronals are associated with a preference for a front tongue body, but front vowels are not associated with any preference for coronal constriction, so a distinct mechanism is required to account for the coronalizing effect of front vowels.

The most basic evidence in favor of this indirect, violable linkage between coronal and front is that not all coronals can condition fronting—velarized coronals and retroflexes do not condition vowel fronting. This follows from the analysis proposed here because only sounds produced with a front tongue body are predicted to condition fronting, and these types of coronals are not fronted. Velarized coronals violate the preference for a front tongue body in order to maintain an additional contrast, and retroflexion is most easily produced with a retracted tongue body (§4.1.3).

Identifying [coronal] with [-back] only addresses the possibility of the observed structural change, i.e. that coronals can condition fronting and vice versa. It makes no predictions about conditions on the target of the change, or any concomitant changes in manner features. So in the UFT, the simplest rule spreading [coronal] from vowels to consonants describes coronalization of consonants without any change in manner, a change which is actually very rare—coronalization is usually accompanied by affrication or frication (§4.2.1). In the analyses proposed here this generalization follows from the fact that coronalization is not an articulatory assimilation—i.e. the consonant is not assimilating to the place of articulation of the vowel. Articulatory assimilation to front vowels yields consonants with a front tongue body, either as a secondary constriction in non-dorsals, or as a shift in the place of articulation of a dorsal.

Coronalization arises through secondary enhancement of palatal frication that results from palatalization of a velar, or high air-flow through a very high front vowel. So frication is a crucial step on the route from palatalization to coronalization. Similarly, round vowels do not seem to cause consonants to become labial without some accompanying change in manner (frication or affrication), although there are relatively few examples to generalize from. In the analysis outlined above (§4.2.2), plain labials develop from rounding via labial frication, so again frication is integral to the process, not an independent effect.

Finally, we have seen that retroflexes can condition backing or rounding of vowels (§4.1.3). The UFT was not developed to account for these data, but it is not obvious how it might be extended to account for them. The structure of the theory suggests that each consonantal feature should condition one vowel feature, and vice versa, so it is difficult to accommodate rounding by both labials and retroflexes in this framework, and the fact that retroflexes can condition both and backing and rounding is similarly problematic.

NOTES

1. The feature [+distributed] is used here partly because it is an established feature, but width of coronal contact may actually be the relevant factor here. A front tongue body is required to bring a substantial width of the tongue blade into contact behind the alveolar ridge, but not all sounds that are classified as laminal by Ladefoged and Maddieson (1996) meet this description. They classify sounds such as the 'retroflex' sibilants of Chinese and Polish as 'laminal flat palato-alveolar', but these sounds do not appear to require a front tongue body because the constriction is formed by a narrow strip just behind the tongue tip at the junction between alveolar ridge and palate (pp.151, 154). Furthermore, they state that English speakers vary between apical and laminal palato-alveolars (p.149), but all speakers use a wide constriction.

2. To be fully consistent with the system of vowel transcription we have been employing here, this should be transcribed as retracted [ɪ̠] since we have used [ɪ] for a front vowel, but it is not desirable to mark diacritics on subscripts.

3. As mentioned in §2.2.2.8, labials have lower F2 than a following unrounded vowel because the labial constriction at release lowers F2. Velar closure is farthest from the vowel constriction in lower back vowels, where the vowel constriction is in the pharynx, which is not near to the palate. In these cases, F2 typically seems to be higher at release than in the following vowel.

4. It is likely that anticipation of lip-rounding at consonant release also contributes to the importance of F2 transitions for maintaining an alveolar-labial contrast in this context, because rounding an alveolar burst results in a reduction in noise frequency.

5. One possibility is that lowering F2 increases the large difference between F2 and F3 which is characteristic of laterals.

6. Matisoff states that the alveolar sibilants can be followed by the high central vowel /ɨ/, but in fact the sounds that he phonemicizes in this way are realized as syllabic fricatives (p.7). I.e. Matisoff's /tsɨ/ is phonetically [tsz̩]. Historically, these syllabic fricatives do derive from the same source as the high central vowel (a short, high, front vowel), but a syllabic fricative would not be expected to be subject to the processes hypothesized here.

7. The mid vowels are often transcribed as [ɛ, œ, ɔ]. They are described by Bauer and Benedict (1997) as intermediate between the tense and lax mid vowels of English, so given the five levels of F1 we are operating with, the intermediate value [F1 *3*] seems appropriate, and we have been transcribing this with [e, ø, o]. Probably they should fall between [F1 *3*] and [F1 *4*] in a finer subdivision of this dimension.

8. Note that we have so far ignored the significance of differences in vowel duration for distinctiveness. For example, the non-transitional portion of a vowel in a closed syllable will typically be shorter than the equivalent portion of a vowel in an open syllable, and this difference would be expected to make equal formant differences more distinct in open syllables. This difference doesn't become relevant here because the [y-u] contrast does not arise in open syllables following coronals due to independent processes of diphthongization in open syllables.

9. Durie transcribes the non-low central vowels with symbols for back unrounded vowels, but comments that they are 'somewhat central auditorily', a description which is supported by his formant measurements (p.18). Given the small number of distinctions we are making on the F2 dimension, it seems most appropriate to represent these vowels as central.

10. Probably *Δ[back] should be ranked below MAXIMIZE CONTRASTS since this is a rather stringent requirement which is almost certainly violated by some legal sequences. Instead, a constraint against moving two steps on the back dimension (*Δ[back]=2)—e.g. from front to central—should be ranked above MAXIMIZE CONTRASTS. This revision would add the following candidates to the tableau in (60): [i̠ᶤʈ] with a retracted vowel and full retroflexion, and [ʏᵾʈ] with a rounded retracted vowel and full retroflexion. The former has the same F2 and F3 specifications as candidate (a) [yt], and hence incurs the same constraint violations. [ʏᵾʈ] satisfies all the constraints shown, like candidate (c), but is dispreferred because it violates low-ranked *Δ[back], while (c) satisfies that constraint. The additional mid-vowel candidates [e̠ᶟʈ] and [ø̠ᶟʈ] suffer the same violations as (61a) and (61c) respectively. I.e. *Δ[back] is not violated here because adequately distinct contrasts can be realized without doing so.

11. Russian is sometimes said to have a palatalized velar that is not a palatal stop. An acoustic study by Keating and Lahiri (1993) indicates that this sound is essentially a fronted velar. Thus, like a palatal stop, it does not involve a secondary articulation of palatalization, it involves a fronting of the primary articulation, but the 'palatalized velar' is less fronted than a palatal stop.

12. This brief description ignores the complication that in some contexts, /i/ retracts rather than conditioning palatalization.

13. References: Akan: Schacter and Fromkin 1968; French: Fouché 1958; Italian and Spanish dialects: Rohlfs 1966, Calabrese 1993; Kinyarwanda: Jouannet 1983; Kirundi: Meeussen 1959; Slavic: Jakobson 1968.

14. Palatalized labials probably do generally have longer (and therefore louder) bursts than plain labials (Richey 2000), but this difference is too small to represent on the scale employed here.

15. Bantu frication by super high vowels generally only targets stops (Ponelis 1974), as we would expect given the proposed aerodynamic basis for this process, but in ChiMwi:ni [ɫ] also alternates with [z] before the perfective, and voiced stops only fricate (to [z]) when preceded by a nasal. It is not surprising that voiced stops should be less prone to produce frication since the adduction of the vocal folds reduces air flow, but it is not clear why a preceding nasal would promote frication. The frication of [ɫ] may be an independent process, e.g. a dissimilation from the suffix [ɫ].

16. In fact, given Hume's (1992) assumption that the features dominated by C-Place and V-Place are literally the same features on the same tiers, spreading [coronal] from V-Place to V-Place across an instance of [coronal] dominated by C-Place violates the No Crossing Constraint in its usual formulation. Hume redefines the NCC to allow this type of configuration, and then adopts an additional constraint against ordering paradoxes which forces later 'cloning' of the offending feature (Hume 1992:149ff.)

17. Clements (1991) also proposes a pharyngeal feature which is not discussed here.

CHAPTER 5

Neutralization

Dissimilatory cooccurrence restrictions, many of which demonstrate interactions between articulatorily diverse sounds (1), provide another source of evidence for auditory representations. In particular they provide examples of neutralization of contrasts in contexts where they would be insufficiently distinct. We will argue that the patterns in (2) are similar in that they also involve neutralization of indistinct contrasts.

(1) Dissimilatory cooccurrence constraints

Front glides cannot cooccur with coronals	*tj	American English (§5.1)
Round vowels cannot cooccur with labials	*up	Cantonese, Highland Yao (§5.2)
Velars and alveolars do not contrast before laterals	*tl *kl	English etc, Katu dialects (§5.3)

(2) Other

Dental fricative becomes labio-dental	ð → v	Cockney English (§5.4)
Palatalized consonant becomes coronal	p^j → t	Old Czech > E. Bohemian Czech (§5.5)
Labialized consonant becomes labial	dw → b kw → p	Early Latin > Classical Latin Latin > Romanian (§5.5)

The analyses of cases in (1) draw heavily on the work of Kawasaki (1982, 1992). Kawasaki shows that a number of these sequence constraints are cross-linguistically common, and proposes auditory motivations for the constraints, based on acoustic analysis of the sequences involved. She proposes that two acoustic factors determine preferences and dispreferences among sound sequences (1982:2), (i) ‘The magnitude of acoustic modulation within a sequence’ and (ii) ‘The degree of acoustic difference between sequences’. The first factor is relevant given the hypothesis that ‘The magnitude of acoustic modulation in a given sound sequence [is] directly related to its perceptual saliency'. I.e. that change is perceptually more salient than a steady state (cf. Ohala 1980), so sequences which involve little spectral change should be dispreferred. The second factor relates directly to the requirement that the distinctiveness of contrasts be maximize—i.e. contrasting sound sequences that are not auditorily distinct are dispreferred.

To a considerable extent, these two criteria converge on the same preferences. For example, sequences such as [tj] involve comparatively little change in formants after release because the palatal has a high F2, and the alveolar has high F2 at release also. For the same reasons, the contrast between [tj] and [t] is relatively subtle: the palatal is characterized by a high F2, but a plain alveolar has a high F2 at release anyway. But there are differences between the two explanations. According to the 'acoustic modulation' hypothesis, a sequence like [tj] is inherently dispreferred because it involves a sequence of sound which are too similar acoustically. On the other hand, the analysis in terms of auditory differences between contrasting sequences implies that there is nothing intrinsically undesirable about a sequence like [tj], it is the contrast with [t] which is undesirable. We shall see that there is evidence in favor of this view. For example, the [t]-[tj] contrast is sometimes neutralized to palatalized [tj], which is a marked sequence according to the acoustic modulation hypothesis. In addition, there are cases in which the contrast between two sequences is barred, but there is free variation, as in Mong Njua where there is variation between [kl] and [tl] clusters. This pattern can only be explained in terms of a dispreference for the contrast between [kl] and [tl], not in terms of an inherent dispreference for either sequence. Thus we will analyze the dissimilatory cooccurrence restrictions in terms of neutralization, but we will consider the applicability of constraints on acoustic modulation to a non-neutralizing pattern in §5.2.2.

5.1. FRONT GLIDES CANNOT CONTRAST AFTER CORONALS

One of the cross-linguistically common sequential co-occurrence constraints identified by Kawasaki is a prohibition against coronals followed by palatal glides. Many of these cases result from palatalization in this environment, e.g. alveolars do not appear preceding palatal glides because they become palato-alveolars. American English dialects provide a clear case of such a cooccurrence constraint which is not the result of assimilation. However, they also show that the restriction is against the occurrence of contrastive palatalization in this position, not the occurrence of a palatal glide per se.

In many dialects of American English, there are restrictions on the appearance of palatal glides following coronals. These restrictions do not apply in 'Received Pronunciation' English (RP), so words such as 'do' and 'dew' are differentiated by the presence or absence of a glide in the onset in RP, but are homophonous in most American dialects since no glide appears in either word (3). In some American dialects, such as Southern Californian, the words are homophonous, but both are produced with a palatal on-glide to the vowel (cf. Ladefoged 1999). This on-glide seems to be less constricted than the palatal glide of RP, and so is transcribed with [^{i}]. No dialect contrasts presence or absence of a palatal glide following palato-alveolars (*tʃ-tʃj).

(3)	British English	General American	S. Californian
‘do’	du	du	d^{i}ʉ
‘dew’	dju	du	d^{i}ʉ
‘tune’	t^{h}jun	t^{h}un	t^{hi}ʉn
‘cartoon’	kɑt^{h}un	kɑɹt^{h}un	kɑɹt^{hi}ʉn

The analysis proposed here is based on the observation that the contrast between plain and palatalized coronals is subtle because palatal glides are distinguished by a high F2, but even a plain coronal has high F2 at release. Since the contrast is relatively indistinct, it is neutralized in most American dialects. Palato-alveolars have an even higher F2 at release, so a palatalization contrast following these sounds would be still less distinct, and this contrast is not found in any dialect of English, and is very rare cross-linguistically.

The difference between ‘General’ American and Southern Californian lies in which term of the opposition surfaces under neutralization. This difference can be accounted for as different resolutions of a conflict between consonant distinctiveness and minimizing effort: palatalizing coronals enhances their distinctiveness from non-coronals by increasing the difference in F2 at release, but it also requires a larger movement from the consonant to the following back vowel [u] (or fronting of this vowel, reducing distinctiveness of vowel contrasts).

We will first formulate the analysis of the difference in contrasts between RP and American English. The palatalization contrast is at risk after alveolars because they typically have a high F2 at release anyway. This is because they are produced with a fronted tongue body to facilitate formation of a coronal constriction at the alveolar ridge (§4.1.1.1). This tendency is universal, but there is substantial cross-linguistic variation in the exact height of F2 at the release of coronals, so the contrast between palatalized and plain alveolars could be more or less distinct depending on the precise realization of the alveolar. A lower F2 at the release of the plain alveolar yields a better contrast with the palatalized alveolar, and can probably be achieved without making the alveolar constriction too effortful, but coronals are also distinguished from non-coronals by having a higher F2 before back vowels, so lowering F2 at the release of a coronal makes the coronal vs. non-coronal contrast less distinct. I.e. the question is not simply whether a palatalized alveolar is sufficiently distinct from a plain alveolar, but also whether the alveolar is sufficiently distinct from non-coronals.

So we will hypothesize that the difference between RP and American English is that American English requires a larger difference in F2 transitions, i.e. the relative ranking of MINDIST = trans F2:3 and MAXIMIZE CONTRASTS differs in the two dialects. This is illustrated by the tableaux in (5) and (6). F2 transitions specifications for relevant sounds are shown in (4). We transcribe an alveolar with high but non-maximal [F2 *4*] with [d^{I}], and an alveolar with [F2 *3*] due to a more central tongue body position and/or more lip-rounding with [d^{Y}]. We will assume that the Southern Californian [d^{i}] and palatalized [d^{j}] do not differ in F2 in terms of our relatively crude scale. In any case the difference between [i] and [j] may lie more in F1 or in intensity (cf. Olive, Greenwood, and Coleman 1993:117). The labial stop is treated as the representative non-coronal on the grounds that the velar-coronal contrast is distinguished by a large difference in burst quality, and so is less in need of enhancement by a difference in F2 transitions. We will also ignore differences in burst quality here, and focus exclusively on the contribution of F2 transitions to the distinctiveness of the contrasts.

(4) Release:

	b^{u}	d^{Y}	d^{I}	d^{i}	d^{j}
F2	1	3	4	5	5

In RP English, MAXIMIZE CONTRAST outranks MINDIST = trans F2:3, so adequate contrasts can be maintained between labial, alveolar and palatalized alveolar (5). In American English, this ranking is reversed, so the contrasts [b^{u}-d^{Y}] and [d^{Y}-d^{j}] are unacceptable since each involves a difference of only F2:2. Consequently the palatalization contrast must be neutralized, but the ranking so far under-determines the result of neutralization. An alveolar with [F2 *4*] or [F2 *5*] yields a satisfactory contrast with the labial (candidates c and d), although [F2 *3*] is insufficient (e). Note that this analysis implies that alveolars before [u] are realized differently in RP and American. This has not been verified experimentally, but it has often been noted that American English speakers show a prolonged high F2 at the release of alveolar stops in [t^{h}u] and [du] sequences (e.g. Olive, Greenwood, and Coleman 1993:136, Oh 2000), a pattern which has not been noted for RP. However, it may be that some English speakers actually enhance the palatalization contrast with burst and affrication differences rather than by retracting the plain alveolars. These enhancements would be blocked in neutralizing dialects because they reduce the distinction between palatalized alveolars and the palato-alveolar affricates [tʃ, dʒ]. Indeed there are English accents in which these contrasts can be neutralized, rendering ‘due’ and ‘Jew’ homophonous, for example.

(5) RP English: MAX CONTRASTS >> MINDIST = trans F2:3

		MINDIST = trans F2:2	MAXIMIZE CONTRASTS	MINDIST = trans F2:3
a.	b^{u}u-d^{I}u-dju	*!	✓✓✓	**
b.	☞ b^{u}u-d^{Y}u-dju		✓✓✓	**
c.	b^{u}u-d^{I}u		✓✓!	
d.	b^{u}u-dju		✓✓!	

(6) American English: MINDIST = trans F2:3 >> MAX CONTRASTS

		MINDIST = trans F2:2	MINDIST = trans F2:3	MAXIMIZE CONTRASTS
a.	b^{u}u-d^{I}u-dju	*	**	✓✓✓
b.	b^{u}u-d^{Y}u-dju		**	✓✓✓
c.	☞ b^{u}u-d^{I}u			✓✓
d.	☞ b^{u}u-dju			✓✓
e.	b^{u}u-d^{Y}u		*!	✓✓

As noted above, there are dialectal differences in the results of neutralizing the palatalization contrast after coronals. These differences are analyzed as resulting from different rankings of constraints favoring maximizing the F2 transition distinction, and avoiding the effort involved in moving from a more palatalized tongue body position to the following back [u]. Maximization of distinctiveness of consonant contrasts is favored by MINDIST = trans F2:4. The minimization of effort constraint, *PALATALIZED-BACK, penalizes moving from a fully front tongue body position to a backed one between consonant release and vowel—i.e. it is violated by [d^{i}u] but satisfied by [d^{I}u].

The effect of varying the ranking of these two constraints is shown in (7) and (8). Ranking *PALATALIZED-BACK higher (7) favors a less fronted tongue body position (candidate b), reducing effort, but also producing a lower F2 transition, in violation of lower-ranked MINDIST = trans F2:4. This is the General American pattern. The Southern Californian pattern is derived by reversing the ranking of these constraints, making the winner the more distinct contrast in candidate (a).

(7) General American: *PALATALIZED-BACK >> MINDIST = trans F2:4

		MINDIST = trans F2:3	MAXIMIZE CONTRASTS	*PALATAL-BACK	MINDIST = trans F2:4
a.	b^{u}u-d^{i}u		✓✓	*!	
b.	☞ b^{u}u-d^{I}u		✓✓		*
c.	b^{u}u-d^{Y}u	*!	✓✓		*

(8) S. Californian: MINDIST = trans F2:4 >> *PALATALIZED-BACK

		MINDIST = trans F2:3	MAXIMIZE CONTRASTS	MINDIST = trans F2:4	*PALATAL-BACK
a.	☞ b^{u}u-d^{i}u		✓✓		*
b.	b^{u}u-d^{I}u		✓✓	*!	
c.	b^{u}u-d^{Y}u	*!	✓✓		

It is also possible to satisfy both MINDIST and *PALATALIZED-BACK by fronting the vowel: [d^{i}ʉ]. This is probably a more accurate representation of the Southern Californian pronunciation. This solution is blocked in General American by ranking MINDIST = V F2:4, requiring distinct vowel contrasts, above MINDIST = trans F2:4 (9).

(9)		MINDIST = V F2:4	*PALATAL-BACK	MINDIST = trans F2:4
a.	b^{u}u-d^{i}u di		*!	
b.	☞ b^{u}u-d^{ɪ}u di			*
c.	b^{u}u-d^{i}ʉ di	*!		

Previous analyses of the General American pattern, e.g. Borowsky (1986), have proposed that palatal glides are [coronal], and that palatal glides cannot appear after coronals due to an OCP-type restriction on adjacent [coronal] segments. However, this analysis does not extend to the Southern Californian pattern where the contrast is also neutralized, but in favour of the palatalized coronal. The existence of dialects like Southern Californian show that it is the contrast between presence and absence of a palatal glide that is problematic following a coronal, not the palatal glide itself. As noted above, these considerations also argue against an account of this phenomenon in terms of the acoustic modulation hypothesis.

There is an additional complication concerning the distribution of palatal glides in English. In all dialects, the glide can appear after coronals following a stressed syllable (10a), although not following obstruents, where we find palatalization instead (10b). In General American this gives rise to alternations such as that shown in (11).

(10)	a.	wíljɨm	‘William’	k^{h}əmp^{h}ánjɨn	‘companion’
		ʌ́njɨn	‘onion’	səvíljɨn	‘civilian’
	b.	míʃən	‘mission’	p^{h}íktʃɚ	‘picture’
(11)		vάljɨm	‘volume’	vαlúmɪnəs	‘voluminous’

Vowel reduction may be relevant to explaining this pattern. In an unstressed syllable, the contrast involved is not [nju] vs. [nu], but rather [njɨ] or [njʊ] vs. [nə], because [u] does not appear in unstressed syllables. As a result the contrast is marked by a difference in the height of the vowel as well as the small difference in F2 at the release of the coronal. These differences are adequate to support a contrast, so neutralization does not occur[1].

English also disallows sequences of a labial consonant followed by a labio-velar glide, i.e. *[pw], *[fw], etc, a pattern which is observed in many languages (Kawasaki 1982). This restriction appears superficially similar to the restriction on coronal-palatal glide sequences under discussion here, but a parallel analysis is not viable because, while labials are characterized by F2 transitions lower than F2 of a following vowel, this still means F2 is typically relatively high before front vowels. Thus contrasts like [pwi-pi] should be quite distinct. In Kawasaki's study, such sequences show greater modulation than velar and alveolar stops followed by [wɛ], which are permissible in English (as in 'quest', 'twenty'). It is more likely that the restriction against [pw] arises out of the difficulty of producing an adequate labial stop release with the lips rounded. That is, rounding of the lips during a labial stop seems likely to result in the loss of closure, or at least a less rapid opening of the closure resulting in loss or weakening of the stop burst. This could make labial+[w] indistinct from [w] alone. Lip-rounding is even less compatible with a labio-dental constriction because lip-rounding involves protruding the lips whereas the lower lip must be retracted towards the upper teeth in a labio-dental.

5.2. RESTRICTIONS ON THE COOCCURRENCE OF LABIALS AND ROUND VOWELS

There are languages that restrict the appearance of labials with round vowels. Cantonese exhibits an extensive set of such restrictions: Front round vowels do not appear with a labial onset or coda, and back round vowels do not appear with a labial coda (Cheng 1991, Kao 1971, Yip 1988):

(12) a. $* \underset{\text{[labial]}}{\text{C}} \; \underset{\begin{bmatrix}\text{+round}\\ \text{-back}\end{bmatrix}}{\text{V}}$ $\qquad * \underset{\begin{bmatrix}\text{+round}\\ \text{-back}\end{bmatrix}}{\text{V}} \; \underset{\text{[labial]}}{\text{C}}$

b. $* \underset{\begin{bmatrix}\text{+round}\\ \text{+back}\end{bmatrix}}{\text{V}} \; \underset{\text{[labial]}}{\text{C}}$

The vowel inventory of Cantonese contains two front rounded and two back rounded vowels as shown in (13). The labial consonants are given in (14). Of these, only the unaspirated stop [p] and nasal [m] can appear in coda position.

(13)

i	y	u
e	ø	o
	a,a:	

(14)

labial	labialized velar
p	k^w
p^h	k^{hw}
m	
w	

I propose that the restrictions on front rounded vowels and back rounded vowels have distinct bases. In outline, front rounded vowels cannot appear adjacent to labials because they are not sufficiently distinct from front unrounded vowels in this environment, due to the effects of the labials on unrounded vowels. The result of neutralization is the unrounded vowel because this yields a better contrast with the back rounded vowels. The restrictions on back rounded vowel, on the other hand, involve neutralization of consonant contrasts. Labial and velar stops are too similar following a back rounded vowel to support a contrast. I.e. back rounded vowels do not appear preceding labials because labials are replaced by velars in that environment. Contrasts among onset consonants are not neutralized because there are many more cues to consonant place in this position, hence the directionality of this cooccurrence restriction.

We will first analyze the restrictions on the distribution of front round vowels. These are enumerated in (15).

(15)

*py	*pø	*yp	*øp
*fy	*fø	*ym	*øm
*my	*mø		
*k^wy	*k^wø		
*wy	*wø		

Front rounded and unrounded vowels differ in that lip-rounding lowers the F2 and F3 of the rounded vowel (Schwartz, Beautemps, Abry, and Escudier 1993). A labial constriction lowers F2 and F3 in the same way as lip-rounding, so coarticulation with a labial renders an unrounded front vowel more similar to a rounded vowel. The analysis proposed here is that in Cantonese the effect of a labial on a front vowel like [i] is sufficient for the contrast between [i] and [y] to violate the crucial minimum distance constraint. This is formalized in terms of the ranking in (17). The top-ranked constraint prevents rapid lip opening after a labial (and rapid lip closing before a labial) so vowels must be produced with some degree of lip constriction (lips approximated) adjacent to a labial, so candidate (a) with spread [i] is eliminated. This lip constriction lowers F2 and F3 of front vowels. The lowering effect is less than that of lip-rounding, since rounding involves protrusion as well as constriction. We have assumed the effects shown in (16), although the precise numbers are less important than the fact that adding some lip constriction to a front vowel makes it more similar to a front rounded vowel. This is sufficient to make the contrast [$i^β$-y] unacceptable due to violation of MINDIST = F3:4 (candidate b). This constraint is ranked above MAXIMIZE CONTRASTS so it is preferable to neutralize the front-rounding contrast adjacent to labials, as in candidates (c) and (d). The unrounded vowel surfaces under neutralization because it yields a more distinct contrast with back rounded vowels (candidate c).

(16)

	i	i^{β}	y	u
F2	5	4	4	1
F3	5	3	1	1

(17) Neutralization of rounding in front vowels adjacent to labials.

		*LIPS CLOSE-LIPS OPEN	MINDIST = F3:4 or F2:3	MAXIMIZE CONTRASTS	MINDIST = F2:3 & F3:2
a.	pi-py-pu	*!		✓✓✓	
b.	pi^{β}-py-pu		*!	✓✓✓	
c.	☞ pi^{β}-pu			✓✓	
d.	py-pu			✓✓	*!

Note that although we have described this case as dissimilation, the analysis is fundamentally the same as for assimilatory rounding of vowels adjacent to labials, e.g. /pɯp/ → [pup] in Acehnese (§4.1.2.2). In both cases a vowel contrast is neutralized because it is rendered insufficiently distinct by partial assimilation to a labial consonant. This can result in either assimilation or dissimilation depending on which term of the contrast surfaces after neutralization. In both cases rounding of the neutralized vowel is selected to maximize the distinctiveness of contrasts with other vowels. In Cantonese, the neutralization is between front vowels, so unrounded vowels are selected to maximize distinctiveness from back vowels. In Acehnese, the neutralization is between back vowels, so rounded vowels yield a better contrast with front vowels. In other words, rounding under neutralization follows the usual pattern of correlation with backness: front vowels are unrounded, and back vowels are rounded.

Back rounded vowels can appear with labial onsets (18), but not with labial codas (19).

(18)

pun	'to move'	p^ho	'old lady'
fu	'rich'	fo	'subject'
mun	'bored'	mo	'slow'

(19)

*up	*op
*um	*om

The restriction against labials following back rounded vowels results from neutralization of the contrast between labials and velars in this position. The formant transitions associated with labials and velars are often almost identical following [u] (e.g. Öhman 1966, Kawasaki 1982:119ff.; Olive, Greenwood, and Coleman 1993:141ff.)[2]. In onset position the contrast between these places is maintained by differences in the quality of the release bursts: A velar has a compact and relatively intense burst, whereas a labial has a diffuse, low intensity burst (20). In coda position, Cantonese stops are glottalized and consequently there is generally no audible release burst to contribute to place distinctions.

(20) Vowel context:

	u			i			a		
	p^u	t^Y	k^u	p^i	t^I	k^i	p^a	t^I	$k^ɨ$
transitions:									
F2	1	3	1	4	4	5	2	4	4
F3	2	3	2	2	5	4	2	4	2
burst:									
diffuse	+	-	-	+	-	-	+	-	-
NF	2	5	1	2	6	4	2	6	2

This difference between pre and post-/u/ contexts is shown in the following two tableau (21–22).The MINDIST constraint relevant to stop place contrasts is complex, as usual, since place contrasts are realized by different combinations of formant and burst differences in different vowel contexts. Following [u], the contrast between labials and velars is neutralized due to the lack of burst cues (21). The output of neutralization is the velar. The basis for this is not clear—the constraint ranking *p >> *k in (21) is a stand-in for whatever constraint prefers velars over labials in this context. Whatever the basis for this preference, it seems to be general in Chinese: in a number of Chinese languages all stop and nasal place contrasts are neutralized in coda, and the result is always a velar stop or a glottal (Chen 1973).

(21) Place contrasts after back rounded vowels

		MINDIST = F2:2 or F3:2 or (F2:1&F3:1) or burst diff	MAXIMIZE CONTRASTS	*p	*k
a.	up˺-ut˺-uk˺	*	✓✓✓	*	*
b.	☞ ut˺-uk˺		✓✓		*
c.	up˺-ut˺		✓✓	*!	

(22) Place contrasts before back rounded vowels

		MINDIST = F2:2 or F3:2 or (F2:1&F3:1) or burst diff	MAXIMIZE CONTRASTS
a.	☞ pu-tu-ku		✓✓✓
b.	tu-ku		✓✓!
c.	pu-tu		✓✓!

Following front or low vowels, all three places of articulation are distinguished by differences in F2 and/or F3 (20), so labials can appear in these contexts.

This analysis of the Cantonese labial-round vowel cooccurrence restrictions has the advantage that it derives the asymmetry between constraints on labial codas and onsets from phonetic differences between onset and coda stops. Previous analyses have appealed to stipulative orderings between syllable construction rules, redundancy rules, and OCP-checking (Yip 1988), or to complex procedures for checking OCP violations which lack independent motivation (Cheng 1991). However, these analyses do also attempt to account for a constraint against the cooccurrence of labial onsets and codas that is not analyzed here.

Labio-velar glides and labialized velars behave like other labials with respect to front vowels (above), but there are some additional restrictions on the cooccurrence of these sounds with back rounded vowels. The labio-velar glide and labialized velars are not contrastive before high back [u] (23a), but do contrast before mid back [o]. Non-high vowels cannot appear without onsets, so [wo] does not contrast with [o] because a default onset ([ŋ] or [ʔ]) must appear in the latter form.

The contrast between [kʷu]-[ku] would be very subtle because the release of a labialized velar has essentially the same features as the release of a velar before [u], so it is unsurprising that they are neutralized here, as in most other languages. Similarly, the contrast between [wu]-[u] is cross-linguistically rare since [u] is very similar to its glide counterpart [w]. On the other hand, the mid-vowel [o] is relatively low, and so [kʷo] is differentiated from [ko] by the lower F1 of the on-glide in the former.

Finally, Cantonese has diphthongs with labiovelar off-glides. Unlike other labials, this off-glide can appear following a back rounded vowel, as in (23c). This does not present any problems for our analysis of labial cooccurrence constraints since the restriction on labial stops following back rounded vowels was analyzed in terms of their similarity to velar stops in that environment. The analysis thus does not extend to labial glides, which only contrast minimally with palatal glides in coda.

(23)	a.	wu ~ u	'lake'		
		ku	'drum'	*kʷu	
	b.	wo	'hay'	ʔo ~ ŋo	'I'
		kʷo	'through'	ko	'fruit'
	c.	hou	'good'		

5.2.1. Other Examples

An interesting variant on the restriction on the Cantonese restriction on labials following back rounded vowels is found in Highland Yao (Downer 1961). In this language the restriction only applies following the high back rounded vowel, so the sequence [op] with a mid vowel is acceptable while *[up] is not.

Highland Yao has the vowel inventory in (24), and allows the stops [p, t, ʔ] in coda. The labial [p] occurs in coda following all vowels except [u] and [ɛ] (which only occurs in open syllables or preceding [t, ʔ, ŋ]). Thus [ɔp] and [op] are acceptable rimes, but *[up] is not (25).

(24)	i		u
	e		o
	ɛ		ɔ
		a, aː	

(25)	dɔ̂p	'to fall, drop'
	tôp	'bean'

Given that velar [k] does not appear in coda[3], the labial-velar contrast that was central to the analysis of Cantonese is not relevant here. However, not only do [up] and [uk] have similar formant transitions, but these transitions are typically essentially level, i.e. the formants during approach transitions are essentially the same as during the steady state of the vowel. This means that both sequences are also similar to [uʔ] with a coda glottal stop, since a glottal stop does not perturb formants of adjacent vowels. Coda stops are described as usually having 'inaudible release' (op.cit., p.536), removing the release burst as a source of difference between labial and glottal stops. Thus the restriction against [up] can be analyzed as a result of neutralization of the contrast between [up] and [uʔ], due to insufficient distinctiveness. Cantonese does not allow coda glottal stop, so this contrast is not an issue in that language.

Unlike labials and velars, labial and glottal stops are differentiated by F1 transitions following non-high back vowels. All supralaryngeal stops have low F1 transitions, whereas glottal stops do not affect any formants. F1 is low in high vowels like [u], so F1 transitions are relatively level in [up], but after a non-high vowel like [o], the labial stop is distinguished from a glottal by a falling F1 transition.

(26) transitions:

	p^u	$ʔ^u$	p^o	$ʔ^o$
F2	1	1	1	1
F1	1	1	1	3

5.2.2. Non-Neutralizing Dissimilation: Lahu

We have so far analyzed restrictions on sequences of round vowels and labials as resulting from neutralization of either vowel or consonant contrasts. In this section we will consider an apparent case of dissimilation between labials and round vowels in Lahu which is non-neutralizing, and therefore not susceptible to the type of analysis developed so far.

Lahu (Matisoff 1972) has the phonemic vowel inventory shown in (27). The high back round vowel [u] becomes unrounded following a labial, and the labial is affricated (28). This process is non-neutralizing since high, back unrounded vowels do not occur in other environments. In fact the unrounded vowel resulting from the dissimilation process contrasts with a high central unrounded vowel (29).

(27)

i	ɨ	u
e	ə	o
ɛ		ɔ
	a	

(28)

/pû/	→	pfɯ̂	'carry on the back'
/pʰûʔ/	→	pfɯ̂ʔ	'turn around'
/bùʔ/	→	bvɯ̀ʔ	'write'
/mû-jè/	→	mvɯ̃jè	'rain'

(29) pfɯ̂ 'carry on the back' pɨ́ 'be able; be good at doing'

One obvious approach to analyzing this pattern is the preference for spectral change in sound sequences hypothesized by Kawasaki and Ohala, since that line of explanation does not rely on neutralization with similar sound sequences. The vowel [u] has [F2 *1*], like the release of a preceding labial. Unrounding the vowel raises F2, resulting in a change in F2 from the release to the vowel—i.e. better spectral modulation. However, it would seem that a similar problem of lack of spectral modulation would arise in sequences of a labial followed by the other back rounded vowels, [o, ɔ], and with sequences of back velars followed by back rounded vowels (Lahu contrasts palatal and 'post-velar' stops), but no unrounding occurs in these contexts (30). Worse still, the higher mid vowel apparently is often raised towards [u], resulting in surface contrasts that Matisoff transcribes as shown in (31) (p.13).

(30)	pʰôʔ	'pile up'	pʰɔ̂	'side; direction'
	bôʔ	'fall over'	mɔ̀	'see; have the experience of'
	pòtʰôo	'my goodness!; wow!'		

(31)	pʰû	'sac, bladder'	pfʰɯ̂	'price'

The mid vowels generally differ from the high vowel, and the release of a labial, in having a higher F1, so the data in (30) might be accounted for if only lack of modulation in both F1 and F2 is problematic. However, this would not account for cases such as those shown in (31), in which a high, back, rounded vowel surfaces following a labial.

These facts suggest that Lahu unrounding may not in fact be an instance of dissimilation. An alternative line of analysis is suggested by Matisoff's characterization of the unrounding and spirantization as a 'transfer [of] the roundedness of the vowel to the preceding consonant'. I.e. the process may involve breaking [u] into [wɯ], with rounding of the labial resulting in affrication. The breaking could be motivated by the need to maintain the distinctiveness of the contrast with /o/ under pressure from the raising of that vowel. However, it is unclear why breaking should be restricted to the environment following a labial given that raising of /o/ also applies in other contexts.

5.3. CORONAL-VELAR NEUTRALIZATION BEFORE LATERALS

An interesting pattern observed by Kawasaki involves restrictions on sequences of a coronal stop followed by a lateral. Sequences of this type are prohibited in a wide range of languages where laterals are permitted to follow labial and velar stops (Kawasaki 1982:14)[4]. On example is English:

(32)	*tl, *dl	
	pl, bl	e.g. 'plead, bleed'
	kl, gl	e.g. 'clue, glue'

This restriction might not appear to provide evidence for auditory features since both sounds involved are coronals. In fact the English data are usually analyzed in terms of an OCP constraint against adjacent coronal consonants. However there is good cross-linguistic evidence that this cooccurrence restriction results from neutralization of the contrast between coronals and velars before laterals. This interpretation is strongly supported by the occurrence of free variation between these sequences in Mong Njua (Lyman 1974) (33) although coronals and velars contrast elsewhere (34).

(33)	kl~tl	klĕ~tlĕ	‘dog’
	k^{h}l~t^{h}l	k^{h}la~t^{h}la	‘to run; jump’
	ŋgl~ndl	ŋglua~ndlua	‘flash (as of lightning)’
	ŋk^{h}l~nt^{h}l	(no examples)	
	pl	pláŋ	‘stomach’
	p^{h}l	p^{h}lu	‘cheek; face’
	mbl	mblôŋ	‘leaf’
	mp^{h}l	mp^{h}lái	‘(finger-)ring’

(34)	kău	‘barking-deer’	tău	‘to dam up water’

This case is similar to English in that the contrast between velar and coronal stops is neutralized before laterals, but the OCP analysis cannot account for these data. It is clearly the contrast between velars and coronals that is not permitted in this environment since the OCP-violating sequences are permitted to occur. As we saw in §2.3.3, neutralization that yields free variation must be analyzed in terms of restrictions on contrasts, rather than restrictions on the occurrence of either term of the contrast.

Similarly, Katu dialects show variation between alveolar stop-lateral sequences and velar stop-lateral sequences (Wallace 1969), although each dialect allows only one of these classes of sequences (35). Again, in spite of the fact that we observe the same neutralization as in English and Mong Njua, the OCP analysis proposed for English cannot account for it, because in the Phúhòa dialect, it is the sequence *[kl] that is excluded.

(35)	An^{ʔ}di^{ʔ}êm	Phúhòa	
	klâm	tlâm	‘urinate’
	gluh	dluh	‘go out’

Finally, we can observe a diachronic change from coronal to velar before laterals in Latin. The medial cluster [tl] resulting from vowel deletion became [kl] (Kawasaki 1982:157f.):

(36)	vetulus > veclus	‘old (diminutive)’
	vitulus > viclus	‘calf’

As Kawasaki suggests, these neutralizations result from the auditory similarity of coronal stop-lateral and velar stop-lateral sequences. The stop closure in a coronal or velar is at or behind the location of the lateral constriction so the properties of the release burst depend largely on the lateral constriction, assuming the stops are released directly into the lateral. So coronals and velars are not well differentiated by their bursts in this environment. A labial stop, by contrast, is formed in front of the lateral constriction, so the quality of the burst is much as in a plain labial stop. Kawasaki's measurements also indicate that the formant transitions into the lateral are very similar for alveolars and velars (pp.68f., 157; cf. Olive, Greenwood, and Coleman 1993:284). At release, F2 is higher than at the release of a labial, although at a relatively low frequency for an alveolar. This appears to be due to velarization of /l/ in all positions in the American English dialects described by these sources. I.e. F2 is very low in the lateral and since F2 in a lateral is largely dependent on tongue body position (Bladon 1979), we can assume that these laterals were produced with a back tongue body. The difference in F2 at release of alveolars and labials is thus parallel to the difference observed preceding back vowels, where tongue body position is anticipated in a labial, but alveolar stops require at least a partially fronted tongue body. It is less obvious why velars show the same pattern as coronals since velars generally anticipate a back tongue body position. However, in a velar-lateral cluster, the velar stop overlaps the lateral, so it is necessary to produce simultaneous velar and alveolar contacts. It is plausible that it is difficult to produce a back velar closure simultaneously with the alveolar contact for the lateral. This may seem inconsistent with the fact that the lateral is itself velarized, however, I suggest that it is more difficult to produce a fully back dorsal closure simultaneously with alveolar contact than it is to produce a back vocalic constriction, as in the velarized lateral.

In any case, specifications based on observed realizations of stops released into laterals are given in (37). Lateral fricatives are not well studied, so it is not clear what exactly distinguishes them from other coronal fricatives. Spectrograms in Ladefoged and Maddieson (1996:204f.) indicate a NF comparable to palato-alveolars. However, the main point is that the burst specifications of [t^l, k^l] are very similar, since both are shaped by a lateral constriction.

(37)

	p^l	t^l	k^l
transitions:			
F2	1	3	3
burst:			
diffuse	+	-	-
NF	2	4	4

In most cases the contrast between coronal and velar is neutralized in favor of the velar before a lateral, although we have seen that the opposite pattern is observed also. It is not obvious what constraints determine the realization of the neutralized stop. One possibility, based on examination of my own productions, is that coronal-lateral clusters are more prone to affrication than velar-lateral clusters, presumably because stop and lateral are homorganic so lateral frication is generated as the sides of the tongue are first lowered. In a velar-lateral cluster, an approximant lateral constriction is in place before the velar is released. This affrication would serve as an enhancement of the contrast with labials in this context, but might reduce distinctiveness from affricates and fricatives. Different rankings of these two considerations would thus yield the two outcomes.

5.4. DENTALS AND LABIO-DENTALS

We turn now to cases of neutralization that do not result in the appearance of dissimilatory cooccurrence restrictions. It seems likely that the cross-linguistic dispreference for non-strident dental fricatives [θ, ð] is due to the auditory similarity of these sounds to the more common labio-dental fricatives [f, v]. Evidence that the confusability with labio-dentals is at least part of the problem with dental fricatives comes from the existence of optional neutralization of these contrasts in Cockney English (Wells 1982:328f.) and in varieties of African-American Vernacular English (Wells 1982:557f). These cases involve substitution of labio-dental fricatives for dentals:

(38)	fɪn ~ θɪn	'thin'
	kif ~ kiθ	'Keith'
	bɹʌvə ~ bɹʌðə	'brother'

The change from dental to labio-dental is problematic for Sagey's articulator-based feature theory, because in those terms, this is an unconditioned change from [labial] to [coronal]. The change can be described more easily in Gorecka's (1989) geometry which specifies both the articulator and the place of articulation. In these terms the place of articulation remains constant. From the present perspective, it is apparent that the relevance of place of articulation derives from the fact that the location of a constriction determines far more of the acoustic properties of a sound than the identity of the active articulator.

The similarity between dental and labio-dental fricatives is clearly indicated by the fact that these sounds are relatively easily confused, even by speakers who consistently contrast them (Miller and Nicely 1955). However, it is not immediately obvious why these fricatives should be so confusable. Certainly the quality of frication noise is very similar in dentals and labio-dentals: both sounds have diffuse low amplitude frication because there is no effective filtering by a cavity in front of the source of frication noise in either type of sound. These sounds are thus distinguished primarily by their formant transitions (Harris 1958). The primary constriction in both sounds is also similarly located at the upper teeth, so if this were the sole constriction in each case, formant transitions would be similar. However, it might be expected that the dental would have higher F2 transitions before back vowels due to fronting of the tongue body to facilitate the formation of a tongue-tip constriction at the teeth, as in many other coronal consonants (§4.1.1.1). Data from English in Olive, Greenwood, and Coleman (1993) and Fowler (1994) shows dentals do have higher F2 transitions than labio-dentals adjacent to back vowels, but the transitions are substantially lower than for alveolars. Adjacent to front vowels, [θ, ð] and [f, v] have very similar formant transitions. It appears that forming a coronal constriction at the teeth while avoiding generation of frication at the alveolar ridge is easier if the front of the tongue is not high—i.e. there should not be a constriction in the front-palatal region, which would be necessary to produce a high F2 (cf. also Stevens, Keyser & Kawasaki 1986:435f.).

On the other hand a coronal-dental constriction is incompatible with a simultaneous fully backed tongue position, so F2 transitions are significantly higher in dentals than labio-dentals adjacent to truly back vowels such as [ɔ] and, in some dialects, [u]. So if neutralization of the contrast between dental and labio-dental fricatives is based on considerations of distinctiveness, we would expect an effect of vowel backness, with the contrast being neutralized first adjacent to front vowels. I am not aware of any studies of the phonological factors conditioning this neutralization which would allow us to test this prediction. Fasold and Wolfram (1970) do report that neutralization is particularly prevalent preceding [ɹ] in African-American Vernacular English (e.g. *free-three*), and this is an environment in which formant transitions would be expected to be dominated by [ɹ], and thus similar for dental and labio-dental. However, the tendency to replace dentals by labio-dentals before [ɹ] might also be attributed to the difficulty of producing a dental immediately preceding the rhotic—at least for speakers with retroflex [ɹ], this involves moving the tongue tip from the teeth to a posterior, retroflexed position.

The analysis of a dialect which neutralizes in all contexts is as follows. Dental and labio-dental fricatives have essentially the same fricative noise, as shown in (39). Given the F2 specifications in (40), they are also never differentiated by more than F2:1 in formant transitions, whereas a contrast between unreleased coronal and labial stops is differentiated by F2:2 in all contexts, so ranking MINDIST = TRANS F2:2 >> MAXIMIZE CONTRASTS results in neutralization of the former contrast, but not the latter.

(39)

	θ	f	ð	v
Diffuse	+	+	+	+
NF	2	2	2	2

(40)

context:	i_		ɑ_		u_		i_		ɑ_		u_	
	f	θ	f	θ	f	θ	p	t	p	t	p	t
transition F2	3	3	2	3	1	2	3	5	2	4	1	3

The F2 transition values in (40) are not the only physiologically possible values. For example, in English, labial and alveolar stops are often produced with nearly identical F2 transitions ([F2 *4*]) before [i] (Kewley-Port 1982). The similarity in formant transitions is not problematic in the prevocalic context because the release burst distinguishes the two places of articulation, but realizing alveolars and labials with the same closure transitions in unreleased coda position would be problematic. It is thus unsurprising that the pattern of F2 transitions following [i] is different—labials are produced with lower F2 transitions than preceding [i] (as shown in 39), and alveolars often have higher

F2 transitions, although in some dialects F2 transitions of alveolars seem to be higher (F2 *5*) in both onset and coda. Presumably the higher onset F2 transitions in [bi] are the minimum effort transitions, resulting from assimilation to the following vowel. This effort avoidance is possible where the burst yields a sufficiently distinct contrast, but in the absence of a burst, more effort is exerted to lower F2 to maintain a distinct contrast. The same F2 transition is presumably possible with labio-dental [f], but, for the reasons given above, it is not possible to raise F2 sufficiently in the transitions of a dental fricative.

This does leave the question of how dentals and labio-dentals are distinguished before [i] in dialects that maintain the contrast. Possibly with greater effort, F2 transitions could be made more distinct than in (40), but examination of my own productions suggests that F2 and F3 transitions are very similar in [fi, θi, vi, ði], so perhaps it is possible to realize more information in the frication noise than Harris (1958) suggests. For example, labio-dental frication is generally more intense than dental frication.

It also possible to produce F2 transitions higher than [F2 *2*] with a dental adjacent to fully back [u] or [ɔ], but this would require a rapid change in lip-rounding which is assumed to be ruled out by effort avoidance constraints (greater tongue body fronting is ruled out for the reasons already discussed).

Where contrasts between dentals and labio-dentals are neutralized, the fricatives are realized as labio-dental. This yields a more distinct contrast with other coronal fricatives, [s, z], in most contexts, since the formant transitions are more distinct, and in many contexts the labio-dental may be easier to produce since it does not conflict with tongue position for adjacent vowels.

5.5. SIMPLIFICATION

The process that we are calling simplification involves the substitution of a simple consonant for a complex consonant or cluster. The cases that are of interest here are those in which the simple consonant differs articulatorily from the complex one, as in the simplification of a palatalized labial stop to a dental. As argued by Ohala (1992) auditory similarity between the clusters and the resulting simple consonants plays a key role in simplification processes.

Most of the cases considered here are diachronic developments, and are not reflected in productive alternations, although they obviously result in new synchronic patterns in the distribution of contrasts. The patterns of interest are simplification of labialized consonants to plain labials, and simplification of palatalized consonants to plain coronals. The first pattern is exemplified by the change from labialized velars to labial stops in the development of Romanian from Latin (Bourciez 1967) (41), and the change from Early Latin labialized coronal [dw] to Classical Latin labial [b] in word-initial position (Maniet 1964) (42). Other examples are mentioned in Kawasaki (1982:30ff.).

(41)	<u>Latin</u>	>	<u>Romanian</u>	
	akwa		apə	'water'
	ekwa		iapə	'mare'
	liŋgwa		limbə	'tongue'
	kwattuor		patru	'four'

(42)	<u>Early Latin</u>	>	<u>Classical Latin</u>	
	dwonos		bonus	'good'
	dwellom		bellum	'war'
	dwis		bis	'twice'

Simplification of palatalized consonants to plain coronals is exemplified by the change of palatalized labials to dental stops in some Czech dialects (Andersen 1973):

(43)	<u>Old Czech</u>	>	<u>Litomyšl Czech</u>	
	p^{j}ěkn^{j}e		tekn^{j}e	'nicely'
	b^{j}ěʒeti		deʒet	'run'
	m^{j}ěsto		nesto	'town'

Some such cases may involve fortition of glides rather than neutralization of indistinct sounds, as in the development of French palato-alveolars from Latin palatal glides (§4.2.1.5). This seems to be true of Romanian, where Latin [w] became [v] initially and after [n], and became [b] after [r] (e.g. Latin [korwu] > Romanian [korb] 'crow') (Hall 1976). This suggests a development along the lines [kw] > [kp], followed by assimilation or deletion of [k], rather than a direct change from [kw] to [p].

In other cases, it is likely that neutralization due to similarity between obstruent-glide clusters and simple consonants only arises where there is some independent weakening of secondary articulations. A labio-velar glide before a front vowel is not very similar to a plain labial. E.g. [k^{w}i] should not be confusable with [pi] because the F2 transition in the former is much lower than in the latter. In general, secondary articulations are most distinct preceding vowels with very different F2 specifications [k^{w}i, p^{j}u], but these are also precisely the environments where their production involves the greatest effort due to the substantial movement between glide and vowel. Consequently, effort minimization might result in assimilation to the vowel, which would result in formant transitions closer to a plain consonant. E.g. [k^{ɥ}i] with some rounding, but no backing of the stop could have formant transitions more comparable to [pi]. It is possible that these or other constraints militating against secondary articulations are the driving force in some cases of simplification rather than elimination of indistinct contrasts per se. For example, the Czech developments described above arose in the course of losing all palatalization contrasts. What all of these scenarios have in common is that they involve changes which are auditorily gradual, although they involve abrupt changes in the articulatory domain, such as a change of primary articulator.

Interestingly there are no examples, diachronic or synchronic, in a which a velarized consonant simplifies to a plain velar, so we can summarize the attested patterns as in (44). This is parallel to the situation observed with respect to consonant-vowel assimilation (§4.3), as is expected given an analysis in terms of auditory similarity. Velarization involves a high back tongue body position, so velarized consonants are characterized by a low F2 at release. However, the F2 at the release of a plain velar depends on vowel context, and so is not necessarily low. The Hume-Clements feature theory, on the other hand, would lead us to expect a relationship between velarized consonants and plain velars. The attested developments could be analyzed in terms of their model as promotion of V-place [labial] or [coronal] to C-place, supplanting the original primary place of the consonant. But such an analysis would predict the development from velarized consonants to velars by promotion of [dorsal].

(44)	labialized C	→	labial	e.g. Latin
	palatalized C	→	coronal	e.g. Czech
	velarized C	–×→	*velar	

5.6. SUMMARY

The neutralization phenomena considered here provide direct evidence for the importance of auditory features in phonology because they exemplify neutralization between sounds or sequences which are auditorily similar but articulatorily distinct. The role of auditory representations in neutralization is accounted for in terms of the requirement that contrasts be auditorily distinct: neutralization is one way to avoid contrasts that would otherwise be insufficiently distinct. Many of these examples also provide support for the claim that distinctiveness constraints evaluate contrasts, showing that indistinct contrasts are problematic rather than the segment sequences themselves. The evidence for this claim comes primarily from typological variation in the outcome of neutralization, e.g. many languages disallow [kl-tl] contrasts, but some achieve this by eliminating [kl], while others eliminate [tl] (§5.3). We saw similar dialectal variation in the results of neutralizing [t-tj] contrasts in American English (§5.1). In both cases, the common factor is the dispreference for an indistinct contrast, and the differences result from variation in the ranking of the constraints that determine the outcome of neutralization.

This chapter completes our analysis of phenomena that provide evidence for auditory representations. The next chapter addresses some problems relating to the analysis of alternations in dispersion theory, and chapter seven concludes the dissertation.

NOTES

1. In some cases, such as [ǽnjuəl] 'annual', a full vowel appears after the palatal glide. This is due to the prevocalic position of the [u]. The vowels [i] and [oʊ] can also appear in unstressed prevocalic position (e.g. [fǽnsi̠əst] 'fanciest', [dʒénoʊ̠ə] 'Genoa'). However, as noted, /u/ does not appear in unstressed syllables without a preceding palatal so no contrast results.

2. In English, F2 at the release of a velar preceding /u/ is often significantly higher than F2 at the release of a labial. This is due to the fact that /u/ is not fully back in many dialects, and is often slightly diphthongized, with F2 dropping through the vowel. Consequently F2 is lower at the closure of a velar following /u/. In languages with a fully back /u/ like Swedish, labials and velars have similar, very low F2 transitions both preceding and following /u/ (Öhman 1966). My own unpublished data from German, another language with a fully back /u/, show the same pattern.

3. Judging from the adaptation of words of Chinese origin, this is the result of a process of glottal replacement (Downer 1961:539 fn.1), but we will not attempt to derive this pattern here.

4. The languages listed by Kawasaki are Breton, Danish, Dutch, English, German, Modern Greek, Norwegian, Pacóh, Kisi, Hayu, Lakkia, Thai, Palaung, Chamorro, Sre, Sedang, Oneida, Cua, Ewe, Wobé and Guéré.

CHAPTER 6

Minimization of Allomorphy

In §2.2.5, we saw that the dispersion theory of contrast needs to be supplemented by a theory of morphophonological alternations. In Prince and Smolensky (1993) the extent of variation between allomorphs is limited by faithfulness constraints because these constraints require surface realizations of a morpheme to be similar to the underlying form of the morpheme. But faithfulness constraints are fundamentally incompatible with dispersion constraints because they also effectively favor maintaining contrasts, a function which is taken over by MAXIMIZE CONTRASTS in dispersion theory.

The alternative approach proposed here is to separate the analysis of restrictions on alternations from the conceptually distinct domain of contrast. Similarity between allomorphs is accounted for in terms of constraints that directly require the surface forms of a single morpheme to be similar to each other. This amounts to a requirement that allomorphy be minimized. This analysis of alternations raises issues that go well beyond the scope of this dissertation. The primary goals of the present discussion are to indicate lines along which we can develop a theory of alternations which is compatible with the dispersion theory of contrast, and to show that this approach is independently motivated.

6.1. ALLOMORPHY

Allomorphic variation is one of the fundamental phenomena that phonology must account for, and the structure of generative phonological theory has been shaped by this task. There are two basic observations: (i) The phonetic form of a morpheme varies with its context, and (ii) this variation is limited. These points are illustrated by the simple English examples in (1). In (1a) we observe two allomorphs of 'atom', and in (1b) three allomorphs of the plural suffix. While in each case the allomorphs differ, they still bear substantial resemblance to each other. Indeed, these similarities of form coupled with consistency of meaning are the basis for positing that they are allomorphs of a single morpheme.

(1) a. ǽɾəm ‘atom’ b. kæts ‘cats’
ət^{h}ámɪk ‘atomic’ dɑgz ‘dogs’
mætʃəz ‘matches’

The standard analysis of similarities between allomorphs involves proposing a unique underlying form of the morpheme from which all surface allomorphs are derived. A second component of the analysis must be some requirement that outputs be similar to inputs, otherwise an output need bear no resemblance to the input, and derivation from a common underlying form would in no way guarantee allomorphic similarity. Faithfulness fulfills this function. This approach is illustrated in (2).

Unique underlying representations are an indirect means of accounting for observed similarities between allomorphs. In effect the underlying form mediates a requirement that the surface allomorphs be similar, because each of the surface allomorphs is required to be similar to that unique underlying representation (3). The observed allomorphic similarities can be accounted for much more directly in terms of requirements that the surface allomorphs of a morpheme be similar to each other (4). Constraints of this form are now familiar from analyses of cyclicity and paradigm leveling effects, as will be discussed further below. We will follow Steriade (1994b, 2000) in referring to them as Paradigm Uniformity constraints, but they are also known as Output-Output Correspondence constraints (e.g. Benua 1997).

(2) /ætɑm/ ‘atom’ /-z/ ‘(pl.)’
↓ ↓ ↓ ↓ ↓
[ǽɾəm] [ət^{h}ám-ɪk] [-s] [-z] [-əz]

(3) [ǽɾəm]←/ætɑm/→[ət^{h}ám]

(4) [ǽɾəm]↔[ət^{h}ám]

Note that this approach eliminates underlying representations from phonology. The work that was done by such a representation is replaced by the direct requirements of similarity between allomorphs of a morpheme. We do need to retain the notion that there is an underlying unity to allomorphs, i.e. that they are realizations of a single morpheme, but morphemes do not have a unique phonological representation. So in the examples in (1), we need to identify a single morpheme that appears in all the forms shown, but no unique underlying phonological representation is assigned to the morpheme. It is realized by a set of allomorphs which are constrained to be similar by Paradigm Uniformity constraints. Anderson (1985:50ff.) attributes a comparable view of alternations to Saussure.

This theory of allomorphic similarity is compatible with the dispersion theory of contrast, as can be seen from an analysis of alternations that arise in the pattern of Sicilian vowel reduction discussed in §2.3.3.1. In Sicilian Italian, a five vowel system, /i, e, a, o, u/, reduces to three vowels /i, a, u/ ([ɪ, ɐ, ʊ]) in unstressed syllables (Mazzola 1976:41):

(5)	vínni	'he sells'	vinnímu	'we sell'
	véni	'he comes'	vinímu	'we come'
	ávi	'he has'	avíti	'you have'
	móri	'he dies'	murímu	'we die'
	úggyi	'he boils'	uggyímu	'we boil'

We analyzed the reduction in contrasts in terms of the constraint ranking shown in (6) and (7). This ranking results in an inventory with three vowel heights in stressed syllables (6), but only two in unstressed syllables due to the constraint *SHORT PERIPHERAL V (7).

(6) Vowels in stressed syllables.

		*SHORT PERIPHERAL V	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	í-á			✓✓!	
b.	> í-é-á			✓✓✓	**
c.	í-é-ɛ́-á		*!*	✓✓✓✓	***
d.	í-ɪ́-á		*!	✓✓✓	*
e.	ɪ́-á			✓✓!	

(7) Vowels in unstressed syllables.

		*SHORT PERIPHERAL V	MINDIST = F1:2	MAXIMIZE F1 CONTRASTS	MINDIST = F1:3
a.	ĭ-ĕ-ă	*!*		✓✓✓	**
b.	ɪ̆-ĕ-ɐ̆		*!*	✓✓✓	**
c.	> ɪ̆-ɐ̆			✓✓	*

While this ranking can account for the reduction in contrasts, it cannot account for the resulting alternations, illustrated in (5), above. A standard analysis of such alternations would posit an underlying form for each root with the vowel quality as seen under stress. When unstressed the vowel would surface with the closest permissible vowel, as determined by the faithfulness constraints. An analysis along these lines is not consistent with the dispersion theory of contrast because the adoption of faithfulness constraints would yield an inconsistent model in which there are two sources of contrast maintenance: MAXIMIZE CONTRASTS and faithfulness.

We can account for the alternations in terms of paradigm uniformity constraints, requiring that the allomorphs of the roots be similar across morphological contexts. We need to break down paradigm uniformity into constraints requiring uniformity with respect to particular dimensions, as shown in (8), where Paradigm Uniformity(*D*) (PU(*D*)) is a constraint requiring that allomorphs of a morpheme have a uniform value on dimension *D*. Violations are assumed to be scalar, according to the difference between allomorphs on the relevant dimension. The two Paradigm Uniformity constraints are added to the existing ranking. The ranking of Paradigm Uniformity with respect to the rest of the hierarchy is indeterminate, but we shall see that the uniformity constraints must be ranked as shown with respect to each other.

In (8) we are considering the case of a root which has a mid vowel when stressed, alternating with a high vowel in unstressed position. The candidates consist of the two morphologically related forms (1st person plural and 3rd person singular) in the first row, with forms contrasting with the 1st person form in vowel F1 arranged below it, to allow evaluation of the contrast constraints. The first two candidates maintain a consistent vowel quality in the root, thus satisfying both Paradigm uniformity constraints, but each is rejected by the constraints on contrasts. Candidate (a) violates *Short peripheral vowel (*S.P.V.), as in (7). The second candidate is rejected because the contrast between [e] and [ɐ] violates MinDist = F1:2. Candidates (c) and (d) have well-formed contrasts, between [ɪ] and [ɐ] (cf. 7), but differ in whether the stressed mid vowel alternates with the higher or lower vowel. In either case there is a violation of paradigm uniformity, but the alternation with the high vowel (candidate c) satisfies higher ranked ‘PU(F2)’, and so is optimal.

(8)		*S.P.V.	MinDist = F1:2	Max contrasts	MinDist = F1:3	PU (F2)	PU (F1)
a.	ve̱nímu ↔ vé̱ni vi̱nímu va̱nímu	*!*		✓✓✓	**		
b.	ve̱nímu ↔ vé̱ni vɐ̱nímu		*!	✓✓	**		
c. ☞	vɪ̱nímu ↔ vé̱ni vɐ̱nímu			✓✓	*		*
d.	vɐ̱nímu ↔ vé̱ni vɪ̱nímu			✓✓	*	*!*	*

Note that we have not considered candidates that satisfy paradigm uniformity by raising the stressed alternant to [ɪ]. Candidates of this form are ruled out by the constraints on contrast since they involve either an insufficiently distinct F1 contrast (6d) or insufficient contrasts (6e).

The precise form of the Paradigm Uniformity constraints remains open. They are intended to evaluate similarity between allomorphs in much the same way that MinDist constraints evaluate difference between contrasting forms, so it is likely that a comparable decomposition of PU constraints is required to reflect the relative magnitude of differences on various dimensions and combinations of dimensions (cf. Steriade 2000, 2001).

This analysis avoids the problems raised by input–output relations by evaluating alternations directly, using PARADIGM UNIFORMITY constraints. The theory of paradigm uniformity outlined here is admittedly. The primary concern here is the theory of contrast, so this account of allomorphy is offered as a program for the resolution of problems raised by the theory of contrast. Full development of a paradigm uniformity-based analysis of allomorphy will have to await further work. However Paradigm Uniformity constraints are independently motivated by analyses of cyclicity, paradigm leveling, and morpheme structure constraints, and we will see that the proposed analysis of alternations is a natural generalization of these applications of Paradigm Uniformity (a point also made by Burzio 1998)[1].

6.2. CYCLICITY AND PARADIGM LEVELING

Cyclicity phenomena can informally be characterized as cases of unexpected similarity between a derived form and a base form (Steriade 1994b, 2000). An example is Spanish depalatalization (Harris 1983). In Spanish, palatal nasals become alveolar in coda, so a form like /desdeɲ/ 'contempt' surfaces with a final alveolar nasal when unaffixed (9a). The fact that this nasal is underlyingly palatal is shown by the infinitive verbal form, where it surfaces in onset, and thus does not undergo depalatalization. However, in the plural of the nominal, depalatalization applies even though the nasal surfaces in onset (9b). This contrasts minimally with second person singular of the verbal form. The over-application of depalatalization in the plural noun appears to be motivated by a requirement of similarity to the bare form of the root, which is the singular.

(9)	a.	des.den	'contempt'		des.de.ɲ-ar	'to despise'
	b.	des.de.n-es	'contempt (pl.)'	cf.	des.de.ɲ-es	'you despise'

The term 'cyclicity' comes from the mechanism which has been proposed to account for such phenomena within a derivational framework (Chomsky and Halle 1968). This standard analysis accounts for unexpected similarities between derived and basic forms by proposing that phonological rules apply to successively larger sub-constituents of a complex word. An illustration of this 'cyclic' mode of derivation is shown in (10) (essentially following Harris 1983).

(10) [[desdeɲ]-es]
↓ cycle 1 - depalatalization
[des.den-es]
↓ cycle 2
des.de.nes

However, the informal characterization of cyclicity as involving unexpected similarity between the surface forms of a morphologically derived word and its base can be directly implemented in terms of a requirement of similarity between the realizations of a morpheme in both the base and the derived form. I.e. cyclic effects can be analyzed as the result of paradigm uniformity constraints which apply to sub-paradigms constituted by forms which are closely related morphologically, such as the singular and plural nouns in (9). This general approach to the analysis of cyclicity effects has been proposed and developed by a number of researchers (e.g. Burzio 1998, Benua 1997, Kenstowicz 1996, Steriade 1994, 2000). This work provides independent evidence for the existence of constraints which enforce similarity between the surface forms of a morpheme, i.e. paradigm uniformity constraints (but see Kiparsky 2001 for counter-arguments).

From the perspective of a general analysis of allomorphic similarity in terms of paradigm uniformity, cyclicity effects are the results of stronger similarity requirements applying to allomorphs in more closely related morphological forms. I.e. in the Spanish example, stricter paradigm uniformity constraints apply to roots within a noun paradigm than apply across the complete paradigm of a root like [desdeɲ], so depalatalization is generalized from the singular to the plural noun, but not from a singular noun to a verbal form. However, weaker paradigm uniformity constraints do enforce the general similarities between noun and verb forms of the root morpheme (cf. Burzio 1998). This is illustrated schematically by the constraint ranking in (11). The constraint enforcing depalatalization, *PALATAL]$_\sigma$, is ranked above MAXIMIZE CONTRASTS, so the contrast between palatal and alveolar nasals is neutralized in coda. NOUN PU, a constraint requiring uniformity within the noun paradigm, is also ranked above MAXIMIZE CONTRASTS, so this neutralization is generalized to the plural noun. However, the general PU constraint which requires similarity across all realizations of a root morpheme is ranked below MAXIMIZE CONTRASTS, so the palatalization contrast is maintained among verbs, even though this results in an alternation between the noun stem [desden] and the verb stem [desdeɲ].

(11) NOUN PU, *PALATAL]$_\sigma$ >> MAXIMIZE CONTRASTS >> PU

We turn now to paradigm leveling, the well-known phenomenon by which rules over- or under-apply in order to maintain uniformity in the realization of a morpheme throughout a paradigm (e.g. Harris 1973, Kiparsky 1982a). Cases of paradigm leveling between multiple derived forms (rather than between a derived form and its base, as in cyclic effects) provide even stronger evidence for the existence of paradigm uniformity constraints because these cases cannot be accounted for in terms of faithfulness to an underlying representation or cyclic derivation, as we will see. This situation is be exemplified by the Latin process of rhotacism (Kiparsky 1982a).

Rhotacism is a process by which *s* becomes *r* intervocalically, and gives rise to alternations such as that shown in (12).

(12) *s* → *r* /V_V e.g. *ōs* (nom. sg.) - *ōris* (gen. sg.) 'mouth'

Rhotacism also applies in the nominative singular of polysyllabic third declension nouns in spite of the fact that the environment for the rule is not present. This can be seen from the forms in (13). The adjectival forms show that the final consonants of these roots is *s*. Rhotacism is expected to apply in the genitive singular, where a vowel-initial suffix is added to the root, however rhotacism also applies in the nominative singular, even though the underlying *s* is not in intervocalic position. This pattern of over-application is regular in polysyllabic nouns of this declension[2].

(13)	Nom. sg.	Gen. sg.				
	honor	honōris	'honour'	cf.	hones-tus	'honest'
	arbor	arbōris	'tree'		arbus-tus	'wooded'
	rōbur	rōburis	'oak'		rōbus-tus	'robust'
	augur	auguris	'augur'		augus-tus	'august'

The explanation for the over-application of rhotacism, proposed by Kiparsky (1982a), is that it serves to produce a consistent final consonant for the stem throughout the nominal paradigm (14), eliminating an allomorph with final *s*[3]. This scenario corresponds to the historical development: the earlier nominative form was *honōs*.

(14)	Nom.	honor	cf. earlier:	honōs
	Gen.	honōr-is		honōr-is
	Acc.	honōr-em		honōr-em
		etc.		etc.

That is, application of rhotacism in the nominative is motivated by a requirement that morphemes should have a consistent form throughout a paradigm. This can be regarded as a particular instance of a more general class of constraints requiring that morphemes should have a consistent form in all environments, i.e. that allomorphic variation should be minimized.

This analysis can be formalized in terms of the constraint ranking in (15). The basis of rhotacism is not properly analyzed here, we simply state a constraint against intervocalic *s*, and assume that unstated constraints enforce the selection of *r* in its place. Our main concern here is not the nature of rhotacism per se, but rather with the analysis of its over-application.

(15)	RHOTACISM,	*s/ V_V
	PARADIGM UNIFORMITY >>	'Avoid root allomorphy in paradigms'
	MAXIMIZE CONTRASTS	

The operation of the ranking is illustrated in (16). The candidate sets here contain a nominal paradigm, with the nominative underlined. In addition, to evaluate MAXIMIZE CONTRASTS, we need the nominative of a possible root that exemplifies this contrast. Only root-final *s-r* contrasts are counted in the tableau, since candidates are assumed to be similar in other respects. The first candidate satisfies RHOTACISM by applying the change intervocalically, but as a result violates high-ranked PARADIGM UNIFORMITY. The second candidate satisfies PARADIGM UNIFORMITY by maintaining the underlying *s* throughout the paradigm, but this violates RHOTACISM in all the forms with vowel-initial suffixes[4]. The winning candidate satisfies uniformity by 'over-application' of rhotacism in the nominative, yielding consistent root-final *r*, but neutralizing any contrast between final *r* and *s*.

(16)			RHOTACISM	PARADIGM UNIFORMITY	MAXIMIZE CONTRASTS
	<u>augus</u> - augur-is augur-em etc	augur augur-is augur- em etc		*!	✓
	<u>augus</u> - augus-is augus-em etc	augur augur-is augur- em etc	*!*…		✓✓✓…
☞	<u>augur</u> augur-is augur-em etc				

PARADIGM UNIFORMITY places a well-formedness condition on a set of forms, namely a paradigm. This property of the constraint is essential to the analysis because, as Harris (1973:75) observes, '..the question of the paradigm is multiderivational. That is, information relevant to derivation of a given form may be found in the paradigms of which this form is a member, rather than in the representations of the form itself'. As a result, paradigm leveling cannot be analyzed in terms of similarity of an output to an input underlying form, because what is involved is a requirement of similarity to the surface form of a separate word.

Moreover, if any form in the paradigm constitutes the base of derivation for the rest in the Latin noun declension, it should be the nominative singular, but this is the form which is altered to satisfy PARADIGM UNIFORMITY, so a cyclic analysis of leveling of rhotacism is untenable[5]. In terms of PARADIGM UNIFORMITY constraints, however, leveling of rhotacism is essentially similar to a cyclicity effect: Both involve stronger uniformity effects applying to a sub-paradigm containing closely related forms of a root. The various case forms of the noun *augur* form a paradigm, as do the various cases of the adjective *augustus*, and both of these paradigms are part of a single extended paradigm since they have a common root (17). Higher-ranked PARADIGM UNIFORMITY constraints apply to the noun paradigm than apply to the complete paradigm of this morpheme, resulting in extension of rhotacism through this sub-paradigm. Lower-ranked general PARADIGM UNIFORMITY constraints enforce the similarities observed across all realizations of the root.

(17)

$$\left[\begin{array}{c}\left[\begin{array}{c}\text{augur}\\ \text{augur-is}\\ \text{:}\end{array}\right]\\ \left[\begin{array}{c}\text{augus-tus}\\ \text{:}\end{array}\right]\end{array}\right]$$

McCarthy (1998) and Flemming (1998) offer a third kind of argument for Paradigm Uniformity constraints: they are necessary for the analysis of apparent morpheme structure constraints within Optimality Theory. For example, morphemes in Spanish do not end in [m]. This is clearly related to the fact that the contrasting nasals are neutralized to [n] in coda[6], but cannot be fully explained by the output constraints that account for this pattern because morpheme-final [m] never surfaces even when vowel-initial suffixes are added which should allow the labial nasal to surface in onset position[7]. That is, neutralization of nasal place contrasts is generalized from the unsuffixed form of morphemes to all realizations of those morphemes. This generalization of neutralization can be analyzed in terms of Paradigm Uniformity constraints. This argument is laid out in detail by McCarthy (1998), who analyzes cases where Paradigm Uniformity constraints allow the principled derivation of apparently idiosyncratic morpheme structure constraints.

The existence of morpheme structure constraints demonstrates a problem with conflating maximization of contrasts with minimization of allomorphy in a single set of faithfulness constraints. It is central to the faithfulness-based analysis of the distribution of contrasts that the set of inputs should be universal ('richness of the base', Prince and Smolensky 1993:91), so faithfulness constraints favor maintaining all possible contrasts, and restrictions only arise from the ranking of markedness constraints with respect to faithfulness. However, if the input is also the construed as the underlying representation, then richness of the base implies that all possible inputs are possible morpheme underlying representations in every language. This means that any constraint ranking that allows more than one output realization of an input segment predicts the existence of alternations between these realizations, given appropriate morphology. E.g. any ranking that accounts for the distribution of nasals in Spanish will faithfully map input [m] to [m] in some environments, but must unfaithfully map [m] to something else (e.g. [n], or [m] followed by a vowel), where it would otherwise surface in coda. This then predicts that underlying [m] should be able to alternate, given appropriate morphology (e.g. vowel-initial suffixes). The existence of morpheme structure constraints shows that this prediction does not generally hold—i.e. there can be neutralization without alternation. Separating maximization of contrasts from the regulation of alternations, as proposed here, eliminates this problematic prediction.

We began this chapter by observing that faithfulness to a unique underlying representation serves to limit allomorphic variation. We have proposed that this function is better served by Paradigm Uniformity constraints that directly require the surface realizations of a morpheme to be similar to each other. In this section we have seen that this analysis represents a natural generalization of the role of Paradigm Uniformity constraints which are independently motivated by cyclicity phenomena, paradigm leveling, and morpheme structure constraints.

NOTES

1. Hayes (1999) also explores the idea that underlying representations should be replaced by Paradigm Uniformity constraints.

2. Leveling only applies in the third declension because stems in other declensions are vowel-final, so suffixation cannot produce rhotacism alternations in the stem. There are two other restrictions on leveling: First, monosyllabic roots such as *flōs* 'flower (nom. sg.)' do not undergo leveling although rhotacism does apply in forms like *floris* (gen. sg.). Kiparsky (1974) suggests that this is due to a general restriction against monosyllabic stems in *–or*. Whatever constraint accounts for this generalization can also account for the failure to generalize rhotacism into this context if it is ranked above PARADIGM UNIFORMITY. Second, neuter nouns in *–us* do not undergo leveling, e.g. *tempus-temporis* 'time' (nom.-gen.), not **tempur – temporis*.

3. Kiparsky has more recently argued that the generalization of rhotacism is actually the result of generalization of an /-is/ form of the nominative singular suffix (Kiparsky 1998).

4. Thanks to Donca Steriade (p.c.) for suggesting this account of the direction of leveling.

5. See Steriade (1999), Burzio (1998), and Kenstowicz (1996) for further evidence that uniformity constraints apply between forms which do not stand in a base-derivative relationship.

6. Some dialects allow velar [ŋ] in coda rather than [n], but all dialects neutralize place contrasts between nasals in this position.

7. Harris (1984) reports one exception to this generalization, citing [adamísmo] ‘Adamism’ and [adámico] ‘Adamic’ as derivatives of [adán] ‘Adam’. Native speakers who I have consulted vacillate on whether they prefer [n] or [m] in these forms.

CHAPTER 7

Conclusions

7.1. THE DISPERSION THEORY OF CONTRAST

The main theoretical proposal advanced in this dissertation is the dispersion theory of contrast. As detailed in chapter two, the core of dispersion theory is the claim that the selection of phonological contrasts is subject to the three goals listed in (1). These goals derive from the communicative function of language. The following sections discuss some important implications of this theory.

(1)
- i. Maximize the number of contrasts
- ii. Maximize the distinctiveness of contrasts
- iii. Minimize articulatory effort

7.2. AUDITORY REPRESENTATIONS

Auditory representations assume a central role in phonology through their importance in the analysis of contrast. That is, distinctiveness is an auditorily-based property, so implementation of the preference for more distinct contrasts requires auditory representations. The formulation proposed here posits MINDIST constraints which require contrasting sounds to be separated by a minimum auditory distance. These auditory distances are determined by comparing the auditory representations of the sounds (§2.2.1). This implication of dispersion theory has been the main focus of this dissertation.

In presenting evidence for auditory representations we have focused on phenomena which involve interactions between sounds that do not have any articulatory basis, but can be understood in auditory terms. However, this should not be taken to imply that auditory representations are only required to account for a few marginal phenomena, and that phonology is otherwise articulatorily-based. On the contrary, MINDIST constraints are obviously very generally applicable, so the model developed here implies that auditory representations are relevant to most phonological phenomena, even those which have been thought to be articulatory in basis. There is already substantial evidence that this is the case. For example, Steriade (1997) argues that the environments in which obstruent voicing contrasts are neutralized are those in which 'cues to the relevant contrast would be diminished', as discussed in §2.3.3 above. Voicing neutralization through devoicing or assimilation is articulatorily natural—i.e. it plausibly results in reduced articulatory effort—but the environments in which it applies are governed by perceptual factors. Similarly Jun (1995), Kohler (1990), and Ohala (1990) provide evidence that the typology of place assimilation in consonant clusters is shaped by perceptual factors. Here we have argued that distinctiveness constraints play a key role in neutralizing vowel reduction, although the relevant patterns are not difficult to describe in articulatory terms (§2.3.3.1).

Finally, we have only documented one type of constraint that refers to auditory representations, but there may be others. For example, it is likely that the PARADIGM UNIFORMITY constraints discussed in chapter six require that the realizations of a morpheme should be auditorily similar (cf. Steriade 2001).

7.3. PARADIGMATIC CONSTRAINTS

A second implication of dispersion constraints is that the well-formedness of a word cannot be evaluated in isolation because it depends on the well-formedness of the contrasts that it enters into. That is, MINDIST and MAXIMIZE CONTRASTS constraints are paradigmatic in the sense that they place requirements on sets of contrasting forms rather than on individual forms. So a form can only be evaluated with reference to a set of forms that it contrasts with. Evidence for this property of the constraints on contrast was presented in chapter 2. PARADIGM UNIFORMITY constraints are also paradigmatic in this sense—they impose constraints on sets of morphologically related words, and thus cannot be evaluated with respect to a single form. The existence of paradigmatic constraints implies a departure from the usual conception of phonological well-formedness as a property of individual words.

7.4. PHONETIC AND PHONOLOGICAL REPRESENTATIONS

The dispersion theory of contrast also has consequences for the relationship between phonetic and phonological representations, removing one of the reasons for distinguishing the two.

It is often assumed that there is a division between phonology and language-specific phonetics (e.g. Keating 1984, 1990; Pierrehumbert 1990). According to such models, the output of the phonology is the input to a phonetic component which maps it onto a phonetic representation as schematized in (2). The phonetic component serves to supply the substantial quantity of phonetic detail that is excluded from phonological representations, much of which is language-specific (Keating 1985). For example, standard phonological representations do not specify the shorter closure duration of voiced stops compared to voiceless stops, or the shortening of vowels before voiceless obstruents.

(2)

Phonology

⇓

Phonetics

⇓

Phonetic representation

A common argument for distinguishing phonetic and phonological representations holds that this is necessary in order to avoid over-predicting the range of possible phonological contrasts. This argument proceeds from the observation that the range of possible phonological contrasts is much smaller than the range of phonetic differences. A common strategy for accounting for this observation has been to restrict phonological representations. I.e. if a given difference is non-contrastive, this is accounted for by making it impossible to represent that difference at the phonological level. For example, no language seems to contrast more than two degrees of nasalization (oral and nasal), so a single binary (or privative) feature [nasal] is posited, making it impossible to represent the finer distinctions of nasalization that can be distinguished phonetically, but do not form the basis for contrasts.

This rationale for restricting phonological representations by minimizing the feature set is expressed clearly by Keating (1984:289) in a comment on laryngeal features:

> '...[Halle and Stevens] (and SPE) don't simply have the wrong features in these instances; they will ALWAYS have TOO MANY features because they want to describe exactly how individual sounds are articulated. While we want the phonological features to have some phonetic basis, we also want to distinguish possible contrasts from possible differences.'

The same idea is expressed in McCarthy's (1994) statement that 'An adequate theory of phonological distinctive features must...be able to describe all and only the distinctions made by the sound systems of any of the world's languages' (p. 191).

The basis of this approach to the analysis of contrast is the assumption that any difference that is representable in lexical representations should be a possible contrast, so to restrict possible contrasts, restrictions have to be imposed on possible representations. This assumption is far from necessary, as the dispersion theory of contrast demonstrates. In dispersion theory, well-formed contrasts are selected from a wide range of representational possibilities by constraints on contrasts. Restrictions on contrast are thus accounted for in terms of the theory of constraints rather than the theory of representations (cf. Kirchner 1997). Specifically, a minimum degree of auditory distinctiveness is required for a contrast to be acceptable in any language—i.e. some MINDIST constraints are inviolable.

Dispersion theory offers a more satisfactory account of restrictions on attested contrasts than an approach based on limiting the phonological feature set. First, restricting the set of features is not sufficient because it is also necessary to restrict possible combinations of features. For example, [nasal] is never contrastive on pharyngeals or glottal stops. There is an obvious explanation for this restriction, namely that lowering the velum during a pharyngeal or glottal has little acoustic effect because a constriction is formed below the velopharyngeal port, so lowering the velum will result in little or no nasal airflow, and thus will not produce significant auditory effects.

Restricting the feature set also has limited explanatory value. Accounting for the fact that languages do not contrast more than two levels of nasalization by positing that there is a single feature [nasal] only defers the question. We can still ask why there is only one such feature, whereas there are usually at least two features that refer to vowel height. Both of these considerations point to the need for a requirement that contrasts reach a minimum level of auditory distinctiveness. Languages do not contrast multiple levels of nasalization because they would not be sufficiently distinct auditorily. This principle also explains why nasalization is not contrastive on pharyngeals and glottals, as outlined above. So, in the context of the Dispersion theory, we can see that these problems reduce to the question of what constitutes a sufficient auditory difference to sustain a contrast.

Finally, attempts to account for restrictions on possible contrasts by restricting representations leads to conflicting requirements on the feature set. Phonological features must also allow us to formulate phonological generalizations or rules, and it is far from clear that a single set can fulfill both functions. It is common to refer to non-contrastive properties such as syllabification in formulating rules, and there is good evidence that we need to refer to non-contrastive segmental properties also, such as the presence of audible release on stops (Steriade 1993a). This conflict can be resolved by abandoning the attempt to account for restrictions on contrast in terms of the feature set. The sole criterion for inclusion in phonological representation is then relevance to phonological generalizations.

In summary, the dispersion theory shows that one of the main arguments for limiting phonetic detail in phonological representation is based on an unnecessary and rather problematic assumption. This opens the possibility that phonological representations include full phonetic detail—i.e. that phonetic and phonological representations are not distinct[1].

NOTES

1. These issues are explored in more detail in Flemming (2001) and Kirchner (1997).

References

Al-Ani, Salman (1970). *Arabic phonology*. Mouton, The Hague.

Andersen, Henning (1973). Abductive and deductive change. *Language* 49, 765–93.

Anderson, Stephen R. (1976). Nasal consonants and the internal structure of segments. *Language* 52, 326–44.

Anderson, Stephen R. (1985). *Phonology in the twentieth century: Theories of rules and theories of Representations*. University of Chicago Press, Chicago.

Anderson, Victoria B. and Ian M. Maddieson (1994). Acoustic characteristics of Tiwi coronal stops. *UCLA Working Papers in Phonetics* 87, 131–162.

Anttila, Arto (1997). Deriving variation from grammar. Frans Hinskens, Roeland van Hout, and Leo Wetzels (eds.) *Variation, change, and phonological theory.* Benjamins, Amsterdam, 35–68.

Archangeli, Diane, and Douglas Pulleyblank (1994). *Grounded phonology.* MIT Press, Cambridge.

Atal, B.S., J.J. Chang, M.V. Mathews, and J.W. Tukey (1978). Inversion of articulatory-to-acoustic transformation in the vocal tract by a computer-sorting technique. *Journal of the Acoustical Society of America* 63, 1535–1555.

Bahl, Lalit R., Frederick Jelinek, and Robert L. Mercer (1983). A maximum likelihood approach to continuous speech recognition. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* Vol. PAMI-5, no. 2, 179–190.

Bauer, Robert S., and Paul K. Benedict (1997). *Modern Cantonese phonology*. Mouton de Gruyter, Berlin.

Beckman, Mary E. (1986). *Stress and non-stress accent*. Foris, Dordrecht.

Bender, Byron (1968). Marshallese phonology. *Oceanic Linguistics* 7, 16–35.

Benua, Laura (1997). *Transderivational identity.* Ph.D. dissertation, University of Massachusetts, Amherst.

Bladon, R.A.W. (1979). The production of laterals: Some articulatory properties and their acoustic implications. Harry F. Hollien and Patricia Hollien (eds.) *Current issues in the phonetic sciences*. John Benjamins, Amsterdam, 501–508.

Boersma, Paul (1998). *Functional phonology*. Ph.D. dissertation, University of Amsterdam.

Borowsky, Toni (1986). *Topics in the lexical phonology of English*. Ph.D. dissertation, University of Massachusetts, Amherst.

Bourciez, Édouard (1967) *Eléments de linguistique romane*, Klincksieck, Paris.

Bright, William (1972). The enunciative vowel. *International Journal of Dravidian Linguistics*, 1.1, 26–55.

Broselow, Ellen, and Alice Niyondagara (1990). Feature geometry of Kirundi palatalization. *Studies in the Linguistic Sciences* 20.1.

Brunot, Ferdinand, and Charles Bruneau (1937). *Précis de grammaire historique de la langue Française*. Masson, Paris.

Burzio, Luigi (1998). Multiple correspondence. *Lingua* 104, 79–109.

Calabrese, Andrea (1988). *Towards a theory of phonological alphabets*. Ph.D. dissertation, Massachusetts Institute of Technology.

Calabrese, Andrea (1993). Palatalization processes in the history of Romance languages: A theoretical study. William J. Ashby, Marianne Mithun, Giorgio Perissinotto and Eduardo Raposo (eds.) *Linguistic perspectives on the romance languages*. John Benjamins, Amsterdam, 65–83.

Campbell, Lloyd (1974). Phonological features: Problems and proposals. *Language* 50, 52–65.

Card, Elizabeth A. (1983). *A phonetic and phonological study of Arabic emphasis*. Ph.D. dissertation, Cornell University.

Chen, Matthew (1970). Vowel length variation as a function of the voicing of consonant environment. *Phonetica* 22, 129–59.

Chen, Matthew (1973). Cross-dialectal comparison: A case study and some theoretical considerations. *Journal of Chinese Linguistics* 1, 38–63.

Cheng, Lisa (1991) Feature geometry of vowels and cooccurrence restrictions in Cantonese. *West Coast Conference on Formal Linguistics* 9, 107–124.

Choi, John D. (1991). An acoustic study of Kabardian vowels. *JIPA* 21, 1–12.

Choi, John D. (1992). *Phonetic underspecification and target interpolation: An acoustic study of Marshallese vowel allophony (UCLA Working Papers in Phonetics 82).* Ph.D. dissertation, University of California, Los Angeles.

Chomsky, Noam, and Morris Halle (1968). *The sound pattern of English*. Harper and Row, New York.

Clements, George N. (1976). Palatalization: Linking or assimilation? *Chicago Linguistic Society* 12, 96–109.

Clements, George N. (1985). The geometry of phonological features. *Phonology Yearbook* 2, 225–252.

Clements, George N. (1991). Place of articulation in consonants and vowels: a unified theory. *Working Papers of the Cornell Phonetics Laboratory* 5, 77–123.

Colarusso, John. (1988*). The Northwest Caucasian languages: A phonological survey.* Garland Publishing, New York.

Dave, Radhekant (1977). Retroflex and dental consonants in Gujarati. A palatographic and acoustic study. *Annual Report of the Institute of Phonetics, University of Copenhagen* 11, 27–156.

Davis, Stuart (1994). Variation in feature geometry: The case of front vowels. Talk presented at Western Conference on Linguistics 1994, Los Angeles.

Delattre, Pierre C., Alvin M. Liberman, and Franklin S. Cooper (1955) Acoustic loci and transitional cues for consonants. *Journal of the Acoustical Society of America* 27, 769–773.

Delattre, Pierre C., and D. C. Freeman (1968). A dialect study of American r's by x-ray motion picture. *Linguistics* 44, 29–68.

Disner, Sandra F. (1983). *Vowel quality: The relation between universal and language-specific factors (UCLA Working Papers in Phonetics 58)*. Ph.D. dissertation, University of California, Los Angeles.

Dorman, Michael F., Michael Studdert-Kennedy, and Lawrence J. Raphael (1977). Stop-consonant recognition: Release bursts and formant transitions as functionally equivalent context-dependent cues. *Perception and Psychophysics* 22, 109–122.

Downer, G.B. (1961). Phonology of the word in Highland Yao. *Bulletin of the School of Oriental and African Studies* 24, 531–541.

Durie, Mark (1985). *A grammar of Acehnese on the basis of a dialect of North Aceh*. Foris, Dordrecht.

Emeneau, Murray B. (1970). Kodagu vowels. *Journal of the American Oriental Society* 90, 145–58.

Fant, C. Gunnar M. (1960). *Acoustic theory of speech production*. Mouton, 'S-Gravenhage.

Fant, C. Gunnar M. (1962). Descriptive analysis of the acoustic analysis of speech. *Logos* 5, 3–17.

Fasold, Ralph W., and Walt Wolfram (1970). Some linguistic features of negro dialect. Ralph W. Fasold and Roger W. Shuy (eds.) *Teaching standard English in the inner city*. Center for Applied Linguistics, Washington, D.C., 41–86

Fischer-Jørgenson, Eli (1952). Acoustic analysis of stop consonants. *Miscellanea Phonetica*, vol. II, 42–59.

Flemming, Edward (1998). Some arguments against using underlying representations in OT phonology. Talk presented at University of California, Irvine.

Flemming, Edward (2001). Scalar and categorical phenomena in a unified model of phonetics and phonology. To appear in *Phonology*.

Foley, James (1977). *Foundations of theoretical phonology*. Cambridge University Press, Cambridge.

Forrest, Karen, Gary Weismer, Paul Milenkovic, and Ronald N. Dougall (1988). Statistical analysis of word-initial voiceless obstruents: Preliminary data. *Journal of the Acoustical Society of America* 84, 115–123.

Fouché, Pierre (1958). *Phonétique historique du Français*. *Vol III: Les consonnes*. C. Klincksieck, Paris.

Fowler, Carol A. (1992). Vowel duration and closure duration in voiced and unvoiced stops: There are no contrast effects here. *Journal of Phonetics* 20, 143–65.

Fowler, Carol A. (1994). Invariants, specifiers, cues: An investigation of locus equations as information for place of articulation. *Perception and Psychophysics* 55, 597–610.

Garbell, Irene (1965). *The Jewish Neo-Aramaic dialect of Persian Azerbaijan: Linguistic analysis and folkloric texts (Janua linguarum, Series practica* 3). Mouton, The Hague.

Gerstman, L. (1957). *Cues for distinguishing among fricatives, affricates, and stop consonants*. Ph.D. dissertation, New York University.

Gibson, L.F. (1956). Pame (Otomi) phonemics and morphophonemics. *International Journal of American Linguistics* 22, 242–265.

Gnanadesikan, Amalia E. (1994). The geometry of coronal articulations. *North-Eastern Linguistic Society* 24, 125–139.

Gorecka, Alicja (1989). *Phonology of articulation*, Ph.D. dissertation, Massachusetts Institute of Technology.

Gudschinsky, S., H. Popovich and F. Popovich (1970). Native reaction and phonetic similarity in Maxakali phonology. *Language* 46, 77–88.

Guenther, F.H., F.T. Husain, M.A. Cohen, and B.G. Shinn-Cunningham (1999). Effects of categorization and discrimination training on auditory perceptual space. *Journal of the Acoustical Society of America* 106, 2900–2912.

Haggard, Mark P., Stephen Ambler, and Mo Callow (1970). Pitch as a voicing cue. *Journal of the Acoustical Society of America* 47, 613–617.

Hall, Robert A. (1976). *Proto-Romance phonology*. Elsevier, Hew York.

Halle, Morris (1995). Feature geometry and feature spreading. *Linguistic Inquiry* 26, 1–46.

Hamilton, Philip (1993). Markedness and coronal structure. Ms., University of Toronto.

Han, Mieko S. (1963). *Acoustic phonetics of Korean*, Technical Report No. 1, University of California, Los Angeles.

Harrington, Jonathon, and Steve Cassidy (1999). *Techniques in speech acoustics.* Kluwer, Dordrecht.

Harris, James W. (1973). On the order of certain phonological rules in Spanish. Stephen R. Anderson and Paul Kiparsky (eds.) *A festschrift for Morris Halle*. Holt, Rinehart and Winston, New York, 59–76.

Harris, James W. (1983) *Syllable structure and stress in Spanish*. MIT Press, Cambridge.

Harris, Katherine (1958). Cues for the discrimination of American English fricatives in spoken syllables. *Language and Speech* 1, 1–15.

Harshman, Richard, Peter Ladefoged, and Louis Goldstein (1977). Factor analysis of tongue shapes. *Journal of the Acoustical Society of America* 62, 693–707.

Hayes, Bruce (1999). Phonological restructuring in Yidiny and its theoretical consequences. Ben Hermans and Marc van Oostendorp (eds.) *The Derivational Residue in Phonological Optimality Theory*. John Benjamins, Amsterdam, 175–205.

Herbert, Robert K. (1986). *Language universals, markedness theory and natural phonetic processes*. Mouton de Gruyter, Berlin.

Hercus, Luise A. (1986) *The languages of Victoria: A late survey*. Pacific Linguistics, Series B, No.77. Australian National University, Canberra.

Herzallah, Rukayyah (1990) *Aspects of Palestinian Arabic phonology: A non-linear approach*, Ph.D. dissertation, Cornell University.

Hetzron, Robert (1969). The morphology of the verb in Modern Syriac (Christian colloquial of Urmi). *Journal of the American Oriental Society* 89, 112–127.

Hinnebusch, Tom and Derek Nurse (1981). Spirantization in Chaga. *Sprache undGeschichte in Afrika* 3, 51–78.

Hoffman, Carl (1963). *A grammar of the Margi language*. Oxford University Press, Oxford.

Houde, Richard A. (1967). *A study of tongue body motion during selected speech sounds*. Ph.D. dissertation, University of Michigan.

Howell, Peter, and Stuart Rosen (1983). Production and perception of rise time in the voiceless affricate/fricative distinction. *Journal of the Acoustical Society of America* 73, 976–984.

Hudson, Joyce, and Eirlys Richards (1969). The phonology of Walmatjari. *Oceanic Linguistics* 8, 171–189.

Hume, Elizabeth (1992). *Front vowels, coronal consonants and their interaction in non-linear phonology*. Ph.D. dissertation, Cornell University.

Hume, Elizabeth (1998). The role of perceptibility in consonant/consonant metathesis. *Proceedings of the West Coast Conference on Formal Linguistics* 17, 293–307.

Hume, Elizabeth, and Keith Johnson (2001). *The role of speech perception in phonology*. Academic Press, San Diego.

Hunter, Georgia G. and Eunice V. Pike (1969). Phonology and tone sandhi of Molinos Mixtec. *Linguistics* 47, 24–40.

Hyman, Larry M. (1970). How concrete is phonology? *Language* 46, 58–76.

Hyman, Larry M. (1973). The feature [grave] in phonological theory. *Journal of Phonetics* 1, 329–346.

Hyman, Larry M. (1976). Phonologization. Alphonse Juilland, A.M. Stephens, and D. Laurence (eds) *Linguistic studies offered to Joseph Greenberg*. Anma Libri, Saratoga, 401–418.

Jakobson, Roman (1968). *Remarques sur l'évolution phonologique du russe*. Travaux du Cercle Linguistique de Prague, 2. Kraus Reprint, Nendeln.

Jakobson, Roman, C. Gunnar M. Fant, and Morris Halle (1952) *Preliminaries to speech analysis*. MIT Press, Cambridge.

Jassem, Wiktor (1979). Classification of fricative spectra using statistical discriminant functions. Björn Lindblom and Sven Öhman (eds.) *Frontiers of Speech Communication Research*. Academic Press, New York, 77–91.

Johnson, Keith (1997). *Acoustic and auditory phonetics*. Blackwell, Oxford.

Jouannet, François (1983). Phonétique et phonologie. Le systeme consonantique du Kinyarwanda. F. Jouannet. (ed) *Le Kinyarwanda: Études linguistiques*. SELAF, Paris, 55–74.

Jun, Jongho (1995). *Perceptual and articulatory factors in place assimilation: an Optimality-Theoretic approach*. Ph.D. dissertation, University of California, Los Angeles.

Jusczyk, Peter W. (1993). From general to language-specific capacities: the WRAPSA model of how speech perception develops. *Journal of Phonetics* 21, 3–28.

Kamprath, Christine K. (1987). Swiss-Romansh glide, extrasyllabicity, and the sonority scale. *Texas Linguistic Forum* 28, 28–40.

Kao, Diane L. (1971). *Structure of the syllable in Cantonese*. Mouton, The Hague.

Kaun, Abigail (1995). *The typology of rounding harmony: An Optimality-Theoretic approach*. Ph.D. dissertation, University of California, Los Angeles.

Kawasaki, Haruko (1982). *An acoustical basis for universal constraints on sound sequences*. Ph.D. dissertation, University of California, Berkeley.

Kawasaki-Fukumori, Haruko (1992). An acoustical basis for universal phonotactic constraints. *Language and Speech* 35, 73–86.

Keating, Patricia A. (1984). Phonetic and phonological representation of stop consonant voicing. *Language* 60, 286–319.

Keating, Patricia A. (1985). Universal phonetics and the organization of grammars. Victoria A. Fromkin (ed.) *Phonetic linguistics*. Academic Press, New York, 115–32.

Keating, Patricia A. (1990). Phonetic representations in a generative grammar. *Journal of Phonetics* 18, 321–34.

Keating, Patricia A. (1991). Coronal places of articulation. Carole Paradis and Jean-François Prunet (eds.) *The special status of coronals: Internal and external evidence*. Academic Press, San Diego. 29–48.

Keating, Patricia A. (1993). Phonetic representation of palatalization versus fronting. *UCLA Working Papers in Phonetics* 85, 6–21.

Keating, Patricia A., and Aditi Lahiri (1993). Fronted velars, palatalized velars and palatals. *Phonetica* 50, 73–101.

Kenstowicz, Michael (1996). Uniform exponence and base identity. Jacques Durand and Bernard Laks (eds.) *Current Trends in Phonology*. CNRS and University of Salford Publications, 363–393.

Kenstowicz, Michael and Charles W. Kisseberth (1977). *Generative phonology: Description and theory*. Academic Press, New York.

Kewley-Port, Diane (1982). Measurement of formant transitions in naturally produced stop consonant-vowel syllables. *Journal of the Acoustical Society of America* 72, 379–389.

Kimenyi, Alexandre (1979) *Studies in Kinyarwanda and Bantu phonology*. Linguistic Research, Inc., Carbondale, IL.

Kingston, John (1990). Articulatory binding. John Kingston and Mary E. Beckman (eds) *Papers in laboratory phonology I: Between the grammar and physics of speech*. Cambridge University Press, Cambridge, 406–434.

Kingston, John, and Randy L. Diehl (1994). Phonetic knowledge. *Language* 70, 419–55.

Kingston, John, and Randy L. Diehl (1995). Intermediate properties in the perception of distinctive feature values. Bruce Connell and Amalia Arvaniti (eds) *Papers in laboratory phonology IV: Phonology and phonetic evidence*, Cambridge University Press, Cambridge, 7–27.

Kiparsky, Paul (1982a). *Explanation in phonology*, Foris, Dordrecht.

Kiparsky, Paul (1982b). Lexical phonology and morphology. I.S. Yang (ed) *Linguistics in the morning calm*. Hanshin, Seoul, 3–91.

Kiparsky, Paul (1995). The phonological basis of sound change. John Goldsmith (ed.) *The handbook of phonological theory*. Basil Blackwell, Oxford, 640–670.

Kiparsky, Paul (1998). Covert generalization. To appear in Geert Booij, Angela Ralli, and Sergio Scalise (eds.) *Proceedings of the first mediterranean morphology conference*. University of Patras, Patras.

Kiparsky, Paul (2000). *Paradigmatic effects and opacity*. To appear, CSLI, Stanford.

Kirchner, Robert (1993). Turkish vowel harmony and disharmony: An Optimality Theoretic account. Ms., UCLA.

Kirchner, Robert (1997). Contrastiveness and faithfulness. *Phonology* 14, 83–111.

Kirchner, Robert (1998). *An effort-based approach to consonant lenition*. Ph.D. dissertation, University of California, Los Angeles.

Kisseberth, Charles W. and Mohammed I. Abasheik (1975). The perfect stem in ChiMwi:ni and global rules. *Studies in African Linguistics* 6, 249–266.

Kluender, Keith R., Randy L. Diehl and B.A. Wright (1988). Vowel length differences before voiced and voiceless consonants: An auditory explanation. *Journal of Phonetics* 16, 153–69.

Kohler, Klaus (1990). Segmental reduction in connected speech in German: Phonological facts and phonetic explanation. William J. Hardcastle and Alain Marchal (eds.) *Speech production and speech modeling*. Kluwer, Dordrecht, 69–92.

Krull, Diana (1987). Second formant patterns as a measure of consonant-vowel coarticulation. *Phonetic Experimental Research, Institute of Linguistics, University of Stockholm* 5, 43–61.

Ladefoged, Peter (1993). *A course in phonetics*. *3rd Edition*. Harcourt Brace Jovanovich, Fort Worth.

Ladefoged, Peter (1997). Linguistic phonetic descriptions. William J. Hardcastle and John Laver (eds.) *The handbook of phonetic sciences*. Basil Blackwell, Oxford, 589–618.

Ladefoged, Peter (1999). American English. *Handbook of the International Phonetic Association*. Cambridge University Press, Cambridge, 41–44.

Ladefoged, Peter, and Ian M. Maddieson (1996). *The Sounds of the World's Languages*. Basil Blackwell, Oxford.

Ladefoged, Peter, and Peri Bhaskararao (1983). Non-quantal aspects of consonant production: A study of retroflex consonants. *Journal of Phonetics* 11: 291–302.

Lahiri, Aditi and Sheila E. Blumstein (1984). A re-evaluation of the feature coronal. *Journal of Phonetics* 12, 133–46.

Laver, John (1994). *Principles of phonetics*. Cambridge University Press, Cambridge.

Lehiste, Ilse (1970) *Suprasegmentals*. MIT Press, Cambridge, MA.

Lehn, Walter (1963). Emphasis in Cairo Arabic. *Language* 39, 29–39.

Lightner, Theodore M. (1972). *Problems in the theory of phonology*. *Vol 1: Russian and Turkish phonology*. Linguistic Research, Edmonton.

Liljencrants, Johan, and Björn Lindblom (1972). Numerical simulation of vowel quality systems: The role of perceptual contrast. *language* 48, 839–62.

Lindblom, Björn (1963a). *On vowel reduction (Report no. 29)*. The Royal Institute of Technology, Speech Transmission Laboratory, Stockholm.

Lindblom, Björn (1963b). Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America* 35, 1773–1781.

Lindblom, Björn (1967). Vowel duration and a model of lip-mandible coordination. *STL-QPSR* 4, 1–29.

Lindblom, Björn (1986). Phonetic universals in vowel systems. John J. Ohala and J.J. Jaeger (eds) *Experimental phonology*. Academic Press, Orlando, 13–44.

Lindblom, Björn (1990a). Phonetic content in phonology. *Phonetic Experimental Research, Institute of Linguistics, University of Stockholm* 11, 101–118.

Lindblom, Björn (1990b). Models of phonetic variation and selection. *Phonetic Experimental Research, Institute of Linguistics, University of Stockholm* 11, 65–100.

Lisker, Leigh (1957). Closure duration and the intervocalic voiced-voiceless distinctions in English. *Language* 33, 42–49.

Lisker, Leigh (1975). Is it VOT or a first formant transition detector? *Journal of the Acoustical Society of America* 57, 1547–51.

Lisker, Leigh (1986). "Voicing" in English: A catalogue of acoustic features signaling /b/ versus /p/ in trochees. *Language and Speech* 29, 3–11.

Lombardi, Linda (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *Natural Language and Linguistic Theory* 17, 267–302.

Lyman, Thomas A. (1974). *Dictionary of Mong Njua, a Miao (Meo) language of Southeast Asia*. Mouton, The Hague.

Maddieson, Ian M. (1984). *Patterns of sounds*. Cambridge University Press, Cambridge.

Maddieson, Ian M. (1987). The Margi vowel system and labiocoronals. *Studies in African Linguistics* 18, 327–355.

Maddieson, Ian M. (1997). Phonetic universals. William J. Hardcastle and John Laver (eds.) *The handbook of phonetic sciences*. Blackwell, Oxford, 619–639.

Mallinson, Graham (1986). *Rumanian*. Croom Helm, London.

Maniet, A. (1964). *L'évolution phonétique et les sons du latin ancien dans le cadre des langues indo-europénnes*. Nauwelaerts, Louvain.

Manuel, Sharon Y., and Kenneth N. Stevens (1995). Formant transitions: Teasing apart consonant and vowel contributions. *Proceedings of the ICPHS 95,* Vol. 4. Stockholm, 436–439.

Marsh, James (1969). Mantjiltjara phonology. *Oceanic Linguistics* 8.2, 131–152.

Martinet, Andre (1952). Function, structure, and sound change.*Word* 8, 1–32.

Martinet, Andre (1955). *Economie des changements phonétiques*. Francke, Berne.

Massaro, Dominic W., and Michael M. Cohen (1983). Consonant/vowel ratios: An improbable cue in speech. *Perception and Psychophysics* 33, 501–5.

Matisoff, James A. (1973) *The grammar of Lahu*. University of California Publications in Lingustics 75, University of California Press, Berkeley.

Mazzola, Michael L. (1976). *Proto-Romance and Sicilian*. Peter de Ridder, Lisse.

McCarthy, John (1988). Feature geometry and dependency: A review. *Phonetica* 43, 84–108.

McCarthy, John (1994). The phonetics and phonology of Semitic pharyngeals. Patricia A. Keating (ed) *Papers in laboratory phonology III: Phonological structure and phonetic form*. Cambridge University Press, Cambridge, 191–233.

McCarthy, John (1998) Morpheme structure constraints and paradigm occultation. *Chicago Linguistic Society 34: The panels*. 125–150.

McGregor, William (1990). *A functional grammar of Gooniyandi*, John Benjamins, Amsterdam.

Meeussen, A.E. (1959). *Essai de grammaire Rundi*. Musée royal de Congo Belge, Tervuren.

Michailovsky, Boyd (1975). On some Tibeto-Burman sound changes. *Berkeley Linguistic Society* 1, 322–332.

Miller, George A. and Patricia E. Nicely (1955). An analysis of perceptual confusions among some English consonants. *Journal of the Acoustical Society of America* 27, 338–352.

Miller, Wick R. (1965). *Acoma grammar and texts*. University of California Publications in Linguistics. University of California Press, Berkeley.

Nelson, W.L. (1983). Physical principles for economies of skilled movement. *Biological Cybernetics* 46, 135–147.

Nosofsky, Robert M. (1986). Attention, similarity, and the identification-categorization relationship. *Journal of Experimental Psychology: General* 115, 39–57.

Oh, Eunjin (2000). Dynamic properties of coarticulation in native and non-native speech. *Proceedings of the 28th Western Conference on Linguistics*, 195–212.

Ohala, John J. (1978a). Southern Bantu vs. the world: the case of palatalization of labials. *Berkeley Linguistic Society* 4, 370–386.

Ohala, John J. (1978b). The production of tone. Victoria A. Fromkin (ed) *Tone: A linguistic survey*. Academic Press, New York, 5–39.

Ohala, John J. (1980). The application of phonological universals in speech pathology. N. Lass (ed.) *Speech and language: Advance in basic research and practice, Vol.3*. Academic Press, New York, 75–97.

Ohala, John J. (1981). The listener as a source of sound change. *Papers from the parasession on language and behavior*, Chicago Linguistics Society, 178–203.

Ohala, John J. (1985). Around *Flat*. Victoria Fromkin (ed.) *Phonetic Linguistics: Essays in honor of Peter Ladefoged*. Academic Press, Orlando, 223–241.

Ohala, John J. (1990). The phonetics and phonology of aspects of assimilation. John Kingston and Mary E. Beckman (eds.) *Papers in laboratory phonology I: Between the grammar and physics of speech*. Cambridge University Press, Cambridge, 258–275.

Ohala, John J. (1992). What's cognitive, what's not, in sound change. *Lingua e Stile* 27, 321–362.

Öhman, S.E.G. (1966). Coarticulation in VCV utterances: Spectrographic measurements. *Journal of the Acoustical Society of America* 39, 151–168.

Olive, Joseph P., Alice Greenwood, and John Coleman (1993). *Acoustics of American English speech: A dynamic approach*. Springer-Verlag, New York.

Passy, Paul (1891*). Etude sur les changements phonétiques et leur caractères généraux*. Librairie Firmin-Didot, Paris.

Peterson, Gordon E., and Harold L. Barney (1952). Control methods used in a study of the vowels. *Journal of the Acoustical Society of America* 24, 175–184.

Pierrehumbert, Janet B. (1990). Phonological and phonetic representation. *Journal of Phonetics* 18, 375–394.

Piggott, Glyne (1992). Variability in feature dependency: The case of nasality. *Natural Language and Linguistic Theory* 10, 33–78.

Platt, J.T. (1972). *An outline grammar of the Gugada dialect: South Australia*. Australian Aboriginal Studies, No. 48, Australian Institute of Aboriginal Studies, Canberra.

Ponelis, Fritz (1974). On the dynamics of velarization and labialization: Some Bantu evidence. *Studies in African Linguistics* 5, 27–58.

Prince, Alan, and Paul Smolensky (1993) *Optimality Theory: Constraint interaction in generative grammar*. Ms., Rutgers University and University of Colorado, Boulder.

Puppel, Stanislaw, Jadwiga Nawrocka-Fisiak, and Halina Krassowska (1977). *A handbook of Polish pronunciation for English learners*. Państwowe Wydawnictwo Naukowe, Warsaw.

Rehg, Kenneth L. (1973). On the history of Ponapean phonology. *Working Papers in Linguistics, University of Hawaii* 5(8), 17–56.

Repp, Bruno H., Alvin M. Liberman, Thomas Eccardt, and David Pesetsky (1978). Perceptual integration of acoustic cues for stop, fricative, and affricate manner. *Journal of Experimental Psychology: Human Perception and Performance* 4, 621–637.

Reynolds, William T. (1994). *Variation and phonological theory*. Ph.D. dissertation, University of Pennsylvania.

Richey, Colleen (2000). Cues for place and palatalization in Russian stops. Ms, Stanford University.

Rohlfs, Gerhard (1966). *Grammatica storica della lingua italiani e dei suoi dialetti*. Einaudi, Torino.

Rubach, Jerzy (1984) *Cyclic and lexical phonology: The structure of Polish*. Foris, Dordrecht.

Rubach, Jerzy (1993). *The lexical phonology of Slovak*. Clarendon Press, Oxford.

Sagey, Elizabeth (1986)*The representation of features and relations in non-linear phonology*. Ph.D. dissertation, Massachusetts Institute of Technology [revised version published by Garland Press, New York 1990].

Saltarelli, Mario (1988). *Basque*. Croom Helm, London.

Schacter, Paul and Victoria Fromkin (1968). *A phonology of Akan: Akuapem, Asante and Fante*. *UCLA Working Papers in Phonetics* 55.

Scharf, Bertram (1978). Loudness. Edward C. Carterette and Morton P. Friedman (eds.) *Handbook of perception, vol. 4: Hearing*. Academic Press, New York. 187–242.

Schein, Barry and Donca Steriade (1986). On geminates. *Linguistic Inquiry* 17.4, 691–744.

Schiffman, Harold F., and Carol M. Eastman (1975). Introduction. Harold F. Schiffman and Carol M. Eastman (eds.) *Dravidian phonological systems*. University of Washington Press, Seattle, xi–xxi.

Schwartz, Jean-Luc, Denis Beautemps, Christian Abry, and Pierre Escudier (1993). Inter-individual and cross-linguistic strategies for the production of the [i] *vs.* [y] contrast. *Journal of Phonetics* 21, 411–425.

Shadle, Christine (1991). The effect of geometry on source mechanisms of fricative consonants. *Journal of Phonetics* 19, 409–424.

Silverman, Daniel (1995). *Phasing and recoverability*. Ph.D. dissertation, University of California, Los Angeles.

Smits, Roel, Louis ten Bosch, and René Collier (1996). Evaluation of various sets of acoustic cues for the perception of prevocalic stop consonants. I. Perception experiment. *Journal of the Acoustical Society of America* 100, 3852–3864.

Smolensky, Paul (1995). On the internal structure of the constraint component *Con* of UG. Handout of talk presented at the University of California, Los Angeles.

Spajić, Siniša, Peter Ladefoged, and Peri Bhaskararao (1994). The rhotics of Toda. *UCLA Working Papers in Phonetics* 87, 35–66.

Steriade, Donca (1987). Redundant values. A. Bosch, B. Need, and E. Schiller (eds.) *Chicago Linguistic Society 23: Papers from the parasession on autosegmental and metrical phonology*, 339–362.

Steriade, Donca (1993a). Closure, release and nasal contours. Marie Huffman and Rena Krakow (eds) *Nasality: Phonological and phonetic properties*. Academic Press, New York, 401–470.

Steriade, Donca (1993b) Positional neutralization. Talk presented at North East Linguistic Society 24, University of Massachusetts, Amherst.

Steriade, Donca (1994a). Complex onsets as single segments: the Mazateco pattern. Jennifer Cole and Charles Kisseberth (eds.) *Perspectives in phonology*. CSLI, Stanford, 203–293.

Steriade, Donca (1994b). Class handouts on lexical phonology. University of California, Los Angeles.

Steriade, Donca (1995). Neutralization and the expression of contrast. Ms, University of California, Los Angeles.

Steriade, Donca (1997). Phonetics in phonology: The case of laryngeal neutralization. Ms, University of California, Los Angeles.

Steriade, Donca (1999). Lexical conservatism in French adjectival liaison. B.Bullock, M. Authier and L. Reed (eds.) *Formal perspectives in Romance linguistics*. John Benjamins, Amsterdam, 243–270.

Steriade, Donca (2000). Paradigm uniformity and the phonetics-phonology boundary. Michael Broe and Janet Pierrehumbert (eds.) *Papers in laboratory phonology V: Acquisition and the lexicon*. Cambridge University Press, Cambridge, 313–334.

Steriade, Donca (2001). The phonology of perceptibility effects: The P-map and its consequences for constraint organization. To appear in *Phonology*.

Stevens, Kenneth N. (1989). On the quantal nature of speech. *Journal of Phonetics* 17, 3–45.

Stevens, Kenneth N. (1999). *Acoustic phonetics*. MIT Press, Cambridge.

Stevens, Kenneth N., and S. Jay Keyser (1989). Primary features and their enhancements in consonants. *Language* 65, 81–106.

Stevens, Kenneth N., and Sheila E. Blumstein (1975). Quantal aspects of consonant production and perception: A study of retroflex consonants. *Journal of Phonetics* 3, 215–233.

Stevens, Kenneth N., and Sheila E. Blumstein (1978). Invariant cues for place of articulation in stop consonants. *Journal of the Acoustical Society of America* 64, 1358–1368.

Stevens, Kenneth N., and Sheila E. Blumstein (1981). The search for invariant acoustic correlates of phonetic features. Peter D. Eimas and Joanne L. Miller (eds.) *Perspectives on the study of speech*. Lawrence Erlbaum, Hillsdale, 1–38.

Stevens, Kenneth N., S. Jay Keyser, and Haruko Kawasaki (1986). *Toward a phonetic and phonological theory of redundant features*. Joseph S. Perkell and Dennis H. Klatt (eds) *Invariance and variability in speech processes*. Lawrence Erlbaum, Hillsdale, 426–449.

Summerfield, A. Quentin, and Mark P. Haggard (1977). On the dissociation of spectral and temporal cues to the voicing distinction in initial stop consonants. *Journal of the Acoustical Society of America* 62, 435–448.

Sussman, Harvey M., Kathryn A. Hoemeke, and Farhan S. Ahmed (1993). A cross-linguistic investigation of locus equations as a phonetic descriptor for place of articulation. *Journal of the Acoustical Society of America* 94, 1256–1268.

Thomas, David B. (1971). *Chrau grammar*. University of Hawaii, Honolulu.

Traill, Anthony (1985). *Phonetic and phonological studies of !Xóõ Bushman*. (Quellen zur Khoisan-Forschung 5.) Helmut Buske, Hamburg.

Vance, Timothy J. (1987). *An introduction to Japanese phonology*. State University of New York Press, Albany.

Wallace, Judith (1969). Katu phonemes. *Mon Khmer Studies* 3, 64–73.

Wells, John (1982). *Accents of English. Vol 3: Beyond the British Isles*. Cambridge University Press, Cambridge.

Westbury, John (1983). Enlargement of the supraglottal cavity and its relation to stop consonant voicing. *Journal of the Acoustical Society of America* 73, 1322–1336.

Westbury, John, and Patricia A. Keating (1986). On the naturalness of stop consonant voicing. *Journal of Linguistics* 22, 145–66.

Whitney, William Dwight (1896) *A Sanskrit grammar (3rd ed.)*. Ginn and Co., Boston.

Wright, Richard (1996). *Consonant clusters and cue preservation in Tsou*. Ph.D. dissertation, University of California, Los Angeles.

Yip, Moira (1988). The obligatory contour principle and phonological rules: a loss of identity. *Linguistic Inquiry* 19, 65–100.

Zee, Eric (1999). An acoustical analysis of the diphthongs in Cantonese. *Proceedings of the 14th International Congress of Phonetic Sciences*, University of California, Berkeley, 1101–1104.

Zimmer, Karl, and Orhan Orgun (1992). Turkish. *Journal of the International Phonetic Association* 22, 43–47.

Zipf, George K. (1949). *Human behavior and the principle of least effort*. Addison-Wesley, Cambridge.

Zue, Victor (1976). Acoustic characteristics of stop consonants: a controlled study. Ph.D. dissertation, Massachusetts Institute of Technology [distributed by Indiana University Linguistics Club].

Zvelebil, Kamil (1970). *Comparative Dravidian phonology*, Mouton, The Hague.

Zvelebil, Kamil (1973). Iruḷa vowels. *Indo-Iranian Journal* 17, 113–122.

Index

Abasheik, Mohammed I., 109
Abry, Christian, 14, 126
Acehnese, 85, 127
Acoma, 91
adaptive dispersion, 4, 15
Ahmed, Farhan S., 22
Al-Ani, Salman, 55
allomorphy, 33–34, 141–144
alternations, 33–34, 141–144
Ambler, Stephen, 58
Andersen, Henning, 138
Anderson, Stephen R., 142
Anderson, Victoria B., 43, 44, 91
Anttila, Arto, 43
Arabic, 54–55
  Cairene Arabic, 54
  Palestinian Arabic, 114
  Saudi Arabic, 60
Aramaic, Modern, 54
Archangeli, Diane, 38
Arrernte, Eastern, 58, 107
articulatory dimensions, 69, 73–74
assibilation, 103–107, 109–110
assimilation, 9–11, 65–118
Atal, B.S., 30
auditory dimensions, 17–25
  diffuseness, 20
  formant frequencies, 18, 22–23
  loudness, 21
  noise frequency, 19, 23
  noise loudness, 20–21, 24
  Voice Onset Time, 21
Barasano, 39
Barney, Harold L., 19
Bauer, Robert S., 80
Beautemps, Denis, 14, 126
Beckman, Mary E., 23
Bender, Byron, 37, 39, 67
Benedict, Paul K., 80
Benua, Laura, 142, 146
Bhaskararao, Peri, 43, 91, 97
Bladon, R.A.W., 134
Blumstein, Sheila E., 43, 56, 57, 58, 73, 107
Borowsky, Toni, 12, 124
Bosch, Louis ten, 23
Bourciez, Édouard, 137
Bright, William, 82
Broselow, Ellen, 100
Bruneau, Charles, 109
Brunot, Ferdinand, 109
Burzio, Luigi, 145, 146, 150

Calabrese, Andrea, 8, 107
Callow, Mo, 58
Campbell, Lloyd, 82
Cantonese, 63, 77–80, 81, 86, 125–130
Card, Elizabeth A., 54
Cassidy, Steve, 59, 73
Caucasian languages, 37, 38
Chaga, 108
Chang, J.J., 30
Chen, Matthew, 60, 128
Cheng, Lisa, 77, 125, 129
ChiMwi:ni, 109, 110

Choi, John D., 37, 39, 67
Chomsky, Noam, 3, 65, 145
Clements, George N., 3, 11, 14, 65, 66, 111–116
Cohen, M.A., 33
Cohen, Michael M., 58
Colarusso, John., 37, 39
Coleman, John, 122, 128, 134, 135
Collier, René, 23
contrastive underspecification, 39–40
Cooper, Franklin S., 22
coronalization, 99–110
cyclicity, 145–146
Czech, 60, 138

Danish, 41, 44
Dave, Radhekant, 43, 91
Davis, Stuart, 114
Delattre, Pierre C., 22, 56
Diehl, Randy L., 47, 58, 59, 63
Disner, Sandra F., 14
dissimilatory cooccurrence constraints, 12, 119
Dorman, Michael F., 23
Dougall, Ronald N., 19
Downer, G.B., 130
Durie, Mark, 85, 86

Eastman, Carol M., 99
Eccardt, Thomas, 105
Emeneau, Murray B., 90
English, 24, 32, 47–48, 55, 56, 57, 59, 60, 67–73, 74, 80, 90, 99, 116, 120–125, 132–134, 135–137, 141
  African-American Vernacular English, 135, 136
  American English, 73, 74, 99, 120–125, 134
  Cockney English, 135
  New Zealand English, 99
  RP English, 120–125
  S. Californian English, 120–125
enhancement, 6–9, 38–40, 53–63, 65–66
Escudier, Pierre, 14, 126

faithfulness constraints, 33–35, 142
Fant, C. Gunnar M., 3, 20, 90
Fasold, Ralph W., 136
Fischer-Jørgenson, Eli, 41
Flemming, Edward, 149, 156
Foley, James, 108, 110
formant transitions, 22–23
Forrest, Karen, 19
Fowler, Carol A., 63, 135
free variation, 41, 42–45
Freeman, D. C., 56
French, 55, 100, 104, 108–109, 138
  Acadian French, 100

Garbell, Irene, 54
Gerstman, L., 105
Gnanadesikan, Amalia E., 68, 114
Gooniyandi, 41, 43–44
Gorecka, Alicja, 107, 135
Greenwood, Alice, 122, 128, 134, 135
Guaraní, 39
Gudschinsky, S., 114
Guenther, F.H., 33
Gugada, 90
Gujarati, 91

Haggard, Mark P., 58
Hall, Robert A., 138
Halle, Morris, 3, 20, 65, 90, 145, 155
Hamilton, Philip, 41
Han, Mieko S., 14
Harrington, Jonathon, 59, 73
Harris, James W., 145, 146, 148
Harris, Katherine, 135, 137
Hayes, Bruce, 150
Herbert, Robert K., 39
Hercus, Luise A., 89–98
Herzallah, Rukayyah, 114
Hetzron, Robert, 54, 55
Hinnebusch, Tom, 108
Hoemeke, Kathryn A., 22
Hoffman, Carl, 103
Hottentot, 108
Houde, Richard A., 22, 71
Howell, Peter, 105

Hudson, Joyce, 41, 68, 114
Hume, Elizabeth, 11, 14, 66, 100, 111–113
Hunter, Georgia G., 91
Husain, F.T., 33
Hyman, Larry M., 61, 101, 109, 110

Irula, 90
Italian, 45–46, 100, 104, 108, 142–143
Sicilian Italian, 45–46, 142–143

Jakobson, Roman, 3, 20, 90
Japanese, 31, 105
Jassem, Wiktor, 19
Johnson, Keith, 19, 56
Jun, Jongho, 111, 154
Jusczyk, Peter W., 33

Kabardian, 37, 38
Kamprath, Christine K., 114
Kao, Diane L., 77, 125
Katu, 133
Kaun, Abigail, 87
Kawasaki, Haruko, 6, 7, 8, 12, 38, 56, 61, 111, 119–120, 125, 128, 131, 132–133, 136, 137
Keating, Patricia A., 22, 39, 42, 47, 60, 66, 74, 105, 107, 154, 155
Kenstowicz, Michael, 112, 146, 150
Kewley-Port, Diane, 136
Keyser, S. Jay, 6, 7, 8, 38, 56, 111, 136
Kimenyi, Alexandre, 103
Kingston, John, 47, 58, 59
Kinyarwanda, 103, 104
Kiparsky, Paul, 146, 147, 150
Kirchner, Robert, 33, 68, 87, 155, 156
Kirundi, 100, 104
Kisseberth, Charles W., 109, 112
Kluender, Keith R, 63
Kodagu, 90
Kohler, Klaus, 154
Krassowska, Halina, 55
Krull, Diana, 22

Ladefoged, Peter, 17, 39, 43, 55, 58, 67, 83, 91, 97, 104, 107, 116, 120, 134
Lahiri, Aditi, 22, 107
Lahu, 75–77, 131–132
Latin, 108–109, 133, 137–138, 146–149
Laver, John, 22
Lehn, Walter, 54
Liberman, Alvin M., 22, 105
Lightner, Theodore M., 86
Liljencrants, Johan, 6, 30
Lindblom, Björn, 4, 6, 15, 16, 22, 30, 33, 46, 61, 68
Lisker, Leigh, 58
Lombardi, Linda, 68
Luganda, 110
Lyman, Thomas A., 41, 132

Maasai, 39
Maddieson, Ian M., 6, 37, 39, 43, 44, 55, 58, 63, 67, 83, 91, 107, 116, 134
Malayalam, Mapila dialect, 82–85
Mallinson, Graham, 103
Maniet, A., 137
Mantjiltjara, 90
Manuel, Sharon Y., 71
Margi, 37, 103
Marsh, J., 90
Marshallese, 37, 39, 67
Martinet, Andre, 16, 32
Massaro, Dominic W., 58
Mathews, M.V., 30
Matisoff, James A., 75, 131, 132
Maxakali, 114
MAXIMIZE CONTRASTS constraint, 26–27
Mazzola, Michael L., 9, 45, 143
McCarthy, John, 149, 155
McGregor, William, 41, 44
Michailovsky, Boyd, 80
Milenkovic, Paul, 19
Miller, George A., 13, 135
Miller, Wick R., 91
MINDIST constraints, 26, 30–33
minimization of effort, 29, 68–69
Mixtec, Molinos, 91

Mong Njua, 41, 132–133
morpheme structure constraints, 149–150

Nawrocka-Fisiak, Jadwiga, 55
Nelson, W.L., 68
neutralization, 40–46, 65–66, 119–139
Nicely, Patricia E., 13, 135
Niyondagara, Alice, 100
Nosofsky, Robert M., 33
Nupe, 61–62, 101–103
Nurse, Derek, 108
Nyangi, 39

Oh, Eunjin, 122
Ohala, John J., 13, 59, 80, 109, 120, 131, 137, 154
Öhman, S.E.G., 71, 128
Olive, Joseph P., 122, 128, 134, 135
Orgun, Orhan, 89
output-output correspondence constraints, 142

Padgett, Jaye, 114
palatalization, 62–63, 101–103, 121–122, 138
paradigm leveling, 146–149
PARADIGM UNIFORMITY constraints, 142-145
Passy, Paul, 16
Pesetsky, David, 105
Peterson, Gordon E., 19
phonetic representations, 154–156
Pierrehumbert, Janet B., 154
Piggott, Glyne, 39
Pike, Eunice V., 91
Platt, J.T., 90
Polish, 55–56, 60, 74, 105, 108, 116
Ponapean, 68
Ponelis, Fritz, 110, 111
Popovich, F., 114
Popovich, H., 114
Prince, Alan, 3, 7, 17, 25–26, 33, 50, 141, 149
Pulleyblank, Douglas, 38
Puppel, Stanislaw, 55, 56

Raphael, Lawrence J., 23
Rehg, Kenneth L., 68, 114
Repp, Bruno H., 105
Reynolds, William T., 43
Rhaeto-Romansch, 114
Richards, Eirlys, 41, 68, 114
Richey, Colleen, 50
Romance, 107
Romanian, 103, 137–138
Rosen, Stuart, 105
Rotokas, 39
Rubach, Jerzy, 100, 108
Russian, 45, 50, 74, 101, 103, 105, 108

Sagey, Elizabeth, 3, 11, 14, 65, 82, 108, 112, 113, 114, 135
Sanskrit, 112
Scharf, Bertram, 23
Schein, Barry, 113
Schiffman, Harold F., 99
Schwartz, Jean-Luc, 14, 126
Shadle, Christine, 73
Shinn-Cunningham, B.G., 33
simplification of consonant clusters, 137–139
Slovak, 100
Smits, Roel, 23
Smolensky, Paul, 3, 7, 17, 25–26, 33, 50, 141, 149
Spajić, Siniša, 43, 44, 91, 97
Spanish, 104, 108, 145–146, 149–150
Steriade, Donca, 9, 24, 25, 39, 40, 41, 43, 58, 113, 142, 145, 146, 150, 153, 154, 156
Stevens, Kenneth N., 6, 7, 8, 14, 19, 23, 38, 39, 43, 56, 57, 58, 71, 73, 111, 136, 155
stop bursts, 23–24
Studdert-Kennedy, Michael, 23
Summerfield, A. Quentin, 58
Sussman, Harvey M., 22
Swazi, 111
Syriac, Modern, 54, 55

Tamil, 99
Tibetan, 80–81
Traill, Anthony, 114
Tukey, J.W., 30
Tulu, 82
Turkish, 86–89, 112

Unified Feature Theory, 11–116

Vance, Timothy J., 105
vowel reduction, 45–46

Wallace, Judith, 133
Walmatjari, 41, 68
Weismer, Gary, 19
Wells, John, 99, 135
Wembawemba, 89–99
Wergaia, 90, 98, 99
Westbury, John, 39, 42, 47, 57
Whitney, William Dwight, 113
Wolfram, Walt, 136
Wright, B.A., 63

Yao, Highland, 130–131
Yip, Moira, 125, 129

Zee, Eric, 79
Zimmer, Karl, 89
Zipf, George K., 16
Zue, Victor, 23
Zvelebil, Kamil, 90